




RESEARCH ARTICLE

Nature requires investment: Applying priority threat management to support biodiversity and climate targets

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Handling Editor: Jiajia Liu**Abstract**

1. Stemming biodiversity loss requires greater investment in conservation and more efficient use of available resources. Prioritizing conservation actions that yield the most biodiversity benefit for the least cost can help maximize return on investment. Actions that have co-benefits for other objectives, such as climate change mitigation, can also help mobilize additional funds for conservation.
2. We used Priority Threat Management to identify actions to secure the greatest number of species groups of conservation concern for the least cost in the Lake Simcoe-Rideau ecoregion, Ontario—one of Canada's biodiversity crisis ecoregions. We also estimated the carbon sequestration benefits of actions related to land protection and restoration.
3. We found that without additional investment in conservation, 13 of 16 species groups were expected to have <50% probability of persistence in this ecoregion by 2050. Implementing all proposed strategies would yield the greatest biodiversity benefits and secure 12 of the 16 species groups with ≥60% probability of persistence, at a cost of CA\$113 million per year over 27 years. In comparison, investing CA\$97 million per year in landowner stewardship, habitat protection and restoration and regeneration strategies could secure 10 species groups and improve the probability of persistence of one additional group from 39% to 55%.
4. The habitat protection and restoration strategies also deliver direct carbon benefits of around 11.2 Mt in total avoided CO₂ emissions and 137.6 Mt CO₂ in total

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potential sequestration, respectively, over the long-term, thus supporting alignment with climate change mitigation targets and delivering co-benefits that may further justify investment.

5. *Practical implication.* By estimating the costs and demonstrating the expected benefits and potential carbon co-benefits of conservation actions, Priority Threat Management can help maximize return on investment and identify actions that address multiple environmental crises.

KEYWORDS

biodiversity conservation, carbon co-benefits, complementarity, conservation prioritization, cost-effectiveness, nature-based climate solutions, return on investment, species at risk

1 | INTRODUCTION

Inadequate funding for conservation action has been linked to species imperilment and repeated failures to meet global biodiversity targets under the Convention on Biological Diversity (CBD) (McKinney, 2002; Waldron et al., 2013). Left unchecked, the continued loss of biodiversity can amplify the interacting effects of climate change and other anthropogenic threats, leading to abrupt and irreversible ecosystem changes (Turner et al., 2020). It is, therefore, critical that we intensify our efforts to halt and reverse biodiversity loss. To this end, the Kunming-Montreal Global Biodiversity Framework (GBF) outlines a set of ambitious goals and corresponding biodiversity conservation targets. The GBF also includes targets to mobilize financial resources through various mechanisms, including enhancing the effectiveness and efficiency of use of those resources and optimizing co-benefits to address the biodiversity and climate crises simultaneously (Convention on Biological Diversity, 2022).

As a signatory to the CBD, Canada is responsible for implementing the GBF within its borders by developing a national biodiversity strategy and action plan and securing sufficient funds for implementation. Since 2018, the federal government has mobilized roughly CA\$10 billion in investments to support biodiversity and climate goals (Environment and Climate Change Canada, 2024). However, additional financial resources will still need to be secured to close Canada's biodiversity finance gap, estimated at around US\$15–20 billion per year (Rally Assets & Nature Conservancy of Canada, 2020) or about \$20–27 billion per year in 2019 Canadian dollars. It is also equally important to make the most of currently available resources by maximizing the return on investment—that is, by prioritizing actions that yield the greatest conservation benefit for a given investment level or that achieve a predetermined conservation goal for the least cost (Boyd et al., 2015; Murdoch et al., 2007).

Conservation return on investment can be improved by taking action at the regional scale (Kennedy et al., 2016), thus benefiting multiple species or ecosystems simultaneously, and by prioritizing actions that maximize biodiversity benefits across a given region for the least cost (Pressey & Bottrill, 2009). In particular, accounting for

the complementarity of actions can help minimize costs by reducing duplication of effort and help ensure that benefits of actions are spread across the suite of target biodiversity features in the region of interest (Chadès et al., 2015; Moilanen, 2008). Considering the potential co-benefits of conservation actions, such as those related to climate change mitigation (Shin et al., 2022) or human well-being (Blicharska et al., 2019), can further maximize the overall benefits to society and the environment.

A variety of decision science tools and frameworks are available to help identify conservation actions that maximize the return on investment (Hemming et al., 2022). One example is Priority Threat Management (PTM), a decision analysis framework developed to identify cost-effective and complementary sets of actions to manage and recover multiple species or other biodiversity features simultaneously across broad regions (Carwardine et al., 2012, 2019). It is a participatory process that brings together diverse groups of experts in the ecology and management of species of conservation concern. PTM also allows for the integration of multiple types of data, including empirically derived data and expert knowledge obtained through a structured elicitation protocol (Martin et al., 2012). The application of PTM in Canada (e.g. Camaclang et al., 2021; Kehoe et al., 2021; Martin et al., 2018) and elsewhere (e.g. Carwardine et al., 2012; Chadès et al., 2015; Firn et al., 2015; Lee et al., 2022; Utami et al., 2020) demonstrates its broad applicability and is leading to positive outcomes for biodiversity through increased investment in priority actions and documented improvements in species recovery (Legge et al., 2011, 2023; Semeniuk, 2018).

Here, we applied PTM to the Lake Simcoe-Rideau ecoregion in Ontario, Canada to identify management strategies that would secure the greatest number of species groups of conservation concern in the region for the least cost. We also estimated the potential co-benefits of proposed strategies for climate change mitigation. The aim was to inform the development of a conservation prospectus that could be used to coordinate actions and establish collaborations among different conservation actors in the region, and aid in securing sufficient investment in conservation action.

The Lake Simcoe-Rideau ecoregion (Figure 1) is highly productive and biodiverse and encompasses most of Ontario's unique

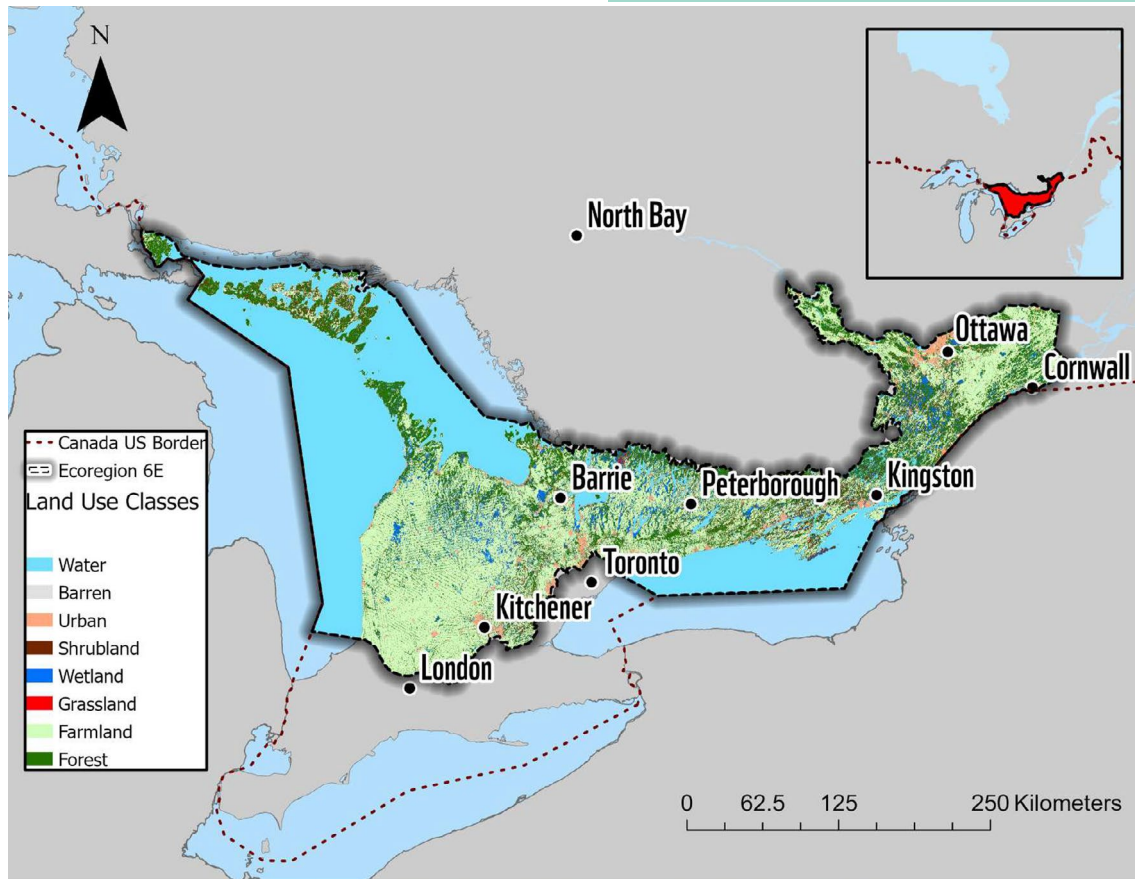


FIGURE 1 The Lake Simcoe-Rideau ecoregion (Ontario Provincial Ecoregion 6E) of southern Ontario, Canada. Data layers: Ecoregion 6E—Ontario GeoHub, Ontario Ministry of Natural Resources and Forestry. *EcoRegion* [Data set]. 2023. Land Information Ontario; <https://geohub.lio.gov.on.ca/datasets/lio::Ecoregion/about>. Land Use Classes—Agriculture and Agri-Food Canada. *Annual Space-Based Crop Inventory for Canada, 2020* [Data set]. 2020. Agroclimate, Geomatics and Earth Observation Division, Science and Technology Branch; <https://open.canada.ca/data/en/dataset/32546f7b-55c2-481e-b300-83fc16054b95>.

alvar habitats and nearly 30 natural heritage areas with significant biological or ecological importance (Crins et al., 2009; see also [Supporting Information: Appendix B](#)). This ecoregion is the second most densely populated in Ontario and also one of Canada's conservation crisis ecoregions (Kraus & Hebb, 2020) due to high development pressure and risk of habitat conversion. Climate change is also expected to greatly impact the region by mid to late century (2050–2080) (Climate Risk Institute, 2023). A 2021 report by the Auditor General of Ontario concluded that the provincial government is failing to protect species at risk, suggesting that populations will continue to decline (Office of the Auditor General of Ontario, 2021). In recent years, the Ontario government also decreased funding for species at risk and dismantled many biodiversity-focused legislative frameworks and programs, resulting in a reduced ability to act at a pace and scale required for species recovery (Bethlenfalvy & Olive, 2021; Mitchell et al., 2021). Given the scale and urgency of conservation issues in Ontario, there is a need to act strategically and collaboratively to ensure that available resources are invested in actions with the greatest benefits for biodiversity and the recovery of species of conservation concern in the region.

2 | MATERIALS AND METHODS

2.1 | Expert elicitation

To identify management strategies that would help secure the persistence of the greatest number of species of conservation concern for the least cost in the Lake Simcoe-Rideau ecoregion, a total of 145 prospective experts—individuals with knowledge of or practical experience with the ecology and management of the species of conservation concern in the ecoregion—were invited to participate in the PTM process. Of those invited, 28 experts agreed to participate. Experts were from government agencies, conservation authorities, First Nations, conservation non-profit organizations, industry and research institutions.

Experts participated in a series of five online workshops and a two-day in-person workshop held between May 2022 and January 2023. With the help of several workshop facilitators, experts discussed and refined the spatial extent ([Figure 1](#)), agreed on a 27-year time horizon (i.e. to 2050) as the temporal scope of the study, identified 133 species of conservation concern in the region ([Supporting Information: Table A1](#)), assessed key threats to those species and

developed a list of actions to implement over the time horizon that would address threats and improve the probability of persistence of those species. Experts were instructed to include only actions that were not already expected to occur and continue over the time horizon. Experts identified a total of 48 actions (Supporting Information: Table A2), which were organized into eight broad management strategies, with the criteria that each strategy could be implemented independently of any other strategy. Experts also identified six combinations of two or more individual strategies that may have synergistic effects when implemented together (S9–S14); along with a final combination that included all individual strategies (S15), this resulted in a total of seven combined strategies (Table 1).

Experts were then asked to provide estimates of the annual costs, in 2022 Canadian dollars, of planning and implementing the proposed actions (Table 1; Supporting Information: Table A2; Appendix B). Costs were converted to present values using the recommended social discount rate of 3% (Treasury Board of Canada Secretariat, 2022). For each action, experts were also asked to provide estimates of the probability that it will be implemented assuming that sufficient funds will be available (i.e. probability of uptake or the social and political feasibility), and the probability that it will be successful if implemented (i.e. technical feasibility). These two estimates were multiplied to obtain a value for the feasibility of the action. We calculated the overall feasibility of a strategy as the average feasibility across all the actions within that strategy, and the overall feasibility of a combined strategy as the average feasibility of all the individual strategies that make up that combination.

To simplify the elicitation of benefits, species were grouped into 16 species groups based on similarities in responses to threats and management actions (Supporting Information: Table A1). A modified Delphi structured elicitation protocol (Carwardine et al., 2012; Hemming et al., 2018) was used to obtain expert estimates of the probability of functional persistence in the region in 2050 for each species group. We defined functional persistence as having viable, self-sustaining populations that continue to perform their ecological function (Camaclang et al., 2021; Chadès et al., 2015; Firn et al., 2015), where a probability of 0 equates to a zero chance of persistence and 1 equates to a 100% chance of persistence. For each value, the most likely estimate (i.e. best guess), as well as the estimate under the most pessimistic scenario (i.e. lowest plausible estimate) and the most optimistic scenario (i.e. highest plausible estimate) were elicited.

For each species group, experts were first asked to provide their individual estimates of the probability of persistence under the baseline or counterfactual scenario—that is, the future without any of the strategies considered in the analysis. Ongoing biodiversity protections and conservation actions were considered 'business-as-usual' and form part of the baseline scenario, along with potential threats and pressures within and beyond the study region over the given time horizon that could impact the species of conservation concern within the region, such as development pressures and impacts of climate change. To inform the development of the baseline scenario, experts were asked to identify and discuss current and anticipated

conservation initiatives as well as ongoing and future threats to biodiversity in the region (Supporting Information: Appendix B).

With reference to future conditions under the baseline scenario, experts were then asked to provide their individual estimates of the probability of persistence with each individual strategy and combination strategy, assuming that all the actions within a given strategy are implemented successfully. The benefit of a strategy was estimated as the difference between the probability of persistence with the strategy and the probability under the baseline scenario. We aggregated the individual expert estimates using the arithmetic mean and used the mean value for subsequent analyses. See Supporting Information: Appendix B for more details about expert elicitation process.

Of the 28 experts, 24 attended two or more workshop sessions. Nine experts attended the in-person workshop to provide estimates of the cost and feasibility of actions, while 16 experts provided individual estimates of the conservation benefits of the proposed management strategies.

2.2 | Cost-effectiveness and complementarity analysis

We used estimates under the most likely scenario to evaluate the cost-effectiveness and the complementarity of management strategies. We calculated the expected benefit of each management strategy as the summed benefit of the strategy across species groups weighted by the estimated feasibility of the strategy. We then derived a cost-effectiveness (CE) score by dividing the expected benefit by the total cost of the strategy.

To assess the complementarity in the benefits of management strategies, we assumed that species groups that achieve a probability of persistence equal to or greater than a particular threshold value to be 'secure'. We set this threshold value to 60%, based on the range of estimates for the expected probability of persistence under the proposed management strategies and the preference of experts for higher probabilities of persistence. We identified the optimal sets of complementary management strategies that could maximize the number of species groups secured while minimizing the cost by solving the integer linear programming problem for a range of budgets (Chadès et al., 2015). The solutions identified are Pareto optimal solutions, representing trade-offs wherein greater benefits can only be achieved by increasing costs (Chadès et al., 2015; Ruzika & Wiecek, 2005).

When the budget is fixed, the solution to implement is typically determined by the budget constraint. However, if the budget is flexible or is yet to be secured, a choice must be made on which of the solutions should be adopted. To help inform this choice, we performed an additional analysis to determine which sets of strategies could maximize both the number of species groups secured with at least 60% probability of persistence and the number of groups that could gain at least 15% probability of persistence above the baseline for the least cost.

TABLE 1 Candidate management strategies for the Lake Simcoe-Rideau ecoregion and their estimated benefits, feasibility, costs and cost-effectiveness (CE) scores.

Management strategies	Number of actions	Total benefit	Feasibility	Total expected benefit	Total cost (million CA\$)	Annualized cost (million CA\$)	CE score	CE rank
Individual strategies								
S1 Human-wildlife management	6	1029.68	0.55	566.32	28.63	1.56	19.78	2
S2 Landowner stewardship	4	1742.55	0.65	1132.66	100.97	5.51	11.22	4
S3 Legislation and policy	6	2262.89	0.42	950.41	27.48	1.50	34.59	1
S4 Protecting habitat	5	1962.82	0.51	1001.04	1461.94	79.77	0.68	15
S5 Wildlife-safe crossings	4	996.68	0.66	657.81	88.51	4.83	7.43	6
S6 Invasive species and diseases management	7	1546.27	0.44	680.36	96.34	5.26	7.06	7
S7 Restoration and regeneration	8	2212.40	0.62	1371.69	216.58	11.82	6.33	8
S8 Industry-targeted policy and practices	8	1562.47	0.60	937.48	57.63	3.14	16.27	3
Combination strategies								
S9 S5 + S7	12	2331.24	0.64	1492.00	305.09	16.65	4.89	10
S10 S7 + S4	13	2797.16	0.56	1566.41	1678.53	91.59	0.93	13
S11 S7 + S4 + S2	17	3206.14	0.59	1891.62	1779.49	97.10	1.06	11
S12 S3 + S4	11	2774.09	0.47	1303.82	1489.42	81.27	0.88	14
S13 S1 + S7	14	2274.43	0.58	1319.17	245.21	13.38	5.38	9
S14 S2 + S8 + S3	18	2818.12	0.56	1578.15	186.07	10.15	8.48	5
S15 All strategies (S1-S8)	48	3838.57	0.56	2149.60	2078.07	113.39	1.03	12

Note: Total costs are in present values, calculated using a 3% discount rate per year over the 27-year time period.

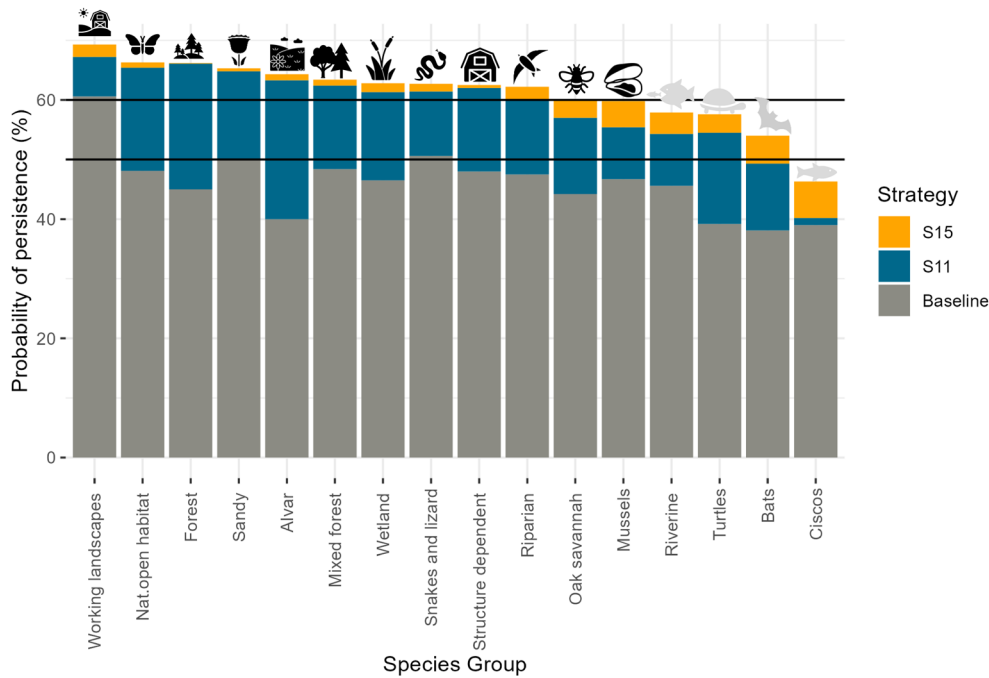


FIGURE 2 Expected probability of persistence of species groups in the Lake Simcoe-Rideau ecoregion over 27 years under the Baseline scenario (business-as-usual) and with implementation of either strategy S11 (combination of S2, S4 and S7) or S15 (combination of all strategies, S1–S8).

See [Supporting Information: Appendix B](#) for a detailed description of the cost-effectiveness and the complementarity analysis, as well as the methods and results of uncertainty analyses that explored the potential effect of variability in benefit estimates and cost discounting rates on the outputs of the complementarity analysis.

2.3 | Carbon co-benefits

To examine how management strategies align with climate change mitigation priorities, we estimated the potential carbon co-benefits of management actions. Here, we use the term ‘co-benefits’ to refer to additional or ancillary benefits that strategies aimed at one objective—in this case, maximizing biodiversity benefits while minimizing the cost—might have for other objectives (IPCC, 2014). In this sense, biodiversity benefits were the primary consideration in identifying optimal sets of complementary strategies; carbon co-benefits were estimated to provide additional information that could be used to help justify or leverage additional funding for conservation. Thus, we focused on actions that are likely to have direct benefits for climate change mitigation, such as avoided CO₂ emissions from habitat protection and long-term sequestration resulting from restoration activities (Drever et al., 2021; Duncanson et al., 2023), and for which we could derive reasonable quantitative estimates—that is, actions with quantitative targets that could be mapped spatially, and for which data on carbon storage values were available. For habitat protection, we calculated potential avoided CO₂ emissions from future land use conversion using a national carbon dataset (Sothe et al., 2022). In the case of restoration, we adapted the approach

used in Currie et al. (2023) to estimate the net restorable carbon for target restoration areas, with higher priority applied towards areas used by species of conservation concern considered in the PTM. For a detailed description of the carbon co-benefits analysis and results for specific actions, see [Supporting Information: Appendix C](#).

3 | RESULTS

3.1 | Expected benefits of management strategies

Under the baseline scenario, 15 of the 16 species groups in the region were expected to have less than 60% probability of functional persistence by 2050 (Figure 2). In contrast, if all strategies were to be implemented (i.e. S15), all but the cisco species group were predicted to have greater than 50% probability of persistence and 12 species groups were expected to have a probability of persistence of 60% or higher (Figure 2). None of the species groups were expected to reach a 70% probability of persistence, although the working landscapes species group comes close with a 69% probability of persistence under strategy S15 (Table 2).

Of the individual strategies, restoration and regeneration (S7) could secure the most species groups (four groups) up to the 60% threshold, while landowner stewardship (S2) was predicted to secure three species groups (Table 2). Overall, S7 and S2 had the highest expected benefits relative to the baseline for all but four species groups (alvar, riverine, turtle and bat species groups). The alvar species group was expected to benefit most from legislation and policy (S3) or protecting habitat (S4), while riverine and turtle species

TABLE 2 Expected probability of persistence (%) of species groups in the Lake Simcoe-Rideau ecoregion over 27 years under the Baseline scenario (business-as-usual; no additional management) and under each individual and combination strategy.

Species groups	Base-line	Individual strategies								Combination strategies						
		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Alvar species	40	42	49	51	50	40	43	48	47	49	58	63	57	49	59	64
Artificial structure-dependent species	48	48	60	53	49	48	48	59	52	60	59	62	55	59	61	63
Bats	38	39	46	43	43	38	48	43	40	43	46	49	46	44	47	54
Forest species	45	54	59	55	55	47	54	62	58	62	64	66	59	62	63	66
Mixed forest species	48	56	55	54	55	52	51	58	55	59	60	62	58	60	60	63
Ciscoes	39	39	39	42	40	40	42	39	41	40	40	40	43	40	45	46
Mussels	47	48	53	51	50	52	54	51	54	54	53	55	53	53	58	60
Naturalized open habitat species	48	53	60	56	57	51	54	59	57	59	63	65	59	60	61	66
Oak savannah species	44	56	54	54	52	44	50	57	50	54	55	57	51	57	57	60
Riparian species	48	50	53	54	56	48	51	59	52	57	59	60	55	57	56	62
Riverine species	46	48	52	52	51	56	50	53	52	55	52	54	53	51	54	58
Sandy species	50	56	58	57	60	50	55	64	56	61	63	65	59	62	59	65
Snakes and lizards	51	54	57	57	58	62	54	62	56	63	59	61	57	59	58	63
Turtles	39	45	48	48	48	56	44	52	45	56	51	55	49	51	50	58
Wetland species	46	50	53	54	56	50	50	57	52	57	59	61	57	55	58	63
Working landscapes species	61	61	68	64	62	61	62	66	65	65	65	67	64	65	68	69
No. of groups secured to ≥60%	1	1	3	1	2	2	1	4	1	5	5	10	1	5	5	12

Note: Highlighted cells indicate probabilities of persistence of 60% or greater.

groups were both expected to benefit most from wildlife-safe crossings (S5). For bats, invasive species and disease management (S6) were expected to be the most beneficial individual strategy.

Of the combined strategies, the combination of all strategies (S15) had the highest expected benefit across all species groups (Table 1) and was expected to secure the most species groups (Table 3) but was also estimated to be the most expensive to implement, with an estimated present value (PV) cost of \$2.1 billion over 27 years or \$113 million per year in annualized values (Table 1). Combination strategy S11—a combination of S2, S4 and S7—was estimated to be \$300 million cheaper (or \$16.3 million per year cheaper) than S15, had the second highest expected benefit (Table 1) and could secure up to 10 species groups (Table 3).

3.2 | Cost-effective and complementary strategies

The single most cost-effective individual strategy was legislation and policy (S3), followed by human–wildlife management (S1) and industry-targeted policy and practices (S8) (Table 1). The high cost-effectiveness scores for these three strategies were largely driven by their costs—at \$27, \$29 and \$58 million, respectively, these strategies were estimated to be the least expensive to implement. However, they were expected to have low to moderate expected benefit across all species groups (Table 1) and were not expected to

secure any additional species groups to ≥60% probability of persistence beyond what would already be considered secure under the baseline scenario (Table 2). In addition, there are likely additional costs for implementing proposed legislation and policy changes in strategy S3 that were not accounted for in the cost estimates due to the high degree of uncertainty regarding those costs.

The complementarity analysis identified the best sets of strategies for ‘securing’ the most species groups to at least a 60% probability of persistence for different levels of investment. For lower levels of investment, S5 would be the optimal strategy at a cost of \$5 million per year over 27 years (Figure 3), securing the snakes and lizards group in addition to the working landscapes species group that was expected to remain secure under the baseline scenario (Table 3). Given a slightly higher budget of \$5.5 million per year, however, it would be optimal to invest instead in S2 (Figure 3), which would secure the artificial structure-dependent and the naturalized open habitat species groups in addition to the working landscapes species group (Table 3). With higher levels of investment, S11 would help secure 10 species groups at a cost of \$97 million per year over 27 years (Figure 3). Securing additional species groups, up to 12 species groups comprising 100 out of 133 species of conservation concern (Table 3), would require investing \$113 million per year to implement S15 (Figure 3).

Most of the Pareto optimal solutions that could maximize the number of species groups secured for the least cost were also

TABLE 3 Species groups that could be secure with $\geq 60\%$ probability of persistence over 27 years under the Baseline scenario and under each optimal set of management strategies.

Species groups	Number of species in group	Baseline scenario	Optimal strategies						
			S5	S2	S14	S5 + S14	S7 + S14	S11	S15
Turtles	8								
Riverine species	19								
Ciscoes	2								
Mussels	10								✓
Oak savannah species	2								✓
Riparian species	3							✓	✓
Alvar species	8							✓	✓
Wetland species	18							✓	✓
Sandy species	7					✓		✓	✓
Bats	4								
Mixed forest species	6				✓	✓	✓	✓	✓
Forest species	19				✓	✓	✓	✓	✓
Artificial structure- dependent species	3			✓	✓	✓	✓	✓	✓
Naturalized open habitat species	12			✓	✓	✓	✓	✓	✓
Snakes and lizards	9		✓			✓	✓	✓	✓
Working landscapes species	3	✓	✓	✓	✓	✓	✓	✓	✓
Number of species groups secured		1	2	3	5	6	7	10	12
Annualized cost (million CAD)		0.0	4.8	5.5	10.2	15.0	22.0	97.1	113.4

Note: Total costs have been discounted to present values at a rate of 3% and annualized to derive an average cost per year.

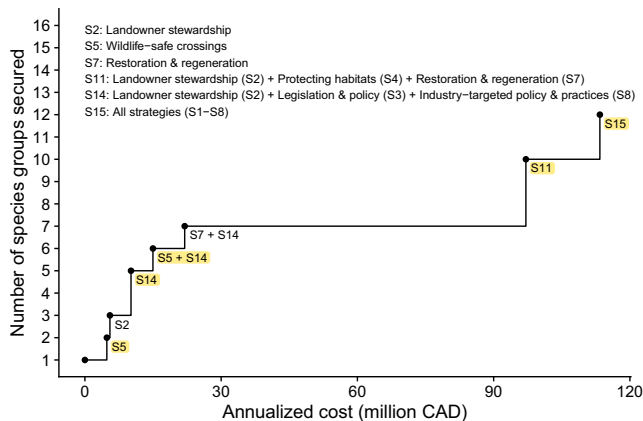


FIGURE 3 Pareto front indicating the number of species groups that could be secured to at least a 60% probability of persistence by different Pareto optimal solutions (represented by the black dots along the line). Highlighted solutions indicate strategies that were also optimal when maximizing the number of species groups that would experience $\geq 15\%$ benefit. Annualized costs are based on the total costs discounted by a rate of 3%.

expected to maximize the number of species groups that gain $>15\%$ in probability of persistence (Figure 3; Supporting Information: Appendix B). In particular, under S11, the turtle species group had an expected probability of persistence of 55%, which is below the 60% threshold but still represents a gain of 16% relative to the

baseline scenario (Table 2). Similarly, although neither the turtle nor bat species groups were expected to achieve a 60% probability of persistence under combination strategy S15, the expected benefits of S15 for both groups were $>15\%$ (Table 2).

The uncertainty analysis also revealed that most of the Pareto optimal solutions identified based on the most likely estimates would also be considered Pareto optimal under the most optimistic and most pessimistic scenarios. This suggests that the uncertainty in estimates did not have a great effect on the results (Supporting Information: Appendix B).

3.3 | Carbon co-benefits

Of the 48 actions considered in this PTM assessment, only seven actions had direct and quantifiable carbon benefits. Of these, sufficient information to calculate carbon co-benefits was available for only four actions: (1) protecting 10% of the ecoregion (S4); (2) restoring 1% of shoreline area (S7); (3) restoring 50 km² of wetland and 25 km² of areas connecting wetlands (S7); and (4) restoring 1200 km² of forest transition zones (S7). We found that protecting habitat (S4) has direct carbon co-benefits equivalent to 11.2 Mt of avoided CO₂ emissions while restoration and regeneration (S7) has direct carbon co-benefits equivalent to 137.6 Mt of CO₂ sequestration (Table 4; Supporting Information: Appendix C).

TABLE 4 Potential carbon co-benefits, in megatonnes (Mt) of carbon (C) or carbon dioxide emissions equivalent (CO₂e), of actions in the protecting habitat (S4) and restoration and regeneration (S7) strategies in the PTM with direct and quantifiable carbon benefits.

Strategy	Action	Total area (km ²)	Average carbon density (kg/m ²)	Area of avoided land conversion (km ²)	Avoided C release (Mt)	Avoided CO ₂ e release (Mt)	Restorable C (Mt)	Restorable CO ₂ e (Mt)
S4	Protect 10% of priority areas	6392.53	27.82	109.83	3.06	11.2	-	-
S7	Restore 1% of shorelines	47.55	28.01	-	-	-	1.33	4.88
	Restore 50 km ² of wetland and 25 km ² of areas connecting wetlands	75	33.86	-	-	-	2.54	9.31
	Restore 1200 km ² of forest transition areas	1200	27.82	-	-	-	33.65	123.38
Total					3.06	11.2	37.52	137.57

4 | DISCUSSION

Our analysis revealed that without additional investment in conservation, 13 species groups, or 114 out of the 133 species of conservation concern, in the Lake Simcoe-Rideau ecoregion, will have <50% probability of persisting with viable, self-sustaining populations that continue to perform their ecological function (i.e. functional persistence) by 2050 (Figure 2). Investing \$97 million per year over 27 years in the combination of landowner stewardship, protecting habitat and restoration and regeneration strategies (i.e. S11) could help secure 10 species groups (88 species) with ≥60% probability of persistence, while implementing the combination of all proposed management strategies (i.e. S15) for \$113 million per year could secure 12 species groups (100 species) (Figure 2; Table 3).

However, even with this level of investment, none of the species groups were expected to have ≥70% probability of persistence. The low estimates of the probability of persistence reflect the high level of threats in the area and are comparable to those for the Fraser River Estuary, British Columbia, Canada (Kehoe et al., 2021)—an area also characterized by high human footprint (Hirsh-Pearson et al., 2022) and high levels of threat from competing demands for space and resources (Kraus & Hebb, 2020). The low expected probabilities of persistence may also be indicative of the inherent difficulty in recovering species that are already at a high risk of extinction, and the current lack of effective management options that adequately address the impact of key historical and ongoing threats to these species groups. For example, the poor status and low potential for recovery of the cisco species group has been attributed to historical overexploitation and more recent threats of habitat degradation and introduced species (COSEWIC, 2003; Fisheries and Oceans Canada, 2012). Similarly, the four bat species are endangered due to the threat of white-nose syndrome, a rapidly spreading infectious disease for which prevention and treatment has proven challenging (Cheng et al., 2021; Grider et al., 2022). For turtle and riverine species, the main threats are the impacts of urban development and agricultural activities, such as habitat loss and alteration (e.g. Ogden's Pondweed, COSEWIC, 2007), changes to water quality (e.g. Redside Dace, Rapids Clubtail; COSEWIC, 2017, 2018) and hydrological flow (e.g. Black Redhorse, COSEWIC, 2015), and barriers to movement (e.g. American Eel, Spotted Turtle; COSEWIC, 2012, 2014). Recovery of these species groups to ≥60% probability of persistence will rely on the successful mitigation of these threats, which will prove to be challenging given the high population density and development pressures in this region.

Uncertainties surrounding the potential impacts of recent policy and legislative changes in Ontario could also have influenced estimates of the expected probability of persistence of species groups. Beginning in 2019, the Ontario provincial government introduced significant changes to the Endangered Species Act (ESA), which led to the delisting of many species at risk and the weakening of previously strong protections under this legislation (Bethlenfalvy & Olive, 2021; Olive & Penton, 2018). In 2022, the provincial government introduced Bill 23, the 'More Homes Built Faster Act', which

made substantial changes to environmental and biodiversity protections in Ontario. Experts noted that these changes will likely lead to further exacerbation of environmental challenges and greater difficulty in implementing conservation actions, with wide-ranging implications for biodiversity.

These recent changes to environmental and conservation policy were also met with controversy (Jones, 2022; SpearChief-Morris, 2022), fuelled partly by Canada's colonial legacy and the provincial government's largely unsuccessful efforts to engage meaningfully and work with Indigenous groups on environmental policy and conservation initiatives (McIntosh, 2023). Indigenous groups in the region were invited to engage with and participate in the PTM assessment; however, many expressed reluctance to participate in the process, in part due to the lack of clarity regarding the views held by participating experts from government agencies about Indigenous-led conservation. In addition, there was insufficient time and funding for this study to support a more inclusive process as has been successfully done recently in a similar elicitation process for the Central Coast of British Columbia (Adams et al., 2023). For conservation to be successful and grounded in just approaches, it is necessary to ensure that there is engagement, consent and collaboration with the First Nations and Métis communities in the region (Seddon et al., 2021). The limited representation of Indigenous values and perspectives in this PTM process means that species, threats or actions may have been overlooked and excluded from the analysis, potentially leading to incomplete conclusions about cost-effectiveness and complementarity. Therefore, when considering the implementation of the proposed strategies, it is crucial to meaningfully engage and work with Indigenous groups in the region (Townsend et al., 2020), through processes that are inclusive, trauma-informed and grounded in the principles of respect and reciprocity (Adams et al., 2023). The outcomes from this PTM process can serve as a valuable starting point for conversations with Indigenous communities, to gather feedback and work together to determine the gaps in the analysis, the potential impacts of the proposed strategies on communities and ways to reduce the barriers to Indigenous participation in the PTM process. Ideally, these discussions will form the basis of a second iteration of the PTM process that is more inclusive, with more explicit consideration of Indigenous values and objectives, and that work to strengthen relations in the region.

The complementarity analysis identified multiple Pareto optimal solutions, representing the trade-off between maximizing benefit and minimizing costs. Without strict constraints on the number of species groups that must be secured or on the total budget, the choice of which Pareto optimal solution to adopt will depend on the values and preferences of those involved in making the decision. This decision may also be influenced by other considerations, such as co-benefits for other objectives and availability of opportunities to generate or leverage additional funding. For example, a solution that also contributes to other targets, such as protected area and restoration targets of the GBF or national climate change mitigation targets, could further increase the total benefits gained and help secure additional funding and resources for conservation

action. In this PTM assessment, protecting habitat (S4) and restoration and regeneration (S7) included actions with potential carbon co-benefits of 11.2Mt CO₂ equivalent in avoided emissions and 137.6Mt CO₂ emissions equivalent in sequestered carbon, respectively (Supporting Information: Appendix C) and thus could be considered as nature-based climate solutions. While these values were based only on a subset of actions in those strategies for which we were able to derive quantitative estimates, the potential carbon co-benefits of S4 and S7 combined could, over the long term, make up for all of Ontario's greenhouse gas emissions in 2021 (Environment and Climate Change Canada, 2023). Choosing a solution that includes one or both strategies would help support alignment with climate change mitigation targets. Doing so can help justify investment and improve the likelihood of securing additional funding for implementation. We note, however, that our estimates were derived from maps of existing carbon stocks (Currie et al., 2023; Sothe et al., 2022) based on several simplifying assumptions and did not account for changes in stored carbon over time due to natural or anthropogenic processes. The estimates therefore represent the maximum potential carbon benefit that could be gained by implementing those actions. A more comprehensive carbon accounting, in accordance with accepted standards, along with independent verification and certification will be needed to secure additional funding through market mechanisms, such as voluntary carbon markets (Kreibich, 2024; Sadikman et al., 2022).

Some actions considered in the PTM may also have carbon co-benefits that we were unable to quantify due to the lack of available data on carbon storage in certain habitats such as sand dunes, or insufficient understanding of the pathways through which the action can yield carbon co-benefits. Further research and modelling of the causal mechanisms linking the actions to their carbon benefits will be needed to estimate the carbon co-benefits of these actions. For others, the main barrier to the quantification of carbon co-benefits was the lack of specificity regarding where, when and how the action will be implemented; carbon co-benefits could potentially be estimated for these actions once these details have been fully specified, for example, during the planning stage prior to implementation.

Many of the actions suggested by experts may also have co-benefits for other environmental and social objectives. For instance, water quality could be improved directly by implementing wastewater treatment (S2) or water allocation (S3) actions (Buttle, 2011). The implementation of actions in urban areas (S7) or in recreational activity hotspots (S6) can contribute to long-term urban regeneration, recreation and overall human and cultural well-being (Colléony & Shwartz, 2019). Finally, co-benefits can be generated through the creation of jobs (Gómez Martín et al., 2020; Raymond et al., 2017). Quantitative pre-assessments of co-benefits can be data-intensive and may be impractical in many cases (Molina et al., 2024) and development of frameworks and methods for assessment are greatly needed (Ommer et al., 2022). Where possible, however, demonstrating and quantifying these co-benefits and any potential dis-benefits will allow them to be explicitly incorporated into formal decision science frameworks, such as multi-criteria decision analysis

(Ürge-Vorsatz et al., 2014), and thus improve the likelihood of uptake and successful implementation and further support the business case for financing biodiversity conservation.

5 | CONCLUSIONS

Our analysis revealed that considerable additional investment—\$2.1 billion over 27 years—is required to safeguard the future of species of conservation concern in the Lake Simcoe-Rideau ecoregion, Ontario. By estimating the costs and expected benefits of different combinations of strategies, PTM can help maximize the return on investment and make the business case for conservation, which can lead to increased investment and positive outcomes for biodiversity. Identifying and implementing actions with co-benefits for climate change mitigation or other environmental or social objectives can further maximize the return on investment in conservation actions, help secure additional funding for implementation and contribute to Canada's efforts to meet its commitments to the CBD's Global Biodiversity Framework.

AUTHOR CONTRIBUTIONS

Abbey E. Camaclang and Tara G. Martin helped develop the data collection methods and analysis used in this study. Emily Giles was responsible for recruiting expert participants and organizing workshops, and Aranya Iyer conducted literature reviews, prepared elicitation materials and conducted data analysis. Abbey E. Camaclang also provided technical advice and assistance with workshop organization and data analysis. Abbey E. Camaclang, Aranya Iyer, Emily Giles, Beatrice Frank and Catherine Paquette facilitated expert elicitation workshops. Chris Liang conducted the carbon co-benefits analysis, with assistance and advice from Victoria Hemming, Abbey E. Camaclang and Tara G. Martin. Katherine I. Alambo, Jennifer Lamoureux, Sarah Matchett, Tyler Miller, D. Ryan Norris, Mary Ann C. Perron, Robyn H. M. Rumney, Frederick W. Schueler and Laura Timms contributed data used in this study. All authors contributed to writing and reviewing the manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflicts of interest.

DATA AVAILABILITY STATEMENT

The anonymized summary data elicited from experts, along with the code for both PTM and carbon co-benefits analysis, are available from <https://doi.org/10.5281/zenodo.17247132> (Camaclang et al., 2025). Input spatial data used for the carbon co-benefits analysis were derived from publicly available sources listed in [Supporting Information: Appendix C](#).

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SUPPORTING INFORMATION

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

Appendix A. Data tables.

Appendix B. PTM detailed methods and additional results.

Appendix C. Carbon co-benefits of management strategies.

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