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Does management of woodland caribou threats provide protection for Canada's other species at risk?

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Abstract

In Canada, the number of species at risk is escalating rapidly, prompting conservation managers to consider how best to allocate funding to effectively address species loss and support ecological integrity. Woodland caribou (*Rangifer tarandus caribou*) have declined extensively across Cananda and are central to the nation's conservation strategy. We use national datasets of spatial distributions and threat listings to examine the extent that woodland caribou-focused conservation might benefit Canadian species at risk, quantified through geographic and threat overlap. Threat overlap is defined here as the extent two species share International Union for Conservation of Nature Threat Classification Scheme subcategories (45 total) published in national conservation documentation, measured using the Jaccard index. We found that 20% of species at risk overlap in range with woodland caribou, and of those 12% overlap in more than 20% of their range. The variables that best predicted an index of shared threats between woodland caribou and sympatric species at risk, were range size and taxonomic group. Woodland caribou were found to share more threats with species at risk that have large ranges, and those from specific taxonomic groups including amphibians and terrestrial molluscs. Management focus on woodland caribou though important in its own right, provides uneven protection for Canada's species at risk, even those that are sympatric.

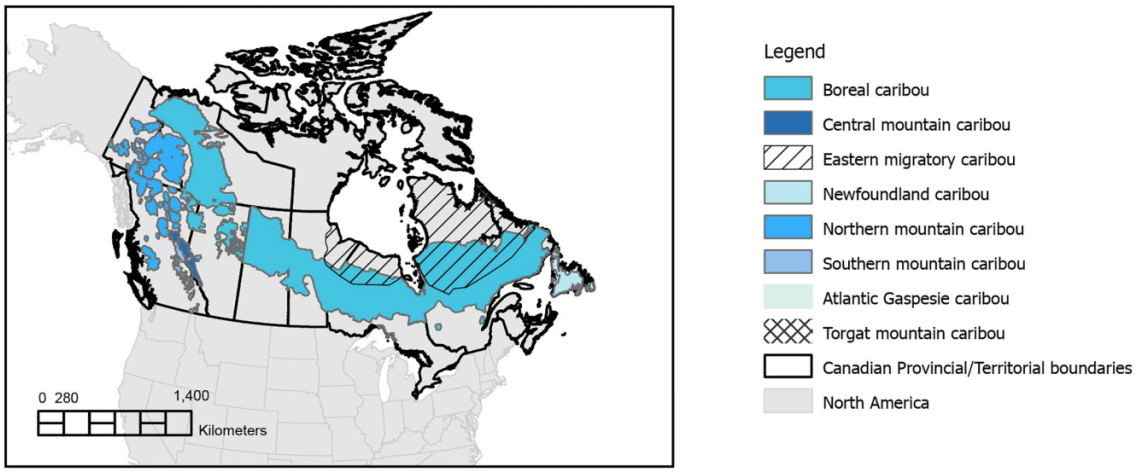
Key words: *Rangifer tarandus caribou*, endangered species, single species conservation, umbrella species, threat management

1. Introduction

Woodland caribou (*Rangifer tarandus caribou*) are just 1 of 649 extant species listed as 'at risk' under Canada's *Species at Risk Act* (2002). Across Canada, biodiversity loss is pervasive, with half of 903 monitored species declining in abundance between 1970 and 2014 (WWF 2018). This has resulted in federal commitments to halt extinctions and restore biodiversity by 2030 (e.g., under the United Nations Convention on Biological Diversity; 2010 Aichi targets and 2022 Kunming-Montreal Global Biodiversity Framework). In Canada, woodland caribou are widespread, culturally significant (Hummel and Ray 2008), and are a priority species for conservation (Hebblewhite and Fortin 2017; Environment and Climate Change Canada 2018*a*). The extent to which protecting woodland caribou may also support other species has emerged as an intellectual and practical question (Micheletti et al. 2025). Woodland caribou are emblematic of older, low productivity forests (Rettie and Messier 2000; Brown et al. 2007), which contrasts with habitat requirements of some species and adds to the debate regarding the extent woodland caribou conservation supports biodiversity more widely. Bichet et al. (2016) and Labadie et al. (2024) suggest that woodland caribou conservation confers protection to sympatric (defined as species that occupy the same geographic area) landbirds, but Micheletti et al. (2023) found contrasting results. Thus, the extent woodland caribou conservation supports co-occurring species remains unresolved, particularly for species at risk where sympatry and conservation overlap with woodland caribou has not been assessed.

Single species conservation approaches can be attractive to managers as they offer a means to address the immense logistical and financial difficulties of managing each species separately (Lindenmayer and Westgate 2020). "Umbrella species" are used as a single species conservation approach, where protection of one or few species may confer benefits to other sympatric species vulnerable to similar threats (Fleishman et al. 2000). Umbrella species are often selected due to factors such as large distributions, important ecosystem roles, or vulnerability to pervasive threats (Caro 2010; Runge et al. 2019). Reviewing the broader efficacy of the umbrella species approach is difficult as the literature varies in both the metrics used and conservation contexts investigated (Lindenmayer and Westgate 2020; Micheletti et al. 2025), as well as a lack of consensus regarding what constitutes success (Hunter Jr

Fig. 1. The distribution of the eight extant at-risk woodland caribou ecotypes: boreal, eastern migratory, Torngat mountain, Atlantic-Gaspésie, Newfoundland, southern mountain, central mountain, and northern mountain caribou. This figure was created using R version 4.4.0 (R Core Team 2025) and assembled from the following data sources: Environment and Climate Change Canada (2023*a*); Government of Canada (2016); U.S. Geological Survey (2004), with no basemap.



et al. 2016). Despite this variation, there are examples of species assessed as effective umbrella species (Sergio et al. 2006; Roberge et al. 2008; Zarri et al. 2024) and those that failed to properly support sympatric species (Bifolchi and Lodé 2005; Wang et al. 2021). For Canada's boreal and mountain habitats, woodland caribou have been suggested as a potential umbrella species (Bichet et al. 2016; Drever et al. 2019; Labadie et al. 2024) due to their national cultural significance (Hummel and Ray 2008), large spatial distribution (Fig. 1), and vulnerability to pervasive threats (Festa-Bianchet et al. 2011).

In Canada, only 27% of remaining boreal caribou (a subgroup of woodland caribou) ranges are self-sustaining, such that they demonstrate stable or positive population growth over the short term, and are large enough to withstand stochastic events and persist over the long term without the need for active management (Environment and Climate Change Canada 2020). The lead hypotheses for woodland caribou population declines are habitat loss, degradation and fragmentation caused by anthropogenic and natural disturbances, and their subsequent effects on predation rates (Festa-Bianchet et al. 2011; Environment and Climate Change Canada 2020). Woodland caribou-focused conservation is an approach that prioritises the management of threats relevant to caribou and the protection of critical woodland caribou habitat. Effectively addressing the likely mechanisms of woodland caribou decline necessitates the regulation of cumulative industrial impacts, making supporting woodland caribou a useful tool for the conservation of Canada's boreal and mountain landscapes. Examples of woodland caribou-focused conservation include its federal listing as a priority species (Environment and Climate Change Canada 2018*a*), agreements between the federal government and the Provinces/Territories that outline steps to be taken toward woodland caribou recovery (Environment and Climate Change Canada 2018*b*, 2024), and industry guidelines that include provisions for woodland caribou habitat protection (Courtois et al. 2004; OMNRF 2014; Mackey et al. 2023).

Conservation focus on caribou has prompted investigations into the extent woodland caribou function as an umbrella species for sympatric wildlife, with analyses of habitat preferences and sympatry producing contrasting results (Micheletti et al. 2025), and limited focus specifically on species at risk. Woodland caribou-focused habitat management of forestry areas, including disturbance minimisation and cut block aggregation, supported bird, small mammal, and insect communities that were more similar to communities in undisturbed landscapes (Bichet et al. 2016). These results are reiterated by subsequent findings, which used integrated models to detect a positive relationship between management that supports caribou survival, and bird and beetle community similarity to assemblages in undisturbed landscapes (Labadie et al. 2024). However, there is debate regarding the extent that protecting land areas based on caribou distribution and habitat preferences effectively supports biodiversity (Drever et al. 2019; Micheletti et al. 2025, 2023). While studies illustrate overlap between boreal caribou and 90% of boreal bird and mammal species (Drever et al. 2019), establishing protected areas based solely on high-quality boreal caribou habitat may exclude species that prefer other habitat types (Micheletti et al. 2023). To date, investigations into the extent woodland caribou act as an umbrella species for species at risk have been limited. Efforts have been made to identify areas where woodland caribou habitat, species at risk occurrence, and carbon storage attributes overlap (Johnson et al. 2022; Martin et al. 2022), and identify boreal species at risk that may benefit from caribou conservation (Drever et al. 2019). No studies have examined the extent woodland caribou serve as an effective umbrella for all species at risk in Canada. Woodland caribou live in the northern and mountainous, remote regions of Canada, but many Canadian species at risk occur closer to the southern border near high density human populations, such as southern Ontario (Hardouin and Hargreaves 2023), suggesting sympatry between woodland caribou and species at risk requires

quantification. Considering threat overlap, as opposed to solely habitat or distribution, may also be critical to assessments of conservation overlap between woodland caribou and species at risk. Threat overlap is defined in this manuscript as the extent two species share International Union for Conservation of Nature (IUCN) Threat Classification Scheme subcategories (45 total) identified in national Canadian conservation documentation. Focusing exclusively on habitat and range overlap may misrepresent the benefits of caribou-focused conservation confers to other species, if those species are not vulnerable to the same threats as woodland caribou.

We use consolidated national datasets of species at risk spatial distributions and threat listings, to quantify spatial sympatry and threat overlap among species at risk and woodland caribou. The goal of this paper was not to examine the efficacy of the umbrella species conservation approach generally, but instead to examine whether the current conservation focus on woodland caribou in Canada is likely to benefit co-occurring species at risk. We focus on woodland caribou as the boreal and mountain forests where they are found are increasingly under pressure from resource extraction, development, and impacts of climate change (e.g., extreme forest fire years), impacting both caribou and other species at risk. We quantify (i) the proportion of Canadian species at risk that overlap in range with woodland caribou, (ii) the most common threats to all Canadian species at risk and those that overlap in range with woodland caribou, and (iii) the predictors (including range size, range overlap with caribou, and taxonomic group) of threat overlap between sympatric species at risk and woodland caribou. Due to the southern distribution of many species at risk relative to the occurrence of woodland caribou, we predict low sympatry between most species at risk and caribou. Among the species at risk sympatric with woodland caribou, we predict species with shared life history traits, like large home range size and similarity in taxonomy, will share more threats with woodland caribou and benefit most from woodland caribou-focused conservation. While we focus on Canada, our approach—which combines geographic and threat overlap to assess conservation benefits of umbrella species—has global applications. Our work identifies which species might benefit from woodland caribou-focused conservation and the extent this conservation approach can address the needs of Canada's most vulnerable species.

2. Methods

2.1. Data sources

2.1.1. Calculating range sympatry with caribou

We identified sympatric ranges of woodland caribou and other Canadian species at risk using federal government spatial data (Environment and Climate Change Canada 2023*a*), available from for 448 of the 649 extant species and subspecies listed under SARA Schedule 1 (301 Endangered, 200 Special Concern, and 148 Threatened, Environment and Climate Change Canada 2023). The dataset was augmented with spatial range data for 13 species downloaded from NatureServe (NatureServe 2024), resulting in a total of 461 species (71%) where spatial data were available. We were unable to find any spatial range data for at risk Canadian marine and freshwater fish, reptiles, molluscs, and mammals (152 species), so these are excluded from spatial overlap analyses. We calculated the total area of woodland caribou range by merging the spatial range extents for the eight designatable units of extant at-risk woodland caribou: boreal, eastern migratory, Torngat mountain, Newfoundland, Atlantic-Gaspésie, southern mountain, central mountain, and northern mountain caribou (Fig. 1). Sympatry between woodland caribou and species at risk was calculated by clipping the species at risk ranges to that of woodland caribou in ArcGIS (ESRI 2023), dividing for each species at risk the resulting range overlap area by their respective total range area, and multiplying by 100. We then calculated for each taxonomic group, (i) the total number of Canadian species at risk, (ii) the total number and percentage of species at risk of a given taxonomic group that overlap in their range with woodland caribou, (iii) the total number and percentage of species at risk of a given taxonomic group that overlap in greater than 20%, 40%, 60%, and 80% of that respective species range with woodland caribou.

2.1.2. Calculating overlapping species at risk threats

We analysed threats to species at risk in Canada using the dataset *CAN-SAR: a database of Canadian Species at Risk information* (referred to hereafter as the CAN-SAR database, (Naujokaitis-Lewis et al. 2022)). This dataset includes 1169 rows of Committee on the Status of Endangered Wildlife in Canada (COSEWIC) conservation documents (recovery plans and status assessments), that relate to 608 Canadian species and subspecies at risk. COSEWIC is an independent advisory panel to the Minister of Environment and Climate Change Canada, that meets twice annually to discuss and evaluate the status of species at risk in Canada. The panel releases documents, including status assessments and recovery plans, that list threats to the respective species at risk using the IUCN Threat Classification Scheme. This scheme includes 11 main threat categories and 45 subcategories (Table S1; IUCN 2022). The CAN-SAR database includes rows for each COSEWIC document (either status assessments, or recovery plans) for the majority of species at risk in Canada. The threats to species at risk detailed in the COSEWIC documents, listed under the IUCN Threat Classification Scheme are present in the CAN-SAR database as columns. In a given threat subcategory column of the CAN-SAR database, 82% of documents (rows) the presence of a threat was indicated by a 1, and absence of that threat indicated by a 0. For approximately 16% of documents (rows) instead of a binary score, the scoring scale included a third category "2" indicating higher threat importance. As this accounted for a low proportion of the dataset, we converted all values of 2 to 1, facilitating consistent comparison between conservation documents.

To calculate the proportion of shared threats between woodland caribou and species at risk (see Section 2.2), we required one row of threat records, per species designatable unit. The CAN-SAR database often includes multiple rows for the same species, which detail threats listed in different conservation documents (status assessments and recovery plans) for that species. If multiple documents (rows) were listed for the same species, we only included the most recent document; if two documents were published in the same year (a rare occurrence), we retained the document with the highest number of threats that were listed additively. We compared the species listed in the CAN-SAR database to the species listed on Schedule 1 of the SARA, to ensure the dataset was complete. As the CAN-SAR dataset did not have records for all Canadian species at risk, we attempted to fill gaps in the dataset by collating conservation documentation for species at risk with available spatial data, from the Canadian federal government website (Government of Canada 2026). COSEWIC status assessments and recovery plans were located for an additional 27 species at risk, and threats listed in these documents were entered into the database under the existing IUCN threat category columns. Processing of these records resulted in a dataset of 618 Canadian species at risk, including 94 that overlapped in range with woodland caribou. Note that sub-species and different designatable units (e.g., Allegheny Mountain dusky salamander Appalachian population and Carolinian population) of the same species were retained as separate rows/records, as these represented conservation significant units of a species that are often subject to very different threats.

The second action required to calculate the proportion of shared threats between woodland caribou and species at risk, was collating threats listed for all eight extant designatable units of woodland caribou (eight separate rows of threat records) into a single row of data under the common name "woodland caribou". The eight extant designatable units of woodland caribou are: boreal, eastern migratory, Torngat mountain, Newfoundland, Atlantic-Gaspésie, southern mountain, central mountain, and northern mountain caribou. If a threat was listed for one of the eight designatable caribou units, it was still recorded as a threat for woodland caribou as a "1". Likewise, if a threat was listed for more than one designatable unit of caribou designatable unit it was also recorded as a threat for woodland caribou as a "1". Threats that were not listed for any of the eight designatable units were recorded for woodland caribou as a "0". Threats listed for all eight designatable units of caribou in the CAN-SAR database were cross checked with the relevant recovery plans and status assessments to ensure accuracy (COSEWIC 2014; Environment and Climate Change Canada 2020). The threat listings for woodland caribou were then used to calculate an index of threat listing similarity with all other species at risk (see Section 2.2). We also examined variation in threat listings across the eight designatable units of caribou that form the woodland caribou ecotype, by calculating the number of designatable units that list each of the 11 IUCN main threat categories.

We quantified threat frequencies for (i) all species at risk, and (ii) sympatric species at risk with woodland caribou, by calculating for each threat the number of species that listed that threat, divided by the total number of species, and multiplying by 100. We then compared if the most prevalent threat categories differed between all species at risk and those sympatric species with woodland caribou. Threat frequencies calculated for all species at risk included marine and freshwater fish, reptiles, molluscs, and mammals. While these species inhabit an aquatic environment very different to woodland caribou, they are still species at risk, and are therefore important to include when understanding dominant threats to Canadian species at risk generally.

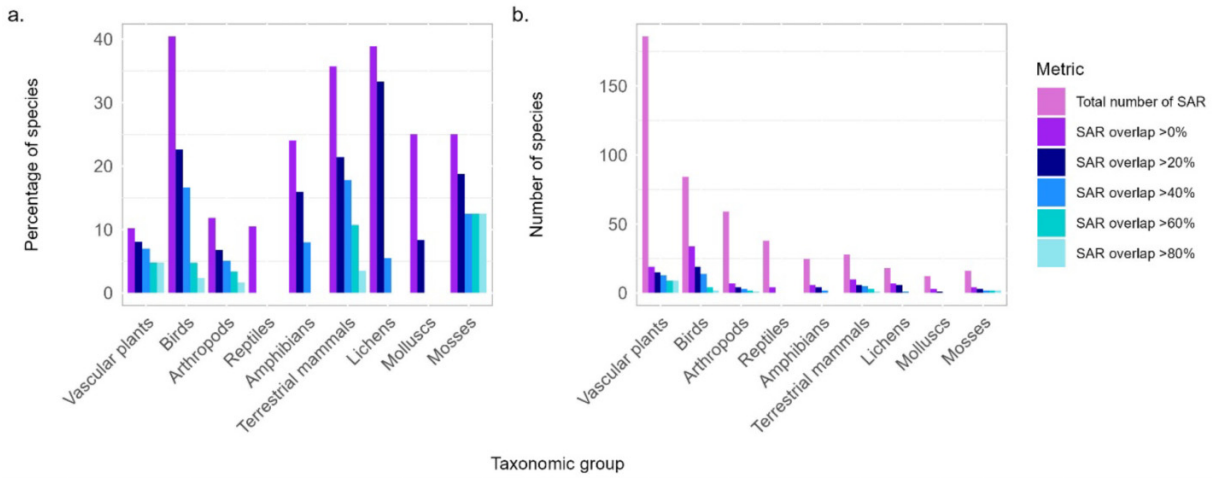
2.2. A Jaccard index of shared threat overlap

We calculated threat overlap between woodland caribou and sympatric species at risk, using the Jaccard index (Jaccard 1908). The Jaccard index compares samples by calculating the ratio between the number of categories shared and those that differ, and has been used in the umbrella species literature elsewhere (Labadie et al. 2024). To calculate the Jaccard index we used threat records from both IUCN Threat Classification Scheme main (first level categories) and subcategories (second level categories, Table S1), and compared the ratio of threats shared and differing between each species at risk and woodland caribou (a row which included threats listed for all eight designatable units of woodland caribou). High values represent more shared threats and low values indicate less shared threats. The 10 species with the highest and lowest Jaccard index scores were noted to identify particular sympatric species at risk that may be most and least benefited by woodland caribou-focused conservation.

2.3. Predictors of threat overlap between caribou and species at risk

We examined the drivers of threat overlap between woodland caribou and sympatric species at risk ($N = 109$) using a beta regression modelling approach. The response variable was the Jaccard index, describing threat overlap between woodland caribou and each species at risk. The Jaccard index varied between (but did not include) either zero or one, and in our case has a slightly right skewed distribution. Only species at risk that overlapped in range with woodland caribou were included as we were interested in what predicts threat overlap between woodland caribou and sympatric species at risk. Note that as no spatial data were available for all freshwater and marine fish, reptiles, molluscs and mammals, species from these environments were automatically excluded from the models. We included as predictor variables range size in kilometres ("total range area"), the percentage of a given species range covered by woodland caribou range ("percentage range overlap"), and taxonomic group ("taxonomic group") including terrestrial mammals, amphibians, terrestrial reptiles, terrestrial molluscs, birds, vascular plants, lichens, terrestrial arthropods, and mosses (Table S2) included as a categorical variable. Total range area and percentage overlap were both standardized using the scale function (0-centered, with an SD of 1) in base R (R Core Team 2025). Variables were checked for correlations and collinearity. No variables had r values of

Fig. 2. The percentage (*a*) and number (*b*) of species at risk (SAR) from different taxonomic groups, whose ranges overlap with woodland caribou. Five different percentage overlap categories (>0%, >20%, >40%, >60%, >80%) are shown, such that "SAR overlap >20%" indicates the percentage (*a*) and number (*b*) of species at risk from a given taxonomic group that have greater than 20% of their range overlapping with woodland caribou. Despite the large range of woodland caribou, across taxonomic groups few species at risk overlap considerably. Terrestrial mammals, lichens, birds, and amphibians were the groups with the greatest proportion of species at risk with ranges that overlap with woodland caribou.



greater than 0.35, and variance inflation factors were less than three for all variables (Zuur et al. 2010).

We fitted beta regression models using the "betareg" package in R (Cribari-Neto and Zeileis 2010; R Core Team 2024). We fitted a set of models representing our four different hypotheses regarding the drivers of threat overlap with woodland caribou including (i) range size, (ii) percent range overlap with woodland caribou, (iii) taxonomic group, or (iv) a global model including a combination of all variables. We identified the best supported model based on AICc scores and weights using the "MuMin" package (Barton 2009), with the lower AICc score and the higher weight indicating greater support (Burnham and Anderson 2002). Models were assessed for error variances, overdispersion, and variance of residuals (Fig. S1). The frequency of threat listings was graphed against variation in key variables such as taxonomic group to better assess the drivers of the modelling results.

3. Results

3.1. Range overlap between species at risk, caribou, and priority places

Of the 649 species listed under SARA Schedule 1, threat and spatial range data were available for 461 (71%). Spatial range data were not available for all freshwater and marine fish, reptiles, molluscs, and mammals and these species were excluded from spatial overlap analyses. The combined spatial range of woodland caribou in Canada (including all eight extant designatable units) was 4325 842.66 km^2. Of the species with threat and range data (461 species), 94 (20%) overlapped with the range of woodland caribou and 59 (12%) overlapped more than 20% of their range with woodland caribou, 40 (8%) overlapped more than 40%, 20 (4%) overlapped more than 60%, and 15 (3%) overlapped more than 80%.

We found variation among taxonomic groups in both the number of species at risk in Canada, and those that overlap with woodland caribou. Vascular plants were the taxonomic group with the most species at risk in Canada (186 species, 40%), followed by birds (84 species, 18%), arthropods (59 species, 12%), reptiles (38 species, 8%), terrestrial mammals (28 species, 6%), amphibians (25 species, 5%), lichens (18 species, 3%), mosses (16 species, 3%), and terrestrial molluscs (12 species, 2%) (Figs. 2 and 3). The taxonomic groups that had the greatest percentage of species at risk that overlapped more than 20% of their range with caribou, were birds (30 species, 6% of at-risk species, 35% of at-risk birds), and vascular plants (15 species, 3% of at-risk species, 4% of at-risk plants), followed by terrestrial mammals (5 species, 1% of at-risk species, 17% of at-risk mammals), and lichens (6 species, 1% of at-risk species, 33% of at-risk lichens). The number and percentage of species at risk with >40%, >60%, and >80% of their ranges overlapping with woodland caribou are available in Table S3 and Fig. 2.

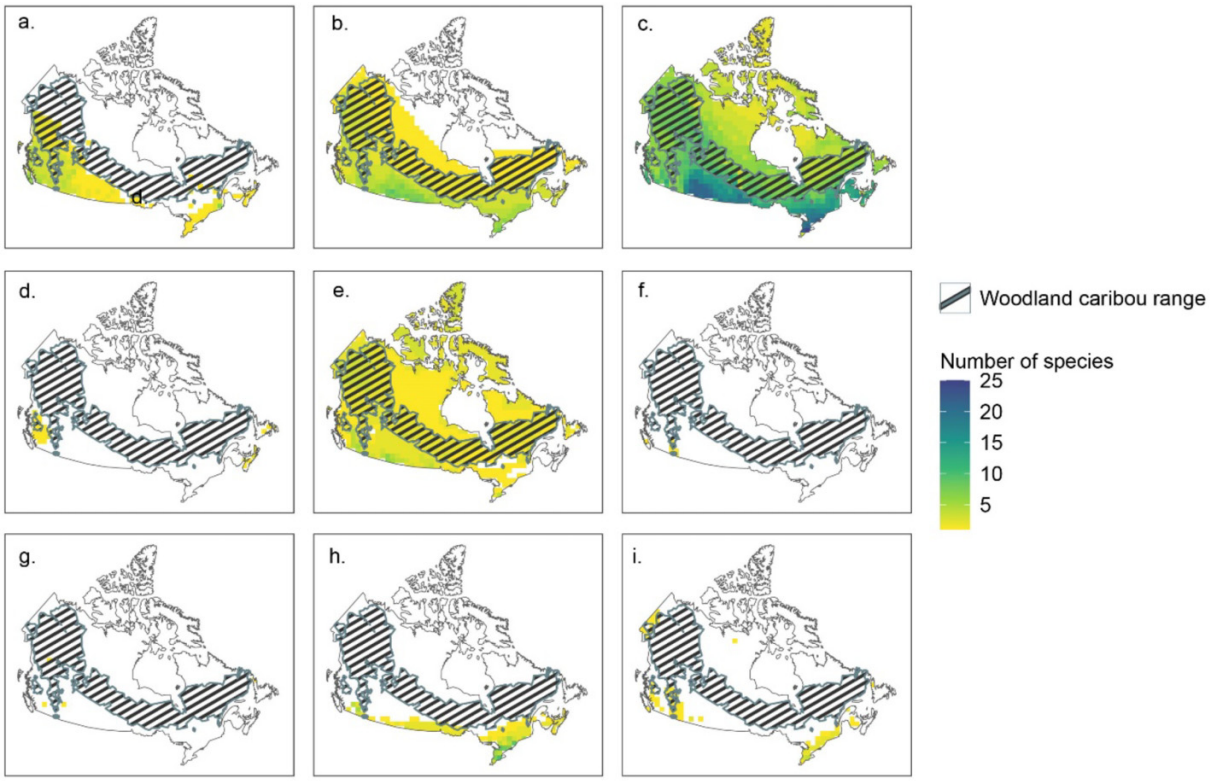
3.2. Common threats to species at risk in Canada

The IUCN main threat categories most commonly listed for species at risk in Canada include invasive and problematic species (85%), natural system modifications (77%), pollution (71%), climate change (70%), and human disturbance (67%). Species at risk that overlapped with woodland caribou had a similar suite of threats (Fig. S3) including invasive and problematic species (88%), climate change (87%), pollution (79%), natural system modifications (75%), and biological resource use (75%).

3.3. Threat overlap with woodland caribou

We found threat listings did vary between the eight caribou designatable units that make up the woodland caribou ecotype (Table S4). The most frequently listed main threat cat-

Fig. 3. The distribution of different taxonomic groups of species at risk in Canada, relative to the distribution of woodland caribou. These taxonomic groups include (*a*) amphibians, (*b*) terrestrial arthropods, (*c*) birds, (*d*) lichens, (*e*) terrestrial mammals, (*f*) terrestrial molluscs, (*g*) mosses, (*h*) terrestrial reptiles, and (*i*) vascular plants. Across taxonomic groups, species at risk are concentrated near the southern border. This figure was created using R version 4.4.0 and assembled from the following data sources: (Government of Canada 2016; Environment and Climate Change Canada 2023*a*; NatureServe 2024), with no basemap.



egories were: energy production and mining (listed by 7 caribou designatable units), transport and service corridors (7), biological resource use (7), natural system modifications (6), invasive and other problematic species (5), and human intrusions and disturbance (5) (Table S4).

Of the species at risk that overlapped in range with woodland caribou, those species that also shared the most common threat subcategories with woodland caribou included: western toad calling and noncalling population (*Anaxyrus boreas*), western tiger salamander prairie/boreal population (*Ambystoma mavortium*), pygmy slug (*Kootenaia burkei*), red-headed woodpecker (*Melanerpes erythrocephalus*), and rusty blackbird (*Euphagus carolinus*). The species with the least number of common threats included the green-scaled willow (*Salix chlorolepis*), crumpled tarpaper lichen (*Collema coniophilum*), dune tachinid fly (*Germaria angustata*), nahanni aster (*Symphyotrichum nahanniense*), and the western bumble bee (*Bombus occidentalis mckayi* and *occidentalis* subspecies) (Table 1).

3.4. Predictors of woodland caribou threat overlap

The model that best predicted threat overlap between woodland caribou and sympatric species at risk in Canada, was the global model including the variables taxonomic group, total range area, and percentage range overlap (with caribou) (Table 2; Fig. S1). The model that included the variable taxonomic group was the next best fitting model, but this model was not considered competitive with the top model (Table 2). Coefficient estimates of the top model suggested caribou had higher threat overlap with species at risk with larger ranges, as well as amphibians, and terrestrial molluscs (Fig. 4). Effect size and direction of estimates was generally consistent between all models (Table S5). Threat overlap with woodland caribou was lower for arthropods. The residual and fitted values of the best fitting model indicated there were three outliers: the western calling toad (calling and noncalling population) and the northern dusky salamander (Carolinian population). Removal of these datapoints drove no noticeable change in either the best fitting model, and therefore these data points were retained (Fig. S2; Table S6).

3.5. Variation in threats listed by taxonomic group

To examine how threats varied among taxonomic groups, we selected species at risk that overlapped with woodland caribou and examined the proportion of species in each taxonomic group that each IUCN threat subcategory was listed for (Fig. 5, with threat categories defined in Table S1). Threat

Table 1. Of the species that overlap in range with caribou, these are the 10 species that are most similar (Jaccard index > 0.6) and most different (Jaccard index < 0.2) to woodland caribou in terms of shared threats.

Common name	Species name	SARA status	Taxonomic group	Jaccard index	Range size (km^2)	% range overlap with caribou
Western toad calling population	*Anaxyrus boreas*	Special Concern	Amphibians	1.00	597 378.76	38.61
Western toad noncalling population	*Anaxyrus boreas*	Special Concern	Amphibians	1.00	739 837.42	43.91
Western tiger salamander prairie/boreal population	*Ambystoma mavortium*	Special Concern	Amphibians	0.75	581 071.96	0.67
Pygmy slug	*Kootenaia burkei*	Special Concern	Molluscs	0.74	1896.54	1.90
Red-headed woodpecker	*Melanerpes erythrocephalus*	Threatened	Birds	0.73	316 390.66	6.33
Rusty blackbird	*Euphagus carolinus*	Special Concern	Birds	0.71	6682 685.20	56.94
Yellow-banded bumble bee	*Bombus terricola*	Special Concern	Arthropods	0.70	12 049.80	0.69
Sheathed slug	*Zacoleus idahoensis*	Special Concern	Molluscs	0.69	1259.27	2.86
Coastal tailed frog	*Ascaphus truei*	Special Concern	Amphibians	0.68	100 987.07	2.13
Northern leopard frog rocky mountain population	*Lithobates pipiens*	Endangered	Amphibians	0.67	147.19	0.45
Felt-leaf willow	*Salix silicicola*	Special Concern	Vascular Plants	0.24	1552.48	19.12
Margined streamside moss	*Scouleria marginata*	Endangered	Mosses	0.22	76.47	100.00
Barrow's goldeneye eastern population	*Bucephala islandica*	Special Concern	Birds	0.19	152 696.25	84.79
Western bumble bee mckayi subspecies	*Bombus occidentalis mckayi*	Special Concern	Arthropods	0.16	669 662.34	81.62
Western bumble bee occidentalis subspecies	*Bombus occidentalis occidentalis*	Threatened	Arthropods	0.16	782 434.34	22.23
Yukon podistera	*Podistera yukonensis*	Special Concern	Vascular Plants	0.16	53 569.63	41.63
Nahanni aster	*Symphyotrichum nahanniense*	Special Concern	Vascular Plants	0.15	3793.59	100.00
Crumpled tarpaper lichen	*Collema coniophilum*	Threatened	Lichens	0.13	1340.43	24.22
Dune tachinid fly	*Germaria angustata*	Special Concern	Arthropods	0.13	36 464.77	64.54
Green-scaled willow	*Salix chlorolepis*	Threatened	Vascular Plants	0.12	1180.02	11.27

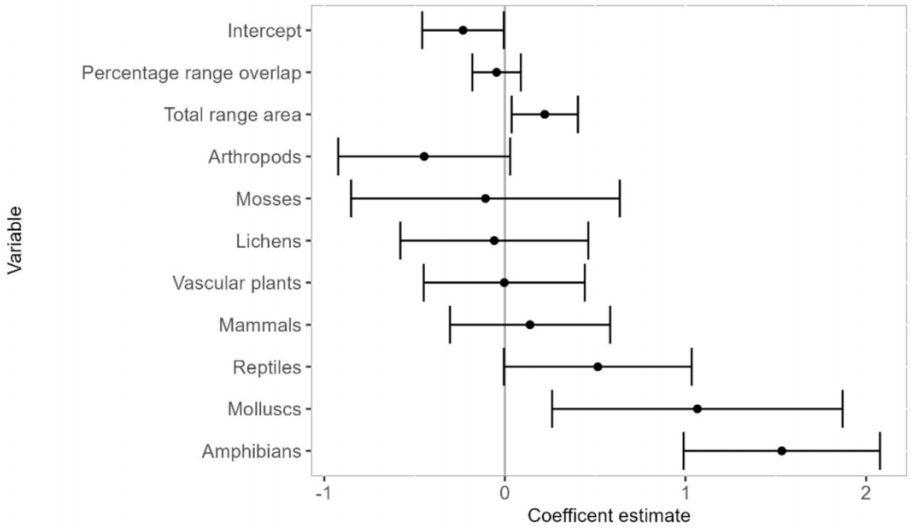
Note: SARA, Species At Risk Act.

Table 2. Competing models describing predictors of threat overlap between woodland caribou and sympatric species at risk in Canada.

Description	Percent range overlap with caribou	Total range area	Taxonomic group	df	logLik	AICc	Delta	Weight
Global model	+	+	+	12	69.58	−111.80	0.00	0.75
Taxonomic group			+	10	65.92	−109.50	2.28	0.24
Percent overlap	+			3	54.21	−102.20	9.61	0.01
Total range area		+		3	51.31	−96.40	15.42	0.00
Null model				2	47.32	−90.50	21.28	0.00

categories common with woodland caribou, that were frequently listed for the taxonomic groups that had greater threat overlap with woodland caribou (amphibians and terrestrial molluscs), included "roads", "recreational activities", "fire and fire suppression", and "commercial and industrial development". Amphibians, terrestrial molluscs, terrestrial reptiles, terrestrial mammals and birds, tended to have more threats listed for them, and have a higher proportion of their threats shared with woodland caribou (Fig. S4). Generally, the taxonomic groups such as arthropods, mosses, vascular plants, and lichens that shared fewer threats with woodland caribou, also appeared to have less threat listings, less threats shared with woodland caribou (Fig. S2), and more variation in threat category listings (Fig. 5). Arthropods had the threats "invasive species" and "agricultural and forestry effluents" frequently listed, which were not shared threats with woodland caribou. Vascular plants had the threats "invasive species" and "hunting and collection of terrestrial plants" fre-

Fig. 4. Coefficient estimates and 95% confidence intervals of variables best fitting model describing threat overlap between woodland caribou and sympatric species at risk in Canada. The reference level for the variable taxonomic group was birds. Threat overlap between woodland caribou and sympatric species at risk was higher for species with larger ranges. Woodland caribou also shared more threats with amphibians and terrestrial molluscs and less with terrestrial arthropods.



quently listed threats that were also not listed for woodland caribou.

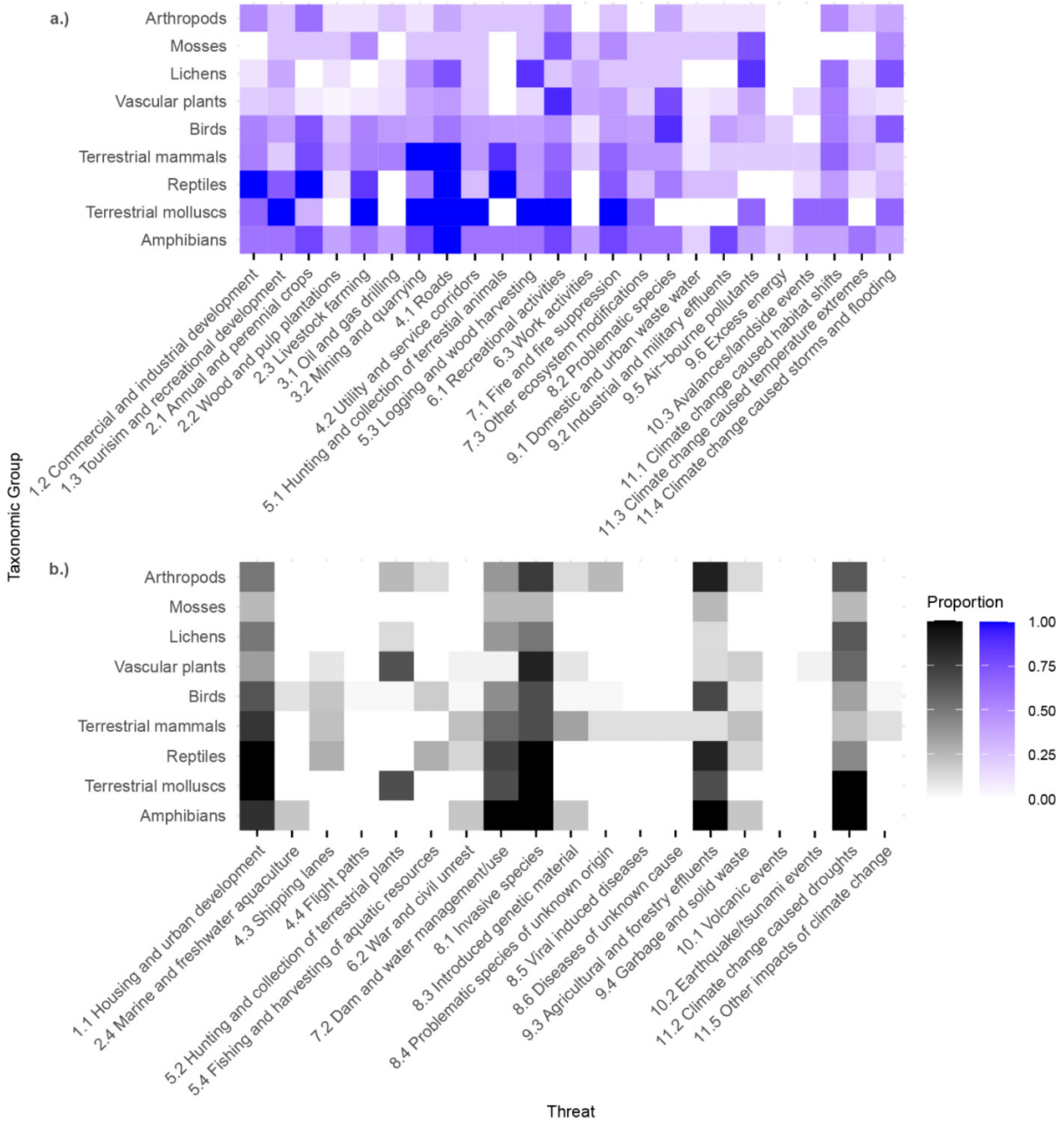
4. Discussion

Woodland caribou are one of 5000 species estimated to be at risk in Canada (Office of the Auditor General of Canada 2024), and our results indicate that conservation focus on this species, though important in its own right, is likely to provide uneven protection for other Canadian species at risk. Previous studies examining the efficacy of umbrella species like woodland caribou, examine co-benefits in relation to all sympatric species (Bichet et al. 2016; Drever et al. 2019; Micheletti et al. 2023; Labadie et al. 2024), rather than specific species at risk, as we have focused on here. While woodland caribou conservation involves the management of human disturbance and industrial impacts at large region wide scales, supporting the health and integrity of Canada's boreal and mountain ecosystems, our results highlight the precise limits of this approach for other species at risk. Nearly a quarter (20%) of species at risk overlap in range with woodland caribou, and only 12% overlap in >20% of their range. When exclusively considering the species that overlap in their range with woodland caribou, we found species with larger ranges also shared more threats with woodland caribou. Woodland caribou-focused conservation requires the management of a large number of threats from industry, tourism, forestry, farming, oil and gas drilling, roads, utility, and service corridor, to name a few (Fig. 5). The greatest number of these threats were most shared by wide ranging species at risk, and also those from specific taxonomic groups including amphibians, and terrestrial molluscs. Therefore, even for sympatric species that overlap in range with woodland caribou, focused conservation approaches that manage localised threats may also be required to prevent species loss.

Woodland caribou are emblematic of intact wilderness in Canada, and conservation focus on this species has precipitated debate as to whether benefits of caribou conservation could be expected for other species, particularly other species at risk. Woodland caribou are culturally central, widespread, and are also vulnerable to pervasive resource extraction that is driving shifts in age, continuity, and ecological dynamics of Canada's forests, across huge geographic areas (Bouchard and Pothier 2011; Molina et al. 2022). Woodland caribou-focused conservation involves the management of key caribou threats and the protection of critical caribou habitat, necessitating the regulation of cumulative industrial impacts (Collard et al. 2020; Environment and Climate Change Canada 2020). The species federal listing under the SARA (2002) also tests both the capacity of the Act, and the ability of the federal government and provinces, to protect a species that is vulnerable to economically valuable industries (Hebblewhite and Fortin 2017; Collard et al. 2020). Therefore, woodland caribou conservation is important, and when executed effectively, benefits mature forest availability (Brown et al. 2007), habitat connectivity (Courtois et al. 2004), and the protection of wilderness. Studies elsewhere have collated recovery actions listed in woodland caribou national and provincial/territorial conservation documentation (Hohnen et al. 2025). The most frequently listed actions were to increase partnerships and data sharing, manage important habitat and connectivity, monitor population trends, manage predators and alternative prey, and manage industrial and forest development. Effectively managing important woodland caribou habitat and connectivity, as well as industrial and forest development, would support the management of industrial disturbance at large spatial scales relevant to the ranges of woodland caribou herds.

However, when examining woodland caribou conservation in the context of the umbrella species concept, the

Fig. 5. For Canadian species at risk that overlap with woodland caribou, the proportion of species within each taxonomic group that list each International Union for Conservation of Nature threat sub category including (*a*) threats shared with woodland caribou and (*b*) threats not shared with woodland caribou. A darker colour indicates a greater proportion of species from this taxonomic group share this threat. Generally, more threats were listed more consistently for at risk amphibians and terrestrial molluscs sympatric with wooldand caribou.



research suggests protecting woodland caribou may best protect species that use similar habitats. Woodland caribou overlap spatially with a large proportion of boreal species (Drever et al. 2019), and appear to act as an umbrella species in forestry applications where areas managed to preserve some woodland caribou habitat are projected to maintain more intact animal assemblages, when compared to no or low management scenarios (Bichet et al. 2016; Labadie et al. 2024). However, choosing protected areas based solely on quality woodland caribou habitat was found to poorly support species that rely on other habitat types (Micheletti et al. 2023). For example, in the Northwest Territories, selecting protected areas based on woodland caribou habitat resulted in lower landbird abundance than randomly selecting protected areas (Micheletti et al. 2023). The results of our study augment these assessments and indicate that for species at risk, woodland caribou-focused conservation best serves large ranging species, and those from specific taxonomic groups.

Quantifying species at risk sympatry with woodland caribou was undertaken here as a first step in assessing the extent woodland caribou can act as an umbrella species for other Canadian species at risk. Twenty percent of species at risk

were sympatric with woodland caribou, with values across all taxonomic groups of species at risk, not exceeding 45% of any group. For example, vascular plants had the highest proportion of species at risk in our dataset (186 of 461 species, 40% of species at risk), but only 23 of those vascular plant species had ranges sympatric with woodland caribou (4% of all species at risk, and 12% of at-risk vascular plants). Birds and lichens had the greatest number of species at risk sympatric with woodland caribou and are thus geographically set to benefit most from woodland caribou-focused conservation efforts. Sympatry between woodland caribou and species at risk in Canada may be due to the density of declining species in key areas on the country's southern border (Hardouin and Hargreaves 2023; Fig. 3). These areas are within the woodland caribou historical distribution, but not its current distribution (Vors et al. 2007; Morineau et al. 2023). Such areas include the more populated Great Lakes and the Okanagan; hotspots that are included in Canada's 12 "priority places" and 18 "community nominated priority places" outlined in current federal conservation strategy (Environment and Climate Change Canada 2018*a*). While federal government identification of priority places is based on biodiversity values, priority species are defined by their special meaning to Canadians, and likelihood of delivering co-benefits to sympatric species (Environment and Climate Change Canada 2018*a*). Overlap between the woodland caribou range and priority places is best represented by areas in Yukon and Newfoundland. There are federal programs in place that aim to collaboratively fund projects that support species at risk in priority places, and these are likely to be important to prevent species loss. It is also important to note that there may be no other at-risk species, that overlap with more Canadian at-risk species than woodland caribou do, but examining this was out of scope for this manuscript.

As we hypothesized, threat overlap between species at risk and woodland caribou was predicted by range size. When considering species at risk sympatric with woodland caribou, those species with larger ranges shared more threats with woodland caribou. This may be because the threats to which woodland caribou are vulnerable operate over large areas, and may similarly impact other wide-ranging species at risk that occur in these areas. Vulnerability to pervasive threats is potentially one of the reasons woodland caribou are candidate umbrella species; however, these results suggest alternate supports are needed for species with small ranges, or species that may be vulnerable to different or specific localised threats.

Conservation focus on woodland caribou may benefit sympatric species from certain taxonomic groups more than others, particularly amphibians, and terrestrial molluscs. The total number of species at risk from taxonomic groups that were found to have greater threat overlap with woodland caribou (nine species amphibians and terrestrial molluscs), equates to 9% of species at risk sympatric with woodland caribou. Woodland caribou are subject to many threats, and when collated, they include all of the IUCN's overarching "main" threat categories (Table S4), and 25 of the 44 subcategories (Table S1). This means that species that share a larger amount of threat overlap with woodland caribou, are also often subject to a large number of threats (Fig. S4). The threat categories most common to woodland caribou, amphibians, and terrestrial molluscs, included "roads", "recreational activities", "fire and fire suppression", and "commercial and industrial development". Effective and large-scale management of these threats for woodland caribou, has potential to benefit species at risk from these taxonomic groups. There were two groups (mammals and birds) that similar to amphibians and terrestrial molluscs, had high numbers of threats listed per species; however, these groups did not have high threat overlap with woodland caribou suggesting that the relationship between threat overlap and taxonomic group, is unlikely to be driven completely by the number of threat listings per species. Woodland caribou shared fewer threats with arthropods. Threats frequently listed for arthropods that were not shared with woodland caribou included "invasive species", "agricultural and forestry effluents", and "climate caused droughts". Taxonomic group was not a good predictor of threat overlap between woodland caribou and at-risk mosses, lichens, vascular plants, and terrestrial mammals, suggesting for these groups other factors like range size may be more important in predicting overlap.

The extent woodland caribou conservation may support sympatric species at risk vulnerable to similar threats, may depend on both the extent species share threats with caribou but also the nature of the threat that is managed. For example, "recreational activities" was a threat listed for woodland caribou and a high proportion of sympatric at-risk mosses and vascular plants. Likewise, "logging and wood harvesting" was a threat shared by woodland caribou and at-risk lichens. If these threats were managed effectively across the woodland caribou range, species that share these threats could benefit. However, for threats like "problematic species", there would be more variability between species at risk regarding the specific invasive or problematic species that threaten them, so management overlap is likely to be lower. Also, since woodland caribou have many threats listed, and management requires allocation of resources across a large area, for species vulnerable to fewer (but overlapping) threats in more localised locations, localised focal management may be also required. For other species, woodland caribou-focused conservation may not manage threats relevant to them in a meaningful way. For example, "plant collection" are threats listed for a high proportion for vascular plants that are not relevant to or listed for woodland caribou. Plant collection could be managed through limiting road construction, a conservation action present in some woodland caribou action plans (Environment and Climate Change Canada 2020). However, if plant collection is an issue in specific areas where roads already occur and restoration is not planned, the necessary targeted management may be overlooked.

An examination of how woodland caribou focused conservation may benefit species at risk requires a closer look at some of the species involved. Calculation of Jaccard index values resulted in identification of the 10 species that shared the most threats with woodland caribou, and the 10 species that shared the least threats. The western toad,

western tiger salamander, and red-headed woodpecker had high indexes of threat overlap with woodland caribou, and also had threats recorded in 10 out of 11 of the IUCN's main threat categories. Both the western toad and the western salamander are vulnerable to habitat loss and fragmentation due to human settlement, agriculture, forestry, oil and gas industry, and transportation corridors, key threats also shared by woodland caribou (COSEWIC 2012; Environment and Climate Change Canada 2020, 2023*b*). However, in some cases there is complexity not completely captured by these threat classifications. For example, both woodland caribou and western tiger salamanders are threatened by problematic native species, but the species (wolves and native fish, respectively), and processes involved in enabling these impacts differ considerably (Environment and Climate Change Canada 2020, 2023*b*). Species that had comparatively low overlap scores such as the dune tachinid fly and the green scaled-willow, have relatively fewer main threat categories listed for them (two and three IUCN main threat categories, respectively). Key threats to the dune tachinid fly include natural succession of dune landscapes to boreal forest, invasive dune stabilising plants, and the disturbance caused by motorized vehicles in dune environments (COSEWIC 2011). Likewise threats to the green scaled willow are specific to small isolated populations, such as trampling from walking trails and hybridisation with closely related species (COSEWIC 2006). These species are vulnerable to more specific localised threats that are not shared by woodland caribou and require intensive management. However, it is conceivable that woodland caribou-focused conservation may also benefit species only vulnerable to one or few threats. For example, the crumpled tarpaper lichen had low threat overlap with caribou as few threats were listed for this species, but this lichen is dependent on old-growth coniferous forest and therefore may benefit from caribou-focused conservation, if it occurs in specific areas where the lichen persists (COSEWIC 2010). Therefore, generally woodland caribou had higher threat overlap scores with species at risk that were subject to more threats, but the complexity of threats and threat listings mean that there are exceptions to these broadscale patterns.

One aspect of this study that requires consideration, is that woodland caribou are an ecotype of caribou that are comprised of eight separate caribou designatable units. Each of those designatable units inhabit different parts of Canada, and are subject to different threats, and therefore have different conservation documentation and threat listings (Table S4). So as to represent all threats to woodland caribou impartially, we collated threats listed for any of the eight caribou designatable units, into one threat record for woodland caribou. Threats listed for other species at risk were then compared to the woodland caribou threat record in the modelling analysis. In doing so, threats listed for one or two woodland caribou designatable units were weighted the same as threats listed for all units. Overall, there was a strong degree of commonality in threats listed for most woodland caribou designatable units (Table S4), with seven designatable units including the main threat categories: "energy production and mining", "transport and service corridors", and "biological resource use", and more than five listing "natural system modifications", "invasive and other problematic species", and "human intrusions and disturbance". However, there were some threats that were only listed for one or two designatable units, indicating that they may not currently be a range wide issue for woodland caribou. For example, "agriculture and aquiculture" was a main threat category listed only for boreal caribou, and "pollution" was a main threat category listed only for boreal and Atlantic-Gaspésie caribou. To understand differences between these designatable units, it would be useful to run separate models for each designatable units of woodland caribou, but sample sizes precluded this possibility.

This study uses a novel approach, examining threat and geographic overlap to assess the extent woodland caribou act as an umbrella species for other species at risk in Canada. This approach facilitates identification of sympatric species and species traits that may be more or less likely to benefit from caribou-focused conservation. Other umbrella species that have been suggested in Canada including grizzly bears (*Ursus horribilis*, Steenweg et al., 2023), polar bears (*Ursus maritimus*, Derocher et al., 2026), coho salmon (*Oncorhynchus kisutch*, Branton and Richardson, 2014), and northern spotted owls (*Strix occidentalis caurina*, Carroll, 2010), and future research could assess the potential efficacy of these species in protecting other species at risk. There were also limitations of the current analysis that require consideration. The species studied here are limited to those that have been assessed by COSEWIC, but the true number of at-risk species in Canada, particularly lesser studied groups such as arthropods, is estimated to be and order of magnitude higher (Office of the Auditor General of Canada 2024). Species ranges are used as unit of occupancy in this study but these do not take into account distribution patchiness, which is much harder to quantify and find reliable spatial data for. Additionally, more recent COSEWIC documentation weights the importance of threats between low, medium, and high but as this weighting was only available for 20% of species at risk documentation, we could not use it. To keep the structure of the database consistent, we summarised all threat strengths (low, medium, and high) to a binary threat presence score of one. Future studies that use threat assessment data would benefit from use of threat strength scores, that would provide more detailed information on threat overlap between species. This is particularly the case for woodland caribou where many threats are listed, but not all are equal in importance. Potentially future research could consider examining other factors that may influence threat overlap including habitat preferences and body size. Another consideration of this analysis is that there is regional variation in threats to different species at risk across Canada, particularly different designatable units of the same species. This was managed by considering different designatable units of the same biological species separately in the dataset. Finally, threat analysis is complex and there may be indirect and unexpected benefits of woodland caribou focused conservation. For example, for wolverine (*Gulo gulo*) trapping is a key cause of mortality, and while caribou-focused conservation may not directly manage wolverine trapping, it may limit road building which limits trapping access (Hohnen et al. 2025).

5. Conclusions

Significant investments in single-species conservation to preserve woodland caribou in Canada, precipitated debate as to whether woodland caribou serve as an effective umbrella for sympatric species at risk. Prioritising conservation funding is difficult, and Canada has ambitious targets around biodiversity conservation and species extinctions. Single species conservation approaches such as woodland caribou-focused conservation, offer a means to address the difficulty of managing each species individually. Woodland caribou-focused conservation is important in its own right, and our results also suggest that this approach does serve additional species. Indeed, many specific taxonomic groups of boreal and montane species are likely to benefit from conservation measures enacted to protect woodland caribou. However, there is low spatial overlap between woodland caribou and many species at risk limiting potential benefits geographically. For those that are sympatric with woodland caribou, the umbrella may still be leaky (Micheletti et al. 2023), proving uneven protection for species with small ranges or those from particular taxonomic groups such as arthropods. Woodland caribou deserve their central place in Canada's conservation strategy, but to prevent the loss of Canada's most vulnerable species, more detailed management of threats to other species at risk is also required.

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Supplementary material

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References

Barton, K. 2009. MuMIn: multi-model inference. Available from http://r-forge. r-project.org/projects/mumin/ [accessed 29 November 2023].

Bichet, O., Dupuch, A., Hébert, C., Le Borgne, H., and Fortin, D. 2016. Maintaining animal assemblages through single-species management: the case of threatened caribou in boreal forest. Ecological Applications, **26**: 612–623. doi:10.1890/15-0525.

Bifolchi, A., and Lodé, T. 2005. Efficiency of conservation shortcuts: an investigation with otters as umbrella species. Biological Conservation, **126**: 523–527. doi:10.1016/j.biocon.2005.07.002.

Bouchard, M., and Pothier, D. 2011. Long-term influence of fire and harvesting on boreal forest age structure and forest composition in eastern Québec. Forest Ecology and Management, **261**: 811–820. doi:10.1016/j.foreco.2010.11.020.

Brown, G.S., Rettie, W.J., Brooks, R.J., and Mallory, F.F. 2007. Predicting the impacts of forest management on woodland caribou habitat suitability in black spruce boreal forest. Forest Ecology and Management, **245**: 137–147. doi:10.1016/j.foreco.2007.04.016.

Burnham, K.P., and Anderson, D.R. 2002. Model selection and multimodel inference: a practical information-theoretic approach. 2nd ed. Springer-Verlag, New York.

Caro, T. 2010. Conservation by proxy: indicator, umbrella, keystone, flagship, and other surrogate species. Island Press, Washington, USA. doi:10.2307/jj.41003793.

Collard, R., Dempsey, J., and Holmberg, M. 2020. Extirpation despite regulation? *In* Environmental assessment and caribou. Conservation science and practice 2:e166. Wiley Online Library.

COSEWIC. 2006. COSEWIC assessment and status report on the Green-scaled willow (Salix chlorolepis) in Canada. Ottawa. Committee on

the Status of Endangered Wildlife in Canada, Ottawa, Canada. pp. vi + 19.
COSEWIC. 2010. COSEWIC assessment and status report on the Crumpled Tarpaper Lichen Collema coniophilum in Canada. Committee on the Status of Endangered Wildlife in Canada, Ottawa, Canada.
COSEWIC. 2011. COSEWIC assessment and status report on the Dune Tachinid Fly Germaria angustatain Canada. Committee on the Status of Endangered Wildlife in Canada, Ottawa, Canada.
COSEWIC. 2012. Western toad (Anaxyrus boreas): COSEWIC assessment and status report 2012. Committee on the Status of Endangered Wildlife in Canada, Ottawa, Canada.
COSEWIC. 2014. COSEWIC assessment and status report on the caribou *Rangifer tarandus*, northern mountain population, central mountain population and southern mountain population in Canada. Committee on the Status of Endangered Wildlife in Canada, Ottawa, Canada.
Courtois, R., Ouellet, J.-P., Dussault, C., and Gingras, A. 2004. Forest management guidelines for forest-dwelling caribou in Quebec. The Forestry Chronicle, **80**: 598–607. doi:10.5558/tfc80598-5.
Cribari-Neto, F., and Zeileis, A. 2010. Beta regression in R. Journal of Statistical Software, **34**: 1–24. doi:10.18637/jss.v034.i02.
Drever, C.R., Hutchison, C., Drever, M.C., Fortin, D., Johnson, C.A., and Wiersma, Y.F. 2019. Conservation through co-occurrence: woodland caribou as a focal species for boreal biodiversity. Biological Conservation, **232**: 238–252. doi:10.1016/j.biocon.2019.01.026.
Environment and Climate Change Canada. 2018a. Pan-Canadian approach to transforming species at risk conservation in Canada. Available from http://epe.lac-bac.gc.ca/100/201/301/weekly_acquisitions_list-ef/2019/19-03/publications.gc. ca/collections/collection_2019/eccc/CW66-582-2018-eng.pdf [accessed 8 November 2023].
Environment and Climate Change Canada. 2018b. Action plan for the woodland caribou (*Rangifer tarandus caribou*), boreal population, in Canada. Species At Risk Act action plan series. Environment and Climate Change Canada, Ottawa, Canada.
Environment and Climate Change Canada. 2020. Amended recovery strategy for the woodland caribou (*Rangifer tarandus caribou*), boreal population, in Canada. Environment and Climate Change Canada, Ottawa.
Environment and Climate Change Canada. 2023. Range map extents—species at risk—Canada. Available from https://open.canada.ca/data/en/dataset/d00f8e8c-40c4-435a-b790-980339ce3121 [accessed 21 December 2024].
Environment and Climate Change Canada. 2024. Report on the progress of the recovery strategy implementation (period 2017–2022) and the action plan implementation (period 2018–2023) for caribou (*Rangifer tarandus*), boreal population, in Canada. Species At Risk Act recovery strategy report series. Environment and Climate Change Canada, Ottawa, Canada. Xii + 125pp.
ESRI. 2023. ArcGIS desktop: release 10.4. Environmental Systems Research Institute, Redlands, CA.
Festa-Bianchet, M., Ray, J., Boutin, S., Côté, S., and Gunn, A. 2011. Conservation of caribou (*Rangifer tarandus*) in Canada: an uncertain future. Canadian Journal of Zoology, **89**: 419–434. doi:10.1139/z11-025.
Fleishman, E., Murphy, D.D., and Brussard, P.F. 2000. A new method for selection of umbrella species for conservation planning. Ecological Applications, **10**: 569–579. doi:10.1890/1051-0761(2000)010%5b0569:ANMFSO%5d2.0.CO;2.
Government of Canada. 2016. Provinces/Territories, Cartographic Boundary File 2016 Census. Available from https://open.canada.ca/data/en/dataset/a883eb14-0c0e-45c4-b8c4-b54c4a819edb.
Government of Canada. 2026. Browse Government of Canada publications. Government of Canada, Ottawa, Canada. Available from https://publications.gc.ca/site/eng/browse/index.html [accessed 2 November 2024].
Hardouin, M.E., and Hargreaves, A.L. 2023. Mapping nationally and globally at-risk species to identify hotspots for (and gaps in) conservation. Proceedings of the Royal Society B: Biological Sciences, **290**: 20222307. doi:10.1098/rspb.2022.2307.
Hebblewhite, M., and Fortin, D. 2017. Canada fails to protect its caribou. Science, **358**(6364): 730–731. doi:10.1126/science.aar2464.
Hohnen, R., Stewart, F.E.C., and Scrafford, M.A. 2025. Wolverine in the slipstream: a systematic review of caribou-focused conservation benefits, gaps and uncertainties for wolverine in Canada. Conservation Science and Practice, e70152.
Hummel, M., and Ray, J.C. 2008. Caribou and the North: a shared future. Dundurn Press, Toronto, Canada.
Hunter, M., Jr, Westgate, M., Barton, P., Calhoun, A., Pierson, J., Tulloch, A., et al. 2016. Two roles for ecological surrogacy: indicator surrogates and management surrogates. Ecological Indicators, **63**: 121–125. doi:10.1016/j.ecolind.2015.11.049.
IUCN. 2022. Threats classification scheme, v 3.3. International Union for Conservation of Nature, Gland, Switzerland. Available from https://www.iucnredlist.org/resources/threat-classification-scheme.
Jaccard, P. 1908. Nouvelles recherches sur la distribution florale. Bulletin de la Société Vaudoise des Sciences Naturelles, **44**: 223–270.
Johnson, C.A., Drever, C.R., Kirby, P., Neave, E., and Martin, A.E. 2022. Protecting boreal caribou habitat can help conserve biodiversity and safeguard large quantities of soil carbon in Canada. Scientific Reports, **12**(1): 17067.
Labadie, G., Bouderbala, I., Boulanger, Y., Béland, J.-M., Hébert, C., Allard, A., et al. 2024. The umbrella value of caribou management strategies for biodiversity conservation in boreal forests under global change. Science of the Total Environment, **907**: 168087. doi:10.1016/j.scitotenv.2023.168087.
Lindenmayer, D.B., and Westgate, M.J. 2020. Are flagship, umbrella and keystone species useful surrogates to understand the consequences of landscape change? Current Landscape Ecology Reports, **5**: 76–84. doi:10.1007/s40823-020-00052-x.
Mackey, B., Campbell, C., Norman, P., Hugh, S., DellaSala, D.A., Malcolm, J.R., et al. 2023. Assessing the cumulative impacts of forest management on forest age structure development and woodland caribou habitat in boreal landscapes: a case study from two Canadian provinces. Land, **13**: 6. doi:10.3390/land13010006.
Martin, A.E., Neave, E., Kirby, P., Drever, C.R., and Johnson, C.A. 2022. Multi-objective optimization can balance trade-offs among boreal caribou, biodiversity, and climate change objectives when conservation hotspots do not overlap. Scientific Reports, **12**(1): 11895.
Micheletti, T., Haché, S., Stralberg, D., Stewart, F.E., Chubaty, A.M., Barros, C., et al. 2023. Will this umbrella leak? A caribou umbrella index for boreal landbird conservation. Conservation Science and Practice, **5**: e12908. doi:10.1111/csp2.12908.
Micheletti, T., Stewart, F.E., McIntire, E.J., and Haché, S. 2025. Reconciling opposite conclusions in umbrella species evaluation .In Press. doi:10.1111/cobi.70106.
Molina, E., Valeria, O., Martin, M., Montoro Girona, M., and Ramirez, J.A. 2022. Long-term impacts of forest management practices under climate change on structure, composition, and fragmentation of the Canadian boreal landscape. Forests, **13**: 1292. doi:10.3390/f13081292.
Morineau, C., Boulanger, Y., Gachon, P., Plante, S., and St-Laurent, M. 2023. Climate change alone cannot explain boreal caribou range recession in Quebec since 1850. Global Change Biology, **29**: 6661–6678. doi:10.1111/gcb.16949.
NatureServe. 2024. NatureServe network biodiversity location data accessed through NatureServe explorer [web application]. NatureServe, Arlington, Virginia. Available from https://explorer.natureserve.org/ [accessed 24 March 2025].
Naujokaitis-Lewis, I., Endicott, S., and Guezen, J.M. 2022. CAN-SAR: a database of Canadian species at risk information. Scientific Data, **9**: 289. doi:10.1038/s41597-022-01381-8.
Office of the Auditor General of Canada. 2024. Supporting Species At Risk assessment and reassessment. 2024 Reports 6 to 10 of the Commissioner of the Environment and Sustainable Development to the Parliament of Canada. Office of the Auditor General of Canada, Ottawa, Canada.
OMNRF. 2014. Forest management guide for boreal landscapes. Ontario ministry for natural resources. Queens Printer for Ontario, Toronto.
R Core Team. 2024. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available from //www.R-project.org/.
R Core Team. 2025. R: A language and environment for statistical computing, V 4.4.0. Available at https://www.R-project.org/ [accessed 2 February 2025].
Rettie, W.J., and Messier, F. 2000. Hierarchical habitat selection by woodland caribou: its relationship to limiting factors. Ecography, **23**: 466–478. doi:10.1111/j.1600-0587.2000.tb00303.x.

Roberge, J.-M., Mikusiński, G., and Svensson, S. 2008. The white-backed woodpecker: umbrella species for forest conservation planning? Biodiversity and Conservation, **17**: 2479–2494. doi:10.1007/s10531-008-9394-4.

Runge, C.A., Withey, J.C., Naugle, D.E., Fargione, J.E., Helmstedt, K.J., Larsen, A.E., et al. 2019. Single species conservation as an umbrella for management of landscape threats. PLoS One, **14**: e0209619. doi:10.1371/journal.pone.0209619.

Sergio, F., Newton, I., Marchesi, L., and Pedrini, P. 2006. Ecologically justified charisma: preservation of top predators delivers biodiversity conservation. Journal of Applied Ecology, **43**: 1049–1055. doi:10.1111/j.1365-2664.2006.01218.x.

Species at Risk Act (SARA). 2002. C-29. An Act respecting the protection of wildlife species at risk in Canada [online]. Available from https://laws-lois.justice.gc.ca/eng/acts/s-15.3/FullText.html [accessed 6 March 2025].

U.S. Geological Survey. 2004. Political Boundary Lines, North America, 2004. Available from http://purl.stanford.edu/yw234jf3747 [accessed 6 March 2025].

Vors, L.S., Schaefer, J.A., Pond, B.A., Rodgers, A.R., and Patterson, B.R. 2007. Woodland caribou extirpation and anthropogenic landscape disturbance in Ontario. The Journal of Wildlife Management, **71**: 1249–1256. doi:10.2193/2006-263.

Wang, F., Winkler, J., Vina, A., McShea, W.J., Li, S., Connor, T., et al. 2021. The hidden risk of using umbrella species as conservation surrogates: a spatio-temporal approach. Biological Conservation, **253**: 108913. doi:10.1016/j.biocon.2020.108913.

WWF. 2018. Living planet report 2018: aiming higher. *Edited by* M. Page Grooten and R.E.A. Almond. World Wildlife Fund, Gland, Switzerland. Available from https://pure.iiasa.ac.at/id/eprint/15549/1/%255bEMBARGO%2030%20OCT%255d%20LPR2018_Full%20Report_12.10.2018.pdf.

Zarri, E.C., Naugle, D.E., and Martin, T.E. 2024. Impacts of umbrella species management on non-target species. Journal of Applied Ecology, **61**: 1411–1425. doi:10.1111/1365-2664.14654.

Zuur, A.F., Ieno, E.N., and Elphick, C.S. 2010. A protocol for data exploration to avoid common statistical problems. Methods in Ecology and Evolution, **1**: 3–14. doi:10.1111/j.2041-210X.2009.00001.x.