Received: 8 July 2022 | Revised: 29 November 2022 | Accepted: 31 January 2023

DOI: 10.1111/csp2.12908

CONTRIBUTED PAPER

Conservation Science and Practice
A journal of the Society for Conservation Biology | Open Access

WILEY

Will this umbrella leak? A caribou umbrella index for boreal landbird conservation

Tatiane Micheletti[1] | **Samuel Haché**[2] | **Diana Stralberg**[3,4] | **Frances E. C. Stewart**[5,6] | **Alex M. Chubaty**[7] | **Ceres Barros**[1] | **Erin M. Bayne**[8] | **Steven G. Cumming**[9] | **Teegan D. S. Docherty**[8] | **Amanda Dookie**[10] | **Isabelle Duclos**[2] | **Ian M. S. Eddy**[6] | **Zuzu Gadallah**[10] | **Claudia A. Haas**[11] | **James Hodson**[11] | **Mathieu Leblond**[12] | **C. Lisa Mahon**[8,13] | **Fiona Schmiegelow**[4,14] | **Junior A. Tremblay**[9,15] | **Steven L. Van Wilgenburg**[16] | **Alana R. Westwood**[17] | **Eliot J. B. McIntire**[1,6]

Correspondence
Tatiane Micheletti, 162 – 46360 Valleyview Road, Chilliwack, BC V2R 5L7, Canada.
Email: tati.micheletti@gmail.com; tati.silva@ubc.ca

Funding information
Canadian Forest Service ADM Innovation Fund; Canadian Network for Research and Innovation in Machining Technology, Natural Sciences and Engineering Research Council of Canada (NSERC); Environment and Climate Change Canada

Abstract

Conservation approaches that efficiently protect multiple values, such as the umbrella species concept, have been widely promoted with expected dramatic ecosystem changes. Due to its social and cultural importance, and recent declining trends, boreal populations of woodland caribou have been suggested as potential umbrella species for other declining taxa, such as boreal landbirds. We propose a generic pixel-based umbrella index that focuses on fine-grained habitat overlaps. In light of ongoing conservation efforts worldwide implementing area-based targets (e.g., 30% by 2030), we used a random neutral model as baseline, as opposed to a no-conservation scenario, which has been used elsewhere. We found that the conservation efficiency of caribou as an umbrella for 71 co-occurring landbirds—three of which are priority species—in the Northwest Territories, Canada, is generally lower than our random model, as 53% of the species presented negative umbrella index medians with the interquartile range not overlapping zero. We conclude that in cases where area-based targets drive decision-making and the issue at stake involves identifying which areas to conserve—not whether to conserve—woodland caribou may be a leaky umbrella for most co-occurring landbird species and these might need complementary conservation actions to be brought in from the rain.

KEYWORDS

boreal songbirds, conservation, ecological forecasting, landscape simulation, multi-species management, Rangifer tarandus, SpaDES, species distribution modeling

For affiliations refer to page 11

1 | INTRODUCTION

The need to address increasing anthropogenic and climate-induced threats to biodiversity with limited resources has triggered a growing awareness of multi-species conservation strategies (Burgar et al., 2019; Early & Thomas, 2007), such as the "umbrella species." This concept (Caro & Girling, 2010; Lambeck, 1997) recognizes the infeasibility of managing every species independently and focuses conservation efforts on one or a few key species aiming at also protecting co-occurring ones. Often, umbrella candidates are culturally important and widely distributed, with well-documented functional ecosystem roles (Wiersma & Sleep, 2016). However, umbrella species management will likely not effectively protect all co-occurring species within a system; identifying how efficient an umbrella species is could improve long-term conservation effectiveness. We define a leaky umbrella species as one that is inefficient in protecting other species of conservation interest. In other words, if conserving high-quality habitat of an umbrella species protects fewer individuals of a species of conservation interest than conserving randomly selected areas of the same size, we may have a leaky umbrella that will not achieve conservation objectives.

Over the last three decades, applications of the umbrella concept have demonstrated value and potential benefits to biodiversity in widely different contexts (Roberge & Angelstam, 2004). Large mammals (Caro, 2003; Thornton et al., 2016), fish (Osgood et al., 2020), reptiles (Demers et al., 2018), and birds (Hawkes et al., 2019) have all been used as umbrellas. For example, Li and Pimm (2016) found that over 96% of giant panda's (*Ailuropoda melanoleuca*) habitat overlapped the top 5% forest hotspots for endemic vertebrates in China, suggesting that panda habitat protection could benefit other vulnerable taxa. However, increasing evidence shows that using umbrella species may not always achieve anticipated conservation gains (Kramer et al., 2019; Wang et al., 2021). While charisma, large body size, and at-risk conservation status create flagship appeal and might help secure conservation resources, these might be poor indicators of a species' umbrella potential (Brennan et al., 2020; Diniz et al., 2018; Sattler et al., 2014), particularly when a single umbrella species is used to guide multi-species conservation (Wang et al., 2021). Therefore, evaluating relationships between candidate umbrella species and broader conservation goals across large spatiotemporal extents could help optimize conservation resource allocation (Diniz et al., 2018). This task, however, presents many challenges ranging from lack of data to computing power and analytical design (Wang et al., 2021), and is often deemed impractical.

Following a global trend, the Government of Canada has also been adopting multi-species and ecosystem-based approaches to wildlife conservation. For example, the Pan-Canadian Approach to Transforming Species at Risk Conservation in Canada promotes multi-species management planning, aligning investment for shared priorities (Brooks et al., 2006; Environment and Climate Change Canada, 2018). The country is also a signatory of the Convention of Biological Diversity (CBD), anticipating 25% of terrestrial areas protected by 2025 and 30% by 2030 (The Pathway Team, 2022). Such initiatives also set the stage for national and international legal obligations to protect critical habitats for Species at Risk (SARA, 2002), such as boreal populations of woodland caribou (*Rangifer tarandus caribou*[1]; hereafter "caribou") and migratory birds (Minister of Justice, 1994). Boreal caribou occur throughout most of Canada's boreal forests and are generally associated with old-growth and mature conifers. They are of high social and cultural value for many Indigenous Peoples (Borish et al., 2021; Hummel & Ray, 2014), and their populations have declined markedly over the last three decades (Hebblewhite, 2017). Co-occurring with caribou, several boreal landbird species (hereafter "landbirds") are also currently listed as at-risk and of special concern, such as Canada Warbler (*Cardellina canadensis*), Olive-sided Flycatcher (*Contopus cooperi*), and Rusty Blackbird (*Euphagus carolinus*) (SARA, 2002). It is estimated that the total number of landbirds in Canadian boreal forests has declined by approximately 500 million individuals between 1966 and 2015 (Rosenberg et al., 2019). In this context, caribou could be a good candidate umbrella species for landbirds.

Drever et al. (2019) showed that proposed areas for caribou conservation were either located in the southern part of caribou distribution or contained relatively small-ranged species, except when constrained to exclude anthropogenic footprint. This was true even though caribou range overlaps with 90% of boreal birds and mammals. Bichet et al. (2016) proposed that management guidelines intended to maintain caribou populations in the Boreal Shield ecozone could also improve the protection of current multi-taxa assemblages (i.e., community composition), including landbirds. Conversely, (Wiersma & Sleep, 2018) showed that, for the same ecozone, caribou may not be as effective as other types of conservation planning targets, and suggested that prioritizing the protection of habitat for several species could be more effective.

Conserving caribou in Canada is, for many, synonymous with protecting large swaths of land due to its need for large areas for population maintenance (Environment Canada, 2012). As more terrestrial areas are placed under protection, more species will be as well. When aiming at increasing protected areas in Canada to

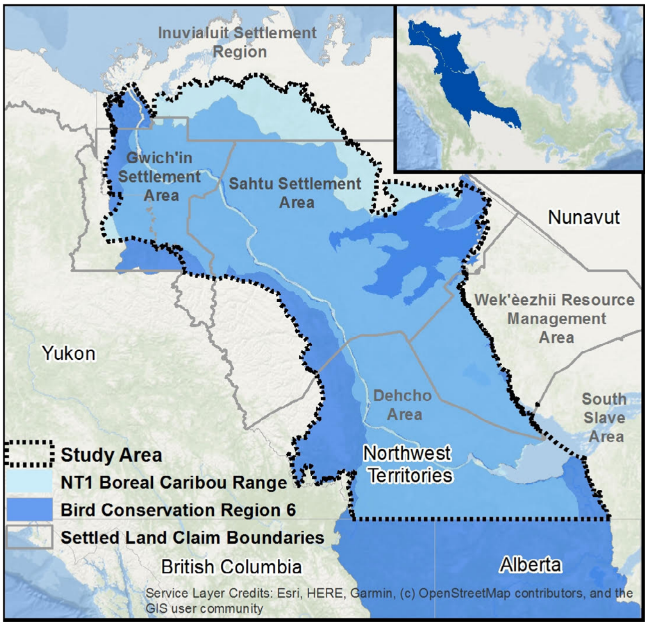

FIGURE 1 Study area showing Bird Conservation Region 6 (in darker blue) and NT1 boreal caribou range (in lighter blue). The study area (black dotted line) for the calculation of the umbrella index is the union of these two areas within the Northwest Territories.

meet CBD targets, caribou is likely a good candidate umbrella species. However, this approach may not be efficient when the conservation policy involves selecting which areas to prioritize for protection, as opposed to using a charismatic and important species to gain support for an increase in the amount of protected area. Umbrella efficiency is even more important under rapid climate change, especially for northern species expected to undergo substantial climate-induced range shifts (Lawler et al., 2009). Determining overlapping habitat needs between umbrella and co-occurring species through time might provide a robust comprehensive assessment of conservation efficiency.

Here, we quantitatively evaluated the current and projected effectiveness of caribou as an umbrella for 71 co-occurring landbirds species—individually and grouped according to their association with habitat—under anticipated climate change. We used SpaDES (Chubaty & McIntire, 2021), a modeling toolkit designed to ease the implementation of a PERFICT approach—make frequent **P**redictions, **E**valuate models, make models **R**eusable, **F**reely accessible and **I**nteroperable, built within **C**ontinuous workflows that are routinely **T**ested—for predictive applications (McIntire et al., 2022). This enabled us to leverage previous efforts to forecast the responses of landbirds (Micheletti et al., 2021) and caribou (see Appendix S1) to landscape changes in the western region of the Northwest Territories, Canada. We brought together a diversity of data sources and model paradigms to estimate current and future tree-species biomass and wildfire dynamics, along with the projected landbird abundance and boreal caribou resource selection, under three climate projections from 2011 to 2091. We then calculated a novel caribou umbrella index for each landbird species and group, which focused on quantifying how efficiently caribou habitat overlaps landbird habitat over time, across a wide range of area-based scenarios.

2 | METHODS

2.1 | Study area

Our study area, the union between NT1 caribou range (Environment Canada, 2012) and Bird Conservation Region 6 (Bird Studies Canada and NABCI, 2014) within the Northwest Territories, Canada (Figure 1), covers 50 million hectares of the Taiga Plains Ecozone. The study area encompasses the Gwich'in, Inuvialuit, Sahtú, and Tłįchǫ settlement areas, as well as Dehcho, Akaitcho, and Métis traditional territories. The study area overlaps with parts of Treaty 8 and 11 territories, where land claim negotiations with First Nations and Métis governments are ongoing. It comprises upland (50%) and lowland (15%) boreal forest, interspersed with waterbodies (15%), and nonforested areas (20%; i.e., shrublands, barren ground, urban development, ice, and rock; Ecosystem Classification Group, 2007). Lowland areas comprise mostly black and white spruce (*Picea mariana* and *P. glauca*, respectively), Jack pine (*Pinus banksiana*), and tamarack (*Larix laricina*), whereas upland areas are primarily deciduous species such as paper birch (*Betula papyrifera)* and trembling aspen (*Populus tremuloides*) (Ecosystem Classification Group, 2007).

NT1 is believed to contain approximately 7000 boreal caribou, considered as a threatened but self-sustaining population (Government of the Northwest Territories, 2019). Avifauna includes approximately 100 landbird species (Lepage, 2019), with ~3% classified as species at risk (SAR) (Government of Canada, 2021; Government of the Northwest Territories, 2019), specifically the Rusty Blackbird, of special Concern under SARA, as well as the Canada Warbler and the Olive-sided Flycatcher, listed as Threatened under SARA (Government of Canada, 2021).

2.2 | Modeling framework and conservation scenarios

We projected current and future landscape drivers and attributes using a combination of data sources and models from diverse modeling paradigms and initiatives. We used existing SpaDES modules for (i) simulating tree dynamics (***LandR Biomass*** modules), (ii) simulating wildfire dynamics, (iii) statistically predicting caribou resource selection (*caribouRSF_NT*), and (iv) statistically predicting boreal landbird densities (*birdsNWT*). With these, we generated annual forest and wildfire dynamics (sensu Micheletti et al., 2021; i and ii), inputs for the caribou and boreal landbird predictions (iii and iv, respectively). We covered an 80-year period (2011–2091) at a spatial resolution of 250 m. The generated caribou resource selection and landbird density maps were then used as inputs to estimate novel (v) boreal caribou umbrella indices (BCUIs, see below) at 20-year intervals, for each species and area-based conservation scenario, as described below. We used five replicates for each of the three climate models to incorporate uncertainty and stochasticity of landscape processes (i.e., forest succession, seed dispersal, and wildfire) (Figure A3). We developed 10 area-based scenarios that varied in terms of the area used for the calculation of the caribou umbrella index: from 5% to 95% of the study area excluding water, in 10% increments. Landscape, caribou, and landbird models and their validation, as well as climate data, are detailed in Appendix S1.

2.3 | Calculating the boreal caribou umbrella index

We developed a generic umbrella index (U) which quantifies how good a candidate umbrella species (u) is for a given ecological value of interest (v) when compared to randomly chosen areas (*rand*). We calculate it as

$$U_{u,v} = \frac{V_{best_u} - V_{rand}}{V_{best_v} - V_{rand}} \tag{1}$$

where

$$V_{best_u} = \sum_N v_{best_u} \tag{2}$$

$$V_{best_v} = \sum_N v_{best_v} \tag{3}$$

$$V_{rand} = \sum_N v_{rand} \tag{4}$$

and represent the summed ecological value of interest across the best N pixels for the umbrella species, for the ecological value of interest and for random pixels, respectively. We define U for caribou as the boreal caribou umbrella index for landbirds (BCUI), V_{best_u} as the caribou index, V_{best_v} as the landbird index, and V_{rand} as the random index (Figure 2). V_{rand} and V_{best_v} act to standardize the caribou index. We calculated this index for different area-based scenarios, varying N from 5% to 95% of the pixels in the study area, in increments of 10%, for each given landbird species or species group (v), at a time period and, since we are using projected future landscapes with stochastic variation, each simulation replicate. BCUI resulted in three possible values: negative, zero, and positive values up to one—which indicate a perfect umbrella (Table 1). We note that there is no lower bound to the BCUI; large negative values may indicate, in addition to suggesting that caribou and landbird species require very different habitats, random indices (V_{rand}) that are relatively close to the landbird index (V_{best_v}). In total, we calculated 750 BCUI values per species derived from five replicates, three climate projections, five points in time, and 10 area-based scenarios. BCUI presented a non-normal distribution with a generally long left tail (Figure 3). Therefore, we used the median as a central tendency and interquartile range (IQR) to describe data dispersion.

To evaluate temporal trends in BCUI for each landbird species or species group, we performed linear regressions of BCUI against the projected year for each landbird species and for each habitat group, where variability in climate projections and replicates contributed to uncertainty. To assess how well selecting the best areas for caribou promoted the abundance of habitat-associated landbird groups in comparison to randomly selected areas, we grouped the 71 landbird species into six habitat categories: shrub, generalist, deciduous, conifer, wetland, and grassland (Table A1). This grouping was done based on landbird model prediction assessment complemented with our expert opinion. The code used for all analyses can be found in the online manual (described in Appendix S2), under the chapter "Repositories."

3 | RESULTS

Across time, area-based scenarios, climate projections, and replicates, of the 71 species included in the study, BCUI for 19 (27%) presented interquartile ranges (IQRs) overlapping 0, whereas, as for the remaining 52 species, median values were negative for 73% ($n = 38$) and positive for 27% ($n = 14$) (Figure 3). The BCUI on average was highest for shrub- and conifer-associated species, such as the American Tree Sparrow (0.68; IQR 0.31–0.90; *Spizelloides arborea*), White-crowned Sparrow (0.58; 0.35–0.79; *Zonotrichia leucophrys*), and Gray-cheeked Thrush (0.51; 0.25–0.81; *Catharus minimus*), and lowest

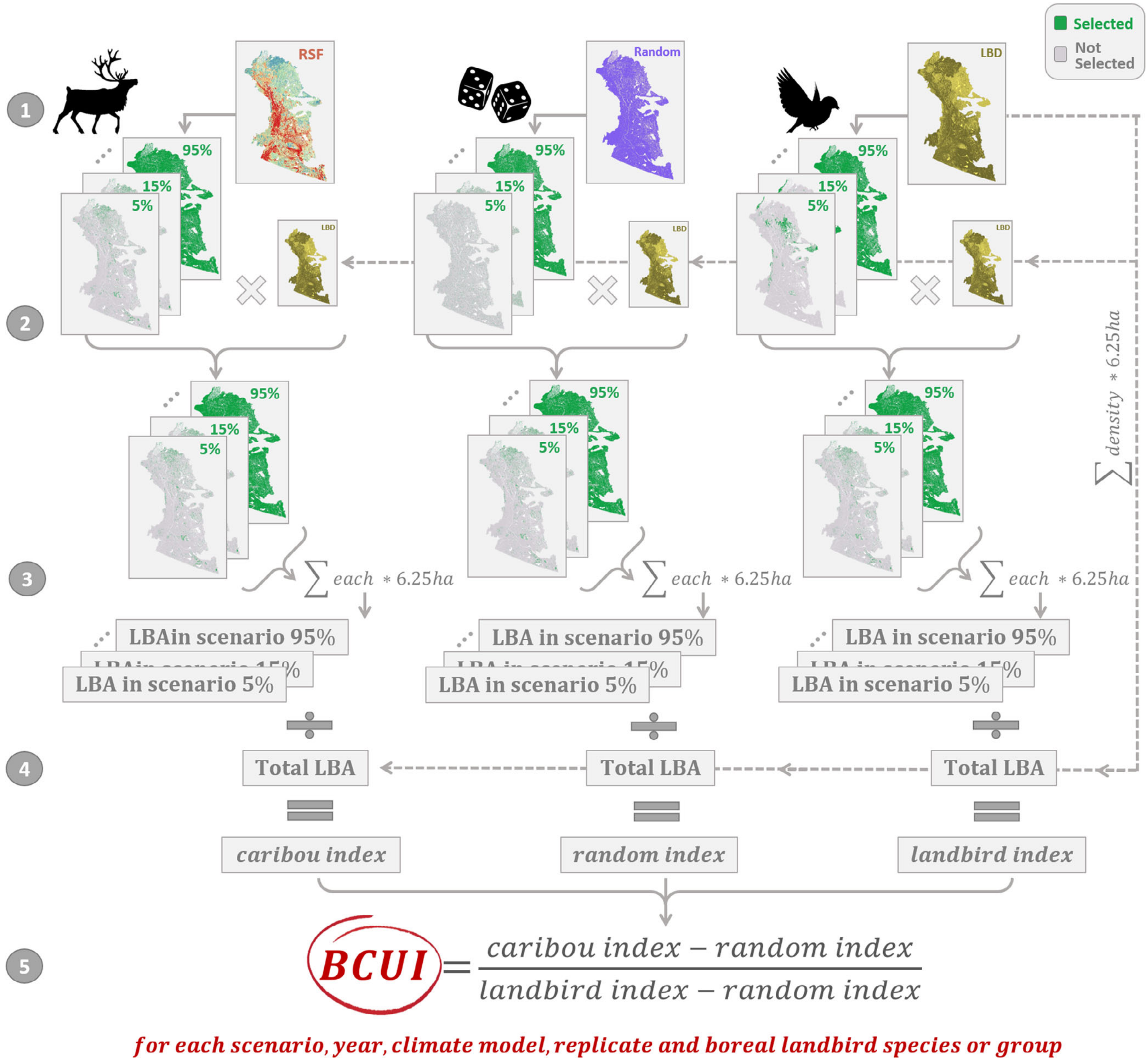

FIGURE 2 Method for calculating boreal caribou umbrella index (BCUI). For each landbird species or group, each year (2011–2091), climate projections (CanESM2, CCSM4, and INM-CM4) and replicate ($n = 5$), we developed the following steps: (1) we selected N pixels totaling the area of interest given an area-based scenario (5%–95% of study area in 10% increments) (a) that best predicted caribou habitat, (b) randomly, and (c) that the best predicted habitat for a given landbird species; (2) we multiplied the maps of selected and nonselected pixels (1 and 0, respectively) for each area-based scenario by landbird density maps (LBD) from a given year; (3) for each scenario, we summed the resulting LBD and multiplied it by pixel area (i.e., 6.25 ha) to get landbird species or group abundance (LBA) per scenario; (4) we then divided LBA of each scenario by total landbird abundance (Total LBA) for that species or group calculated from the landbird density maps of that year; (5) we rescaled the caribou index with respect to the random index and the landbird index, resulting in the BCUI for each scenario, year, climate model, replicate and boreal landbird species (Equations (1) to (4)).

for deciduous- and mixedwood-associated species, such as Ovenbird (−0.62; −1.15 to −0.30; *Seiurus aurocapilla*), Rose-breasted Grosbeak (−0.58; −1.04 to −0.29; *Pheucticus ludovicianus*) and Black-and-white Warbler (−0.55; −0.87 to −0.32; *Mniotilta varia*) (Figure 3). Boreal caribou presented a median positive umbrella index for two SAR species: the conifer-associated Rusty Blackbird (0.42; 0.28–0.54) and Olive-sided Flycatcher (0.02; −0.02 to 0.11), although, for the last, IQR overlapped zero. Median BCUI was negative for all deciduous-associated species, including the at-risk Canada Warbler (−0.46; −0.90 to −0.15) (Figure 3).

TABLE 1 Possible values for the Boreal caribou umbrella index (BCUI), possible case, and interpretation.

BCUI value	Case	Interpretation
BCUI < 0	$A_{best_u} < A_{rand}$	The proportional landbird abundance for selected pixels that maximize caribou habitat quality is smaller than the proportional landbird abundance when random pixels are selected. In other words, protecting pixels for caribou provide conservation opportunities that are worse than randomly protecting pixels.
BCUI = 0	$A_{best_u} = A_{rand}$	The proportional landbird abundance for selected pixels that maximize caribou habitat quality is the same as the proportional landbird abundance when random pixels are selected. In other words, protecting pixels for caribou provide conservation opportunities that are no better than randomly protecting pixels.
BCUI > 0	$A_{best_u} > A_{rand}$	The proportional landbird abundance for selected pixels that maximize caribou habitat quality is higher than the proportional landbird abundance when random pixels are selected. In other words, protecting pixels for caribou provide conservation opportunities that are better than randomly protecting pixels.

Note: A_{best_u} is the summation of the ecological value of interest across all pixels that represent the best N pixels for the umbrella metric, A_{best_v} is the summation of the ecological value of interest across all pixels that represent the best N pixels for the highest values for the ecological value of interest, and A_{rand} is the summation of the ecological value of interest across N random pixels.

Across habitat-associated groups, BCUI median and IQR values were only positive for shrub-associated species (0.12; 0.07–0.29) (Figure 4). Conifer- (0.008; −0.11 to 0.17), grassland- (−0.07; −0.23 to 0.06), and wetland-associated species (−0.09; −0.30 to 0.08) presented positive and negative medians for which IQR overlapped zero, being considered no better than random. Generalist- (−0.21; −0.36 to −0.12), mixedwood- (−0.27; −0.46 to −0.14), and deciduous-associated species (−0.41; −0.71 to −0.17) presented negative BCUI median and IQR values. The overall median caribou umbrella index across all landbird groups, climate projections, time periods, scenarios, and replicates had an average value of −0.11 (−0.32 to 0.07) with IQR overlapping zero.

Through time, BCUI presented stable (i.e., nonsignificant changes), increasing, and decreasing trends for approximately 32%, 28%, and 39% of species, respectively (Appendix S2). Stronger declining trends were observed for grassland, shrub, and wetland habitat-associated groups and for scenarios with larger amounts of the area selected (i.e., above 75%) (Table A2). More accentuated increasing trends were seen for deciduous-associated birds, again for area-based scenarios above 75% of area selected (Table A2). Individual species-specific linear models through time can be seen in Appendix S2.

Most species showed nuanced spatiotemporal patterns in BCUI values, presenting different behaviors for trends through time and area-based scenarios (Figure 5). For instance, the American Robin (*Turdus migratorius*) presented negative trends in BCUI through time, while Lesser Yellowlegs (*Tringa flavipes*) presented a positive trend (Figure 5, top and bottom left panels), both regardless of the area-based scenario used. However, while Lesser Yellowlegs presented positive BCUI medians across all scenarios, American Robin's BCUI signal changed through time, suggesting caribou could shift from being better than random to worse than random on average for this species. Across area-based scenarios, while American Robin presented a linear-like declining trend for BCUI, Lesser Yellowlegs presented a logit-like increasing trend.

In contrast to American Robin, the American three-toed woodpecker (*Picoides dorsalis*) showed temporal trends that varied among area-based scenarios. The signal of BCUI for the American three-toed woodpecker was negative for 5%–45% of the area selected, but shifted to positive values for areas above 45%, indicating a more efficient umbrella function in comparison to random protection with the increase in area selected. Across area-based scenarios, the American three-toed woodpecker presented a linear-like trend, although in this case, positive (i.e., increase in the area protected increased BCUI; Figure 5, top right panel). Winter Wren (*Troglodytes hiemalis*) on the other hand, presented changes in BCUI trend through time, from negative in scenarios with little area selected to positive in scenarios with increased area selected, with a parabola-like across area-based scenarios (Figure 5, bottom right panel). Figures for all other species are presented in the online manual described in Appendix S2.

4 | DISCUSSION

We presented a novel approach to quantify the effectiveness of using boreal caribou as an umbrella species for 71 boreal landbirds species in the Taiga Plains portion of the Northwest Territories under current and future

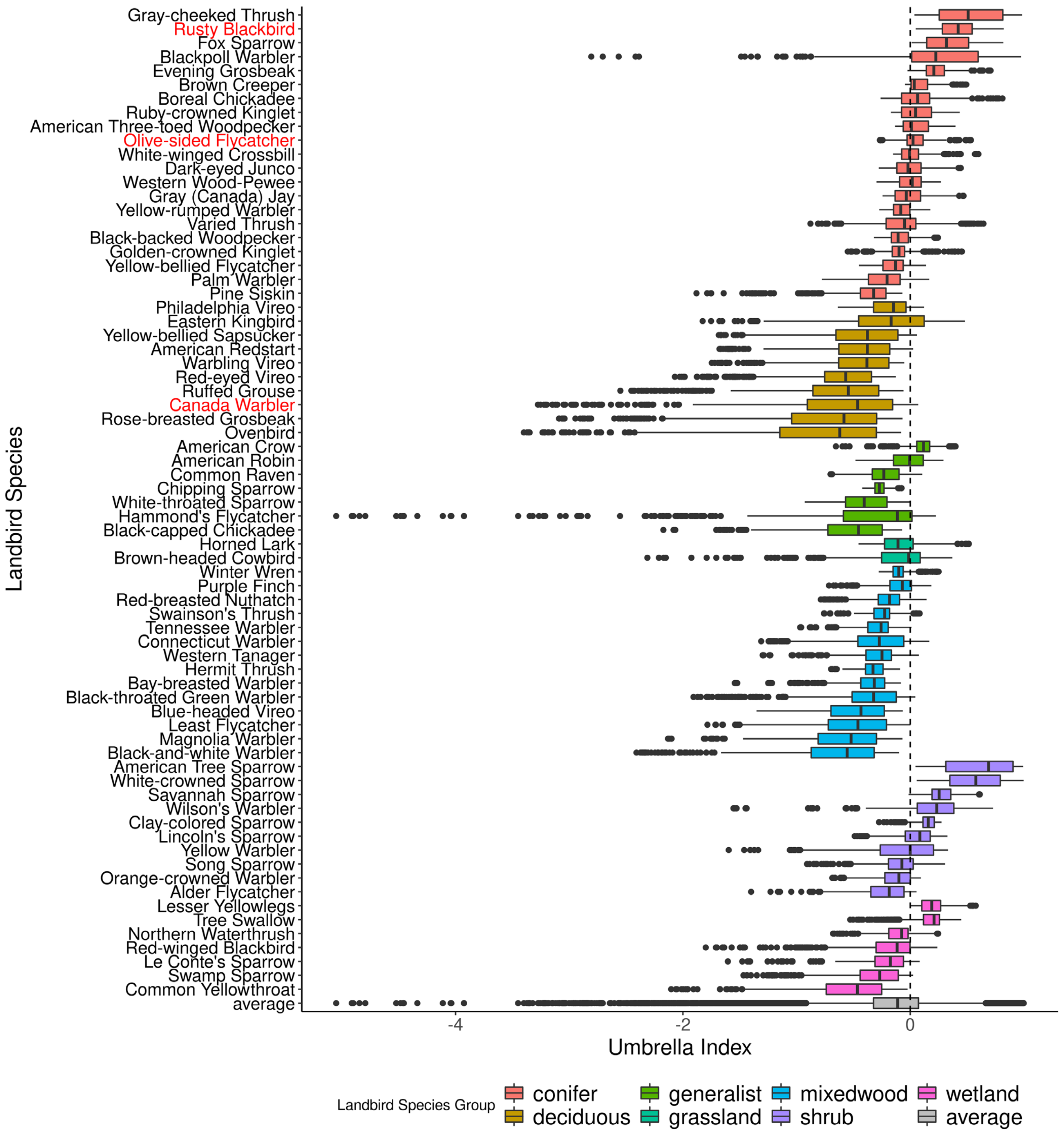

FIGURE 3 Boxplots showing the median (vertical lines), interquartile range (IQR, box), 1.5 times the IQR (whiskers), and individual outlying points of boreal caribou umbrella indices (BCUI) for 71 landbird species, over time (2011–2091; $n = 5$) and across scenarios (i.e., 5%–95%, every 10% of total area selected, $n = 10$), under replicate simulations ($n = 5$) for each of three climate projections (CanESM2, CCSM4, and INM-CM4, $n = 3$), totaling 750 BCUI values per species. Species at risk are shown in red and species scientific names are defined in Table A1. Summary and detailed individual species results can be found in the online manual described in Appendix S2.

conditions. Our main objectives were to assess caribou as a general umbrella species for landbirds in Northern Canadian forests when considering overlapping habitat quality, as well as identify landbird species that do not share core habitats with this threatened species. The concept of an umbrella index has been previously explored (Fleishman et al., 2000) and has been applied both in theoretical exercises (Diniz et al., 2018) and to support

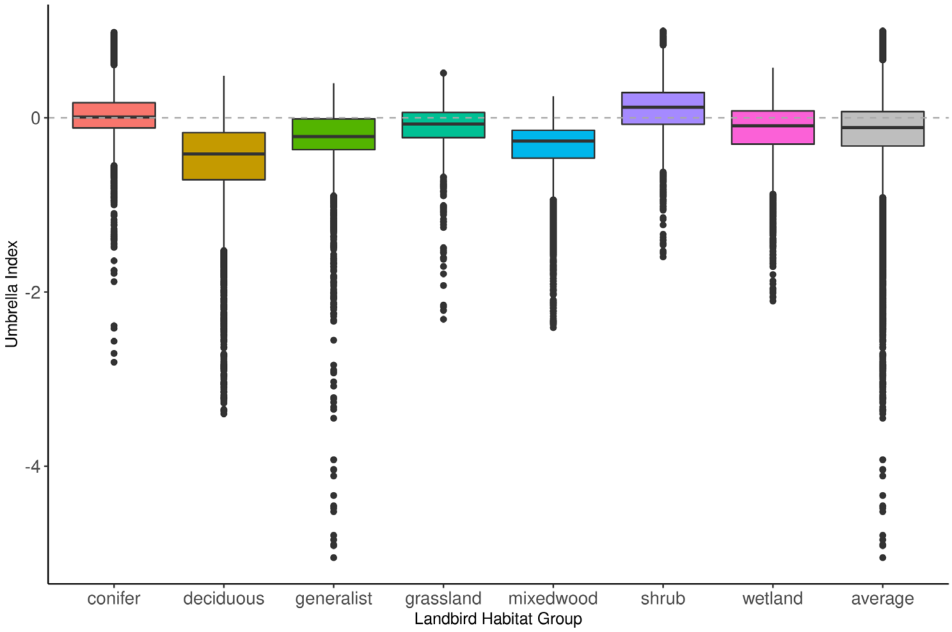

FIGURE 4 Boxplots showing the median (vertical lines), interquartile range (IQR, box), 1.5 times the IQR (whiskers) and individual outlying points of boreal caribou umbrella indices (BCUI) by landbird habitat association calculated across time (2011–2091), climate projections (CanESM2, CCSM4, and INM-CM4), percentage of area (0.05%–0.95%) and replicates ($n = 5$), as well as the weighted average across these (in gray dashed line). The average is weighted based on the number of species in each group. Summary and detailed individual species results can be found in the online manual described in Appendix S2.

conservation goals (Bried et al., 2007; Kietzka et al., 2019). However, this index focused on comparing umbrella species candidates, as opposed to quantitatively evaluating how efficiently a candidate umbrella species might perform among co-occurring ones. Our results suggest that, for our study area, boreal caribou is a relatively inefficient umbrella, performing generally worse than randomly selected areas for most boreal landbird species. Such performance is consistent in both the short- and the long-term, and is likely due to a lack of overlap in habitat needs between caribou and landbirds. Exceptions include the American Tree and White-crowned sparrows, species associated with shrub habitats, which were reasonably well covered by the caribou umbrella, as these habitats are also generally selected by caribou (DeMars et al., 2020). Selection of the most suitable caribou habitat in the Northwest Territories was also predicted to benefit SAR associated with conifers such as Rusty Blackbird when compared to choosing random areas for conservation. For Canada Warbler, a deciduous-associated species, randomly selected areas were more beneficial than selections based on caribou habitat, even under projected climate-induced replacement of conifers by deciduous species (Micheletti et al., 2021). Our results should, however, be interpreted as general trends. Species presented important individual spatiotemporal patterns, with nuanced responses to either or both total areas selected (i.e., scenarios), and changes in the landscape through time, as discussed below.

Historically, the umbrella species concept has been applied using notions of species distributions and area required for population persistence, which results in the inclusion of both high-quality habitat overlap and incidental low-quality habitat for the umbrella species that is high quality for the co-occurring species. In other words, protecting large contiguous areas ensures the inclusion of a large diversity of habitats, including bad habitat for the umbrella species that might be good for co-occurring ones. Our study does not deny that protecting large, contiguous areas for caribou will provide incidental landbird protection (Bichet et al., 2016; Drever et al., 2019). However, our results show that protecting the best areas for caribou is inefficient at protecting the habitat of most boreal landbirds in the Northwest Territories. By identifying species that have particularly different habitat requirements than caribou, we can prioritize other conservation measures for such species.

Our approach combines dynamically simulated landscape changes with a broad temporal scale as recommended by previous studies (Favreau et al., 2006; Roberge & Angelstam, 2004). In addition, predicted species densities, as used here for co-occurring species, were shown to more efficiently identify and conserve overlapping priority areas when compared to other metrics, such as occurrence and species richness (Veloz et al., 2015). The concept of an umbrella index changing over time was expanded upon by both Rozylowicz et al. (2011) and Wang et al. (2021) when quantifying the umbrella function for large carnivores and the giant panda, respectively. However, these backcasting studies may have missed important upcoming changes this century. In our study, most species showed projected negative or positive trends through time into the future, highlighting the importance of conducting spatiotemporal forecasts. For several species ($n = 38$), the umbrella index went from worse-than-random to better-than-random—or vice-

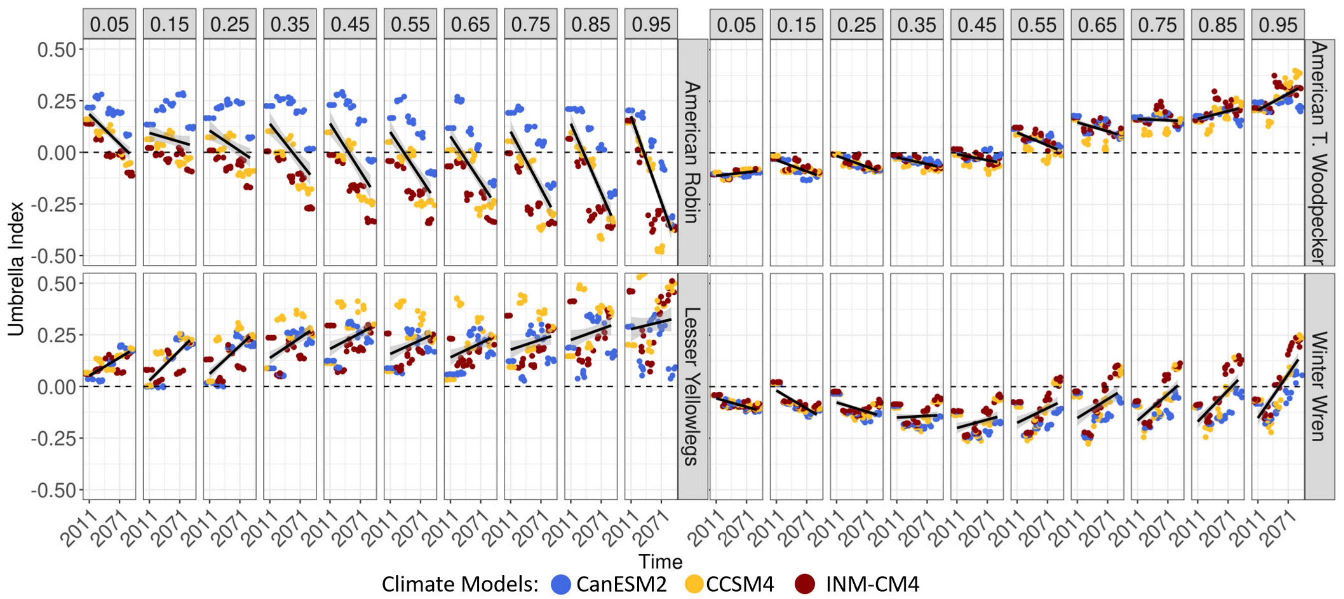

FIGURE 5 Caribou umbrella indices (BCUI) through time (2011–2091, every 20 years) for four different landbird species (AMRO, American Robin; LEYE, Lesser Yellowlegs; ATTW, American three-toed woodpecker; WIWR, Winter Wren) by percentage of land area selected for the analysis (0.5 –0.95%, by 10%), using different climate projections (CanESM2, CCSM4, and INM-CM4) and replicates ($n = 5$) to account for uncertainty. Black lines represent trends with CI95% (gray area) across time for each scenario, across replicates and climate models.

versa. These changes happened over time (72%), with changes in area-based scenarios (8%), or both combined (20%). Evaluating a system of dynamic (i.e., floating) conservation units as originally proposed by Cumming et al. (1996) is outside of the scope of this study, although there are recent examples that demonstrate effectiveness under some situations (Reynolds et al., 2017). However, our results do suggest that both the total selected area, as well as the simulation of landscape change across a large temporal span can influence the umbrella index for a given species, emphasizing the importance of forecasting landscape changes when investigating potential umbrella species and their conservation coverage.

Favreau et al. (2006) reviewed 53 studies on the effectiveness of umbrella species to conserve co-occurring ones and estimated that 73% of these were partially or fully effective. Our results suggested a different story. Only 13% of landbirds presented positive averaged medians not overlapping zero, with the highest value of caribou umbrella function being 0.69 for American Tree Sparrow. This implies that caribou habitat would, in comparison to randomly selecting areas, protect approximately 70% of this species' abundance that could potentially be protected with other measures, suggesting that for some species using caribou as an umbrella (i.e., conserving high-quality caribou habitat) could be an efficient conservation measure. On the other hand, we demonstrated that for 44% of the landbird species, selecting areas based on caribou habitat would support lower landbird abundance than randomly selected areas (i.e., negative median umbrella index not overlapping zero). Furthermore, across all landbird groups, the average BCUI median tended to also be negative (−0.11; −0.32 to 0.07). Our study builds on a growing body of evidence demonstrating the importance of investigating the expected relationships between potential umbrella species and others that could benefit from their conservation in the present and the future (e.g., Gilbert et al., 2020; Westwood et al., 2020).

Although we did not identify an overlap of good quality habitat between boreal caribou and most landbirds in the Northwest Territories, caribou might still be an important umbrella for other taxa (e.g., other mammals, lichens, other avian species, etc.), valued ecological components (e.g., carbon sequestration), or for landbirds in other regions. Further studies should (i) evaluate the consistency of these results when de facto selecting areas for boreal caribou conservation (i.e., assessing conservation values of specific areas, configuration, and connectivity), and (ii) evaluate the species umbrella potential of caribou for a broader range of taxa, such as wood bison (*Bison bison athabascae*), whooping crane (*Grus americana*), other SAR, and ecosystem services.

For the present work, we opted for the use of percentage area targets over other targets such as the percentage of species abundance. While some argue against using area-based targets because they reflect political rather than biological criteria (Wiersma & Sleep, 2016), this has nonetheless become a widespread practice over the last few decades (Svancara et al., 2005). To our knowledge, it is still the most commonly used approach (Wiersma & Sleep, 2016), likely because it bridges science and decision-making, avoids making erroneous or biased statements about abundance values, and does not require setting species population targets or minimum protected area units without scientific guidelines. Such metrics also have greater decision-making appeal because they are easier to communicate to managers, politicians, and the general public (Wiersma & Sleep, 2018), and could therefore be successfully used (Margules & Pressey, 2000).

Conservation planning per se is outside of the scope of the current work. Nevertheless, our results could be affected by (i) changes in anthropogenic footprint through time, which would influence suitable caribou habitat by limiting areas that could be selected by the species, (ii) size, configuration, and connectivity of retained areas of intact habitat necessary to sustain boreal caribou and avian populations, which would also influence the specific pixels selected for each scenario, and (iii) model formulation. Although increases in human disturbance over time might be expected, current levels of human disturbance in the study area are low, with less than 9% of the area being currently affected, and increasing at 0.2% per year (Canadian Wildlife Service, 2019). Forecasting anthropogenic disturbance is challenging due to its needs on local, national, and global economic drivers. We currently lack models capable of providing spatially explicit forecasts of human footprint for this region. Still, our approach would allow for seamless integration of such models when available (following McIntire et al., 2022), leading to an improvement in both caribou resource selection forecasts and its umbrella function assessment.

Size, configuration, and connectivity are important considerations for systematic conservation planning and the selection of priority areas for conservation. This is particularly important because boreal caribou need a minimum of 300 individuals with contiguous areas of a minimum of 10,000 km^2 in size for sustainable population growth (Environment Canada, 2012). Clearly, all habitat that is included when selecting large contiguous areas for conservation—high and low quality for the umbrella—will bring value (Leblond et al., 2022). However, while using a pixel-based approach does not include the important notions of contiguity and connectivity of conservation areas, it estimates how efficient caribou are as an umbrella species. It is important to highlight that our results do not suggest all conservation areas to be scattered at 250 m^2, but instead demonstrate that it is possible to identify which species will reliably benefit and which will need extra management measures to ensure the desired incidental protection when conserving for an umbrella species. This triage can be an important additional tool and help simplify conservation planning efforts: our results showed that in the Northwest Territories if caribou habitat is protected, Rusty Blackbird could be sufficiently protected, while the listed Canada Warbler will likely need additional conservation efforts.

While previous studies have reported high value in applying single-species management for wildlife conservation (Bichet et al., 2016), these were based on the management guidelines for boreal caribou and not the umbrella potential of the caribou per se. Hence, our approach offers a way to evaluate more directly the effectiveness of caribou as an umbrella species for multispecies conservation in the long term rather than its large area requirement. This may offer flexibility for management, as establishing large conservation areas can be challenging in some regions. Selecting priority areas for conservation requires consideration of many factors. Complementary analysis that could, for example, apply the umbrella index in a management context could considerably improve the understanding of different umbrella species' roles, identify species and habitats that should be covered by additional conservation measures, and aid the selection of areas for conservation.

Different model formulations might also influence our results. First, we used an all-year model for caribou. Seasonal (i.e., summer) caribou models could better cover higher-quality habitats for landbirds. However, we based our choice on both a model that would match our landscape simulation time-frame (i.e., annual model) and cover a larger variety of habitats, protecting caribou across all seasons. Second, both caribou and landbird models include climate effects indirectly (i.e., via vegetation and fire changes through time), but only the landbird models explicitly include climate variables as covariates in the model. Although this could be a reason for changes in the umbrella index through time, as these models would diverge more markedly with stronger effects of climate changes, landbirds may instead respond more rapidly to changes in climate (Mayor et al., 2017) than caribou (Mallory & Boyce, 2018), leading to changes in BCUI over time. For example, forecasted conversion from conifer habitat (which caribou selects for) to deciduous habitat (which caribou avoids) would generally reduce caribou habitat quality. To maintain the total area chosen, more deciduous habitat would be instead selected when calculating the caribou index, especially under scenarios with larger areas for conservation, due to the lack of conifer habitat. The caribou umbrella index would then increase for a deciduous-associated landbird species with time. Our results support this hypothesis.

Over the last five decades, more than half of boreal forest landbird species have shown declines in abundance, with an average decline of 37% (Rosenberg et al., 2019). Climate change is expected to exacerbate these trends, especially in the southern parts of the boreal forest (Cadieux et al., 2020; Micheletti et al., 2021; Stralberg et al., 2015). Identifying suitable umbrella species for long-term landbird conservation, especially under changing climate, could improve general conservation efficiency. Boreal caribou conservation on its own is extremely valuable, especially for Northern Indigenous Peoples, and our study demonstrated that for a few key landbirds, such as Rusty Blackbird, it may also serve as a conservation surrogate. However, relying exclusively on the umbrella species concept for comprehensive conservation has been repeatedly shown to be an inefficient strategy (Brennan et al., 2020; Thorne et al., 2006; Wang et al., 2021; Wiersma & Sleep, 2016) and potentially result in poor outcomes for natural resource and biodiversity management (Lindenmayer & Westgate, 2020). We demonstrated that there is potentially high value for long-term conservation in investigating whether an umbrella species and co-occurring ones overlap high-quality habitats, as opposed to only investigating umbrella species function in an applied exercise (i.e., considering minimum area requirements). Our results showed that woodland caribou is a leaky umbrella for most boreal landbird species in Northwest Territories; strategies other than exclusively relying on it as an umbrella species might be necessary to protect a broader suite of landbirds in the long term. Protection of habitat for complementary umbrella species and population management strategies for species of interest could be successful in bringing these in from the rain. While the assessment of boreal caribou as an umbrella species would likely vary across the boreal regions and methods due to the inclusion of other species, simulation of anthropogenic disturbance, and inclusion of contiguous minimum areas for the assessment, our results might be a good starting point for focused conservation efforts for boreal landbirds within the larger context of boreal caribou conservation.

AFFILIATIONS

[1]Faculty of Forestry, University of British Columbia, Vancouver, British Columbia, Canada
[2]Canadian Wildlife Service, Environment and Climate Change Canada, Yellowknife, Northwest Territories, Canada
[3]Northern Forestry Centre, Canadian Forest Service, Natural Resources Canada, Edmonton, Alberta, Canada
[4]Department of Renewable Resources, University of Alberta, Edmonton, Alberta, Canada
[5]Biology Department, Wilfrid Laurier University, Canada
[6]Pacific Forestry Centre, Canadian Forest Service, Natural Resources Canada, Victoria, British Columbia, Canada
[7]FOR-CAST Research & Analytics, Calgary, Alberta, Canada
[8]Department of Biological Sciences, University of Alberta, Edmonton, Alberta, Canada
[9]Department of Wood and Forest Sciences, Laval University, Quebec City, Quebec, Canada
[10]Canadian Wildlife Service, Environment and Climate Change Canada, Gatineau, Quebec, Canada
[11]Department of Environment and Natural Resources, Government of the Northwest Territories, Yellowknife, Northwest Territories, Canada
[12]Landscape Science and Technology Division, Environment and Climate Change Canada, Ottawa, Ontario, Canada
[13]Canadian Wildlife Service, Environment and Climate Change Canada, Whitehorse, Yukon Territories, Canada
[14]Yukon Research Centre, Yukon University, Whitehorse, Yukon Territories, Canada
[15]Wildlife Research Division, Environment and Climate Change Canada, Quebec City, Quebec, Canada
[16]Canadian Wildlife Service, Environment and Climate Change Canada, Saskatoon, Saskatchewan, Canada
[17]School for Resource and Environmental Studies, Dalhousie University, K'jipuktuk (Halifax), Nova Scotia, Canada

ACKNOWLEDGMENTS

This research was funded by a Discovery Grant of the Natural Sciences and Engineering Research Council of Canada (NSERC) and the Canadian Forest Service ADM Innovation Fund (Natural Resources Canada) to EJBM, by NSERC Discovery and Engage grants to SGC, and by research contacts awarded to SGC and EJBM by Environment and Climate Change Canada. This manuscript was enhanced through discussions with the Predictive Ecology research group at the Canadian Forest Service. We gratefully thank J. Marchal for his input and contribution to this integrated workflow. We thank the Alberta Ministry of Agriculture and Forestry and the Saskatchewan Ministry of the Environment for collecting and archiving the permanent sample plot datasets. We also acknowledge the World Climate Research Programme's Working Group on Coupled Modeling, which is responsible for CMIP. We thank the climate modeling groups for CCSM4 (Gent et al., 2011), CanESM2 (Chylek et al., 2011), and INM-CM4 (Volodin et al., 2010) for producing and making available their model outputs. For CMIP the U.S. Department of Energy's Program for Climate Model Diagnosis and Intercomparison provides coordinating support and led the development of software infrastructure in partnership with the Global Organization for Earth System Science Portals.

DATA AVAILABILITY STATEMENT

Data and code needed to reproduce the analysis is open and can be found at:

Tati Micheletti, Eliot McIntire, Frances Stewart, Diana Stralberg, Steve Cumming, Alex Chubaty, Jean Marchal, Ana Raymundo, and GeDTimmons. 2023. "Tati-Micheletti/NWT: Will This Umbrella Leak? A Caribou Umbrella Index for Boreal Bird Conservation." Zenodo. https://doi.org/10.5281/ZENODO.7646157.

Some proprietary data (i.e., high-resolution landcover product; GNWT) might need a data sharing agreement previous to access. These can, however, be replaced by open-source data. Please refer to the module repository in such cases.

ORCID

Tatiane Micheletti https://orcid.org/0000-0003-4838-8342
Alex M. Chubaty https://orcid.org/0000-0001-7146-8135
Ceres Barros https://orcid.org/0000-0003-4036-977X
Mathieu Leblond https://orcid.org/0000-0002-2833-6265
Junior A. Tremblay https://orcid.org/0000-0003-4930-0939

ENDNOTE

[1] Vadzaih, Mbedzih, Tǫdzi, Tuktut, ɛtthɛn, Tuttut, Sakaw atihk.

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SUPPORTING INFORMATION

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

How to cite this article: Micheletti, T., Haché, S., Stralberg, D., Stewart, F. E. C., Chubaty, A. M., Barros, C., Bayne, E. M., Cumming, S. G., Docherty, T. D. S., Dookie, A., Duclos, I., Eddy, I. M. S., Gadallah, Z., Haas, C. A., Hodson, J., Leblond, M., Mahon, C. L., Schmiegelow, F., Tremblay, J. A., … McIntire, E. J. B. (2023). Will this umbrella leak? A caribou umbrella index for boreal landbird conservation. *Conservation Science and Practice*, e12908. https://doi.org/10.1111/csp2.12908