**ORIGINAL PAPER** 



# Southern Canada's crisis ecoregions: identifying the most significant and threatened places for biodiversity conservation

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#### Abstract

Identifying and protecting key areas for biodiversity is a cornerstone of effective nature conservation. This conservation assessment analyzes 77 ecoregions across the southern, settled part of Canada to identify priorities for conservation action. Our analysis included 34 measures of biodiversity, threat and conservation response. We categorized all ecoregions based on their overall biodiversity and threat scores. This categorization identified nine "crisis ecoregions." These ecoregions have higher biodiversity and threat scores compared to other ecoregions in the study area. These ecoregions represent less than 5% of Canadian lands and inland waters but provide habitat for over 60% of Canada's species at risk. Twenty-one ecoregions have higher biodiversity but lower threat scores. Primarily distributed in the more intact portions of the study area, these ecoregions generally have lower biodiversity scores for species diversity, but score very high for intactness, habitat diversity and congregatory species. This assessment can help to contextualize existing and proposed conservation actions by highlighting key biodiversity, threat and conservation attributes of ecoregions across southern Canada. Our assessment can be used to focus efforts on new protected areas, species at risk recovery, capacity building and ecological monitoring. The results of the conservation assessment can be applied to set and track progress toward national, regional and organizational conservation goals, including post-2020 biodiversity targets. Regular reanalysis of the ecoregions to track their trends in biodiversity, threat and conservation responses will support monitoring the effectiveness of conservation programs and highlight ecoregions where continued focus is most needed to conserve Canada's biodiversity.

**Keywords** Conservation assessment  $\cdot$  Aichi Target 11  $\cdot$  Connectivity  $\cdot$  Species at risk  $\cdot$  Representation  $\cdot$  Protected areas

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#### Introduction

Over the last 150 years, biodiversity in Canada has been declining. The decline in species and habitats has been particularly acute in the southern areas of Canada, which have the longest history of colonization, agricultural, urban and industrial land uses, and where most Canadians live. For example, only 25% of Canada's prairies remain, southern Ontario has lost 85% of its forest cover and 70% of southern British Columbia's estuary marshes have been lost or degraded (Federal Provincial and Territorial Governments of Canada 2010).

Habitat loss is the main threat to wildlife in Canada, including species at risk (McCune et al. 2013; Venter et al. 2006). Canada has 724 wildlife species at risk, an increase of over 200 in just the last decade alone (COSEWIC 2016). Many other wildlife populations are declining (WWF Canada 2017). For example, Canadian breeding bird populations have decreased 12% since 1970, and some bird groups, such as grassland birds, aerial insectivores and shorebirds, are showing steep declines of up to 70% (NABCI 2012).

While northern Canada still contains vast areas of forest, wetland and tundra, including some of the planet's last areas of wilderness (Watson et al. 2018), the amount of habitat loss in southern Canada is similar to other settled landscapes around the world (Watson et al. 2016). Protection of Canada's north offers some of the last global opportunities to conserve large, intact landscapes; however, the urgency for conservation is greatest in the south where the human footprint is the highest and continues to expand.

The identification of important areas to protect biodiversity is a cornerstone of effective conservation. Place-based conservation priorities that are founded on an assessment of biodiversity, threat and existing conservation responses can be used to provide context for existing efforts, guide funding opportunities and support planning for future conservation action.

Over the last two decades, the ability to carry out systematic conservation assessments at broad geographic scales has advanced through the availability of new analytic tools and comprehensive datasets. Information on land use and land use change, species ranges, rare species and existing conservation lands can be used to assess gaps in protected areas (Jenkins et al. 2015). Assessments over large geographical scales have also highlighted gaps in connectivity (McGuire et al. 2016) and representation of species in protected areas (Wiersma and Nudds 2009) and ecoregions (Parks Canada 2016). Global assessments have shown mismatches between conservation actions and areas for migratory birds (e.g. Runge et al. 2015) and freshwater species (e.g. Darwall et al. 2011).

Comprehensive conservation assessments have been completed in many countries including the United States (Jenkins et al. 2015), Kenya (Habel et al. 2016) and Australia (Natural Resource Management Ministerial Council 2010). The Nature Conservancy of Canada (NCC), The Nature Conservancy and partners developed ecoregional assessments for parts of southern Canada that have helped to drive the work of NCC since the early 2000s, but these assessments are regionally based (Anderson et al. 2006; Gratton 2010; Henson et al. 2005; Riley et al. 2007). Other ecoregional assessments have been done for some parts of Canada, such as the Northern Appalachian/Acadian Ecoregion (Trombulak et al. 2008) and southern Ontario (ECCC 2014), and for freshwater ecosystems (World Wildlife Fund Canada 2017). However, a comprehensive assessment has not been completed for all of southern Canada using common approaches and methods. The recently published framework to guide protected areas designations in Canada (Coristine et al. 2018) focuses on gaps in protected areas to guide the establishment of new parks and conservation lands, but does not integrate threats or the full range of biodiversity values

(e.g. globally rare species) that many conservation groups are working to protect, particularly in southern Canada on the private land base. Global and North American conservation assessments that have included Canada (Olson and Dinerstein 2002; Ricketts et al. 1999) contextualize the importance of Canadian ecoregions from a broader conservation perspective but do not assess priorities from a Canadian context, such as national species at risk or connectivity between national parks, and do not use current national information on biodiversity, threat and conservation response.

A conservation assessment that ranks and prioritizes conservation in the ecoregions of southern Canada is needed to support measuring Canada's progress toward international biodiversity commitments including the Convention on Biological Diversity and Aichi Biodiversity Targets (2011–2020) (Secretariat of the Convention on Biological Diversity 2010). Reporting on biodiversity within ecoregions will provide greater resolution and consistent indicators to existing national reporting (e.g. ECCC 2018b). Perhaps most importantly, maps and information from a conservation assessment of southern Canada can provide Canadians with a better understanding of our country's biodiversity and most urgent conservation priorities.

## Methods

Southern Canada was selected as the focus of the assessment because there are widespread and pervasive threats to biodiversity, and there is more comprehensive information. This area is predominantly under private land ownership, and has the greatest human influence index (Sanderson et al. 2002). Southern Canada is the most productive and biodiverse area of Canada and much of this areas is poorly represented in Canada's protected areas network (Andrew et al. 2011).

The study area was stratified by ecoregions based on Canada's ecoregion framework (Agriculture and Agri-Food Canada 1999; Marshall et al. 1999). Ecoregions are characterized by distinctive regional factors, including climate, physiography, soil and vegetation. These factors influence both biodiversity and land use with each ecoregion which makes them useful units of analysis for our study.

In total, 77 ecoregions are included in the analysis (Fig. 1). The study area includes all ecoregions south of the Boreal ecozones (Boreal Cordillera, Boreal Plains, Boreal Shield), plus 23 ecoregions in the southern Boreal ecozone and all ecoregions on the island of Newfoundland.

We identified three major categories for the assessment: biodiversity, threats to biodiversity and conservation responses. We then assembled datasets that could be used as measures for each category. Only datasets that were readily available, spatially referenced and with relatively uniform and comprehensive coverage across the study area as of August 2017 were used. Some important measures, such as connectivity, did not have a Canada-wide dataset and we completed separate analyses to create these datasets to include in the assessment.

We compiled and used 34 different measures in the analysis (Table 1). Within each of the three major categories, we then grouped similar measures into criteria. For example, the criterion of species richness (B1) is composed of two measures: species richness based on range maps (B1a) and species richness based on species tracked by Conservation Data Centres (B1b).



Fig. 1 Study area

To control for potential effects of ecoregion size on our measures we conducted a regression analysis where the raw values of each measure were regressed with ecoregion area. Where area had a significant effect on a measure, the residual variation from this relationship was extracted from the mean value of that measure and subsequently the raw values were replaced by the adjusted values. In all analyses, significance thresholds were set at an Alpha = 0.05.

We then determined if any of our biodiversity, threat and conservation response measures were highly correlated with each other. Highly correlated measures are redundant in the analysis and could result in double-counting for the final score. We used three different statistical methods to determine this redundancy. First, we used a redundancy analysis to detect measures with significant collinearity (Legendre and Legendre 2012). Collinearity only arises because of how the measures are calculated and not because of real ecological relationships. Second, we used a cluster analysis to group measures that are similar to a degree that they can be regarded as a single measure (Legendre and Legendre 2012). Our final check to remove redundancy was a hierarchical cluster analysis based on Spearmanranked correlations to identify significant relationships between different measures. We then used the correlation matrix from the cluster analysis to visualize relationships between the measures and identify significant linear correlations (Zar 1999). The literature recommends R<sup>2</sup> cut-off values ranging from 0.70 to 0.80 (Berry and Feldman 1985; Watts et al. 2015). Because higher degrees of collinearity do not necessarily translate into greater  $R^2$  values (Berry and Feldman 1985), we used a conservative cut off value of  $R^2 = 0.70$ . Measures were removed from the analysis if two of the three statistical methods identified them as redundant. As a result, nine original measures were not included in the final analysis.

The scores were based on the value of the measure in comparison to other ecoregions. For three of the measures, natural cover, largest blocks of intact habitat and percentage protected areas, scores were based on assigned breaks to reflect recommended ecological thresholds or established conservation targets (see Table 1). But in most cases, the range of scoring values was classified into five natural breaks using the Jenks optimization method (ESRI 2012) and a numerical score of 1 (lowest) to 5 (highest) was applied to each

Criteria/measures	Description <sup>a</sup>	
Biodiversity		
B1 Total species richness		
B1a Species richness based on range maps	Total number of different species, based on range maps (mammals, birds, amphibians and trees) by ecoregion.	
B1b Species richness based on species tracked by Conservation Data Centres	Total number of different species (all taxa) tracked by provincial Conservation Data Centres.	
B2 Richness of Canadian species at risk		
B2a Richness of COSEWIC assessed wildlife species*	Total number of different COSEWIC assessed wildlife species (Endangered, Threatened, Special Concern) scored based on level of risk.	
B2b Irreplaceability of COSEWIC assessed wildlife species*	Each species scored based on number of occurrences.	
B2c Richness of wildlife species that are candidates to be assessed by COSEWIC*	Total number of different wildlife species that are candidates to be assessed by COSEWIC.	
B2d Irreplaceability of COSEWIC candidate wildlife species*	Each species scored based on number of occurrences.	
B3 Richness of Species of Global Conservation Concern		
B3a Globally vulnerable species*	Total number of different globally rare species (G1–G3/ T1–T3) scored based on rank.	
B3b Irreplaceability of globally vulnerable species*	Each species scored based on number of occurrences.	
B4 Canada's conservation responsibility		
B4a Richness of nationally endemic species	Each species scored based on number of occurrences.	
B4b Richness of species with high national conservation responsibility	Total count of species by ecoregion with $\geq$ 75% of range within Canada.	
	Global range was calculated for mammals, breeding birds and amphibians.	
	Trees based on North American range, which includes Canada, United States and Mexico.	
B5 Richness of unique species		
B5a Richness of species restricted to one ecoregion (range maps)	Total number of species unique to one ecoregion based on range maps.	
B5b Richness of species restricted to one ecoregion (tracked species)	Total number of tracked species unique to one ecoregion.	
B5c Richness of species with limited range <sup>*</sup>	Each species scored based on the inverse of the number of occurrences across all ecoregions.	
B5d Beta-diversity of species	Each species scored based on the inverse of the number of occurrences in adjacent ecoregions.	
B6 Congregatory species		
B6a Key biodiversity areas	Area of <i>Important Bird and Biodiversity Area</i> within the ecoregion scored based on significance (global, continental, national) for congregatory species.	
B7 Intactness		
B7a Natural cover	Percent of ecoregion in natural cover (including freshwater). Thresholds based on <i>How Much Habitat is Enough</i> (Environment Canada 2013).	

Table 1 Measures and criteria used in the analysis to determine the total biodiversity score for each ecoregion (\*Measures not used in final scoring as a result of the redundancy analysis)

#### Table 1 continued

Criteria/measures	Description <sup>a</sup>
B7b Intact mammal fauna	Percent of ecoregion with areas including polygons identified as intact mammal fauna (Morrison et al. 2007; Sanjayan et al. 2012).
B7c Size of largest block of intact habitat	Number and extent of contiguous intact habitat blocks based on habitat block analysis (Ricketts et al. 1999).
B7d Connectivity	Percent of ecoregion containing corridors. Analysis completed for this study.
B8 Ecosystem distinctiveness	
B8a Distinctiveness of natural cover	Each land cover type scored based on number of occurrences across all ecoregions.
B8b Beta-diversity of natural cover	Each land cover type scored based on number of occurrences in adjacent ecoregions.
Threats	
T1 Human footprint	
T1a Human footprint <sup>*</sup>	Mean grid value for ecoregion.
T1b Change in human footprint	Mean percent change in grid value for ecoregion (1993 to 2009).
T2 Watershed Stress	
T2 Watershed stress	Cumulative sum of index values.
T3 Risk index	
T3a Conservation risk index	Habitat protected : habitat converted (terrestrial portion).
T3b Habitat risk index <sup>*</sup>	Habitat natural : habitat converted (terrestrial portion).
T4 Fragmentation	
T4 Amount of habitat fragmentation	Mean resistance value for ecoregion.
T5 Land use change	
T5 Land use change	Conversion from natural cover to urban and cropland (2000–2010).
T6 Rate of climate change	
T6a Mean temperature change	Rate of absolute change in mean temperature from the 1961–1990 and 1981–2010 climate normal period.
T6b Mean precipitation change	Rate of absolute change in mean precipitation (i.e. wetter or drier) from the 1961–1990 and 1981–2010 climate normal periods.
T6c Change in growing degree days	Rate of absolute change in the mean number of growing degree days from the 1961–1990 and 1981–2010 climate normal period.
T7 Lack of water	
T7 Lack of water	Mean score for ecoregion based on water demand divided by water supply.
Conservation response	
R1 protected areas	
R1 Protected areas	Percent of ecoregion (terrestrial and inland waters) included in protected areas. Some thresholds based on Canada Target 1 (Environment and Climate Change Canada 2016).
R2 Representation	······································

Criteria/measures	Description <sup>a</sup>
R2 Representation	Mean percent of enduring landform features protected in ecoregion (terrestrial portion).

<sup>a</sup>Additional detail on data sources and analysis conducted for this study are included in the Supplementary Materials

measure. Scores of zero were used in measures with no values. For example, some ecoregions do not have any Key Biodiversity Areas and scored zero for this measure.

We then determined the final score for biodiversity and threat for each ecoregion using two different approaches. We summed each individual measure to produce final scores for biodiversity and threat. The final score was also determined based the sum of all measures within each criterion. The sum for each criterion was then rescaled back to a score from 1 to 5 using natural breaks. These rescaled scores were calculated for all criteria with multiple measures, and then the criteria scores were added together to produce a total score for each ecoregion.

To identify a threshold between higher and lower scoring ecoregions, the resulting total biodiversity and threat scores were each reclassified into five natural break categories. The threshold between the third- and fourth-highest categories was used to define ecoregions with higher relative total scores.

To identify the ecoregions with the higher biodiversity and threat values, the total scores for the both scoring approaches were combined, with the highest category from either approach taking precedence. Both approaches to sum the scores are equally valid, and a combined approach ensured that the highest scoring ecoregions would be identified. These were plotted on a scatter diagram divided into quadrants based on final scores for biodiversity and threat. Each ecoregion was then categorized into one of four groups based on these quadrants: higher biodiversity/higher threat, higher biodiversity/lower threat, lower biodiversity/higher threat and lower biodiversity/lower threat. This approach is based on the framework for identifying priority conservation areas using irreplaceability and vulnerability (Margules and Pressey 2000). Ecoregions were then further grouped within these quadrants based on their conservation response scores.

#### Results

#### Biodiversity

We identified 30 ecoregions with higher biodiversity scores relative to other ecoregions in the study areas (Fig. 2). These ecoregions are distributed across southern Canada and include Fundy Coast, Maritime Lowlands, Southern New Brunswick Uplands, Appalachians, St. Lawrence Lowlands, Lake Erie Lowland, Manitoulin-Lake Simcoe, Mid-Boreal Lowland, Mid-Boreal Uplands, Interlake Plain, Mixed Grassland, Eastern Continental Ranges, Northern Continental Divide, and Eastern and Western Vancouver Island. Ecoregions that ranked highest for biodiversity generally have greater species diversity or large areas that are important for congregatory birds.



Fig. 2 Biodiversity scores by ecoregion

## Threat

We identified 22 ecoregions with higher threat scores relative to other ecoregions in the study area (Fig. 3). Ecoregions with the highest overall threat scores include Lake Erie Lowland, Fescue Grassland and Manitoulin-Lake Simcoe. Ecoregions with the highest threat score are concentrated in geographies with the greatest amount of agriculture and settlement. This includes agricultural areas of the Maritimes (Annapolis and St. John's valleys, Prince Edward Island), southern Ontario and Quebec, the Prairies, the lower mainland of British Columbia and Eastern Vancouver Island. Ecoregions with the lowest total threat scores occur in the Boreal Shield and Boreal Plains ecozones and many of the mountain ecoregions of western Canada.

### **Conservation response**

Only 16 ecoregions have higher scores for conservation response relative to other ecoregions in the study area (Fig. 4). Most ecoregions in southern Canada are not well represented in Canada's systems of parks and protected areas. Only 13 of 77 ecoregions meet Canada's national protected areas target of 17%. These include Eastern Continental Ranges (67.7%), Queen Charlotte Ranges (52%) and Cape Breton (50%). Most ecoregions that



Fig. 3 Threat scores by ecoregion



Fig. 4 Conservation response scores by ecoregion

scored in the highest categories for representation also scored high for amount of protected areas. However, the analysis reveals some ecoregions where protected areas appear to be under-representing the full diversity of landform features. Ecoregions with a higher score for total protected areas compared to representation include: Îles-de-la-Madeleine, Cascade Ranges, Selkirk-Bitterroot Foothills and Queen Charlotte Lowland.

#### **Crises ecoregions**

One of the goals of the assessment is to identify ecoregions in southern Canada in greatest need of immediate conservation action. We have defined this need based on higher biodiversity values and threats and refer these ecoregions as 'crisis ecoregions'. Our definition of crisis ecoregion builds on the original use of the term (Hoekstra et al. 2004), and subsequent applications (Watson et al. 2016) by incorporating biodiversity significance and an index of risk factors.

We identified nine crises ecoregions. These ecoregions rank in the highest categories for both biodiversity and threat compared to all other ecoregions in southern Canada (Fig. 5; Table 2).

These nine ecoregions represent 15.7% or 459,945 km<sup>2</sup> of the study area, and only 4.6% of Canadian lands and inland waters. Over 60% of Canada's species at risk are found in these ecoregions. These nine ecoregions are distributed across Canada's most heavily settled landscapes (Fig. 6) and are home to 70% of the Canadian population. Five of these ecoregions are in the lowest category of percent protected and representation scores. This includes the three ecoregions in the Mixedwood Plains ecozone and the Prince Edward Island and Aspen Parkland ecoregions. The Lower Mainland, Mixed Grassland and Eastern Vancouver Island ecoregions also have lower conservation response scores. Only the Northern Continental Divide has a higher conservation response score. One of the key threats in this ecoregion is habitat fragmentation that could impact wildlife migration locally and within the broader context of the Yellowstone to Yukon corridor.

	Appalachians Central Laurentians Interlake Plain Maritime Lowlands	Atlantic Coast Mid-Boreal Uplands Western Vancouver Island	Aspen Parkland Lake Erie Lowland Maniferijin Jaka Simean	
	Strait of Belle Isle Western Alberta Upland	Columbia Mountains and Highlands Southwest Nova Scotia Uplands Thunder Bay-Quetico	Prince Edward Island	
	Fundy Coast Lake of the Woods		St. Lawrence Lowlands	
	Mid-Boreal Lowland	Cape Breton Highlands Eastern Continental Ranges	Lower Mainland	
	Rainy River	Queen Charlotte Ranges	Eastern Vancouver Island	
	Southern New Brunswick Uplands		Mixed Grassland	
liversit			Northern Continental Divide	
Higher Biod	Avalon Forest Central Newfoundland Fraser Basin Northeastern Newfoundland Northern New Brunswick Uplands Skeena Mountains South Avalon-Burin Oceanic Barrens Southen Laurentians	Bulkley Ranges Fraser Plateau Georgia-Puget Basin Iler-dei-Addeeine Interior Transition Ranges Lac Temiscomingue Lowland Lake Nipigon Maritime Barrens New Brunswick Highlands Selkirk-Bitterroot Foothills South-central Nova Scotia Uplands	Annapolis-Minas Lowlands Fescue Grassland Lake Manitoba Plain Moist Mixed Grassland Saint John River Valley	
	Abitibi Plains		Southwest Manitoba Uplands	
	Central Canadian Rocky Mountains Long Range Mountains Nass Basin Nass Ranges Northern Peninsula Omineca Mountains	Chikotin Ranges Coastal Gap Queen Charlotte Lowland Western Continental Ranges	Algonquin-Lake Nipissing Perc Cascade Ranges Prot Cypress Upland Okanagan Highland Pacific Ranges	ent ected > 25% 18-25 11-17

Higher Threat →

Fig. 5 Final categorization of ecoregions based on biodiversity and threat. Ecoregions with the highest total biodiversity and total threat scores are in the top right quadrant. Shading indicates the percentage of the ecoregion that is currently protected

#### Other ecoregions

A total of 21 ecoregions (999,825 km<sup>2</sup> or 34.1% of the study area) score high for biodiversity but lower for threat. Six of these ecoregions have higher conservation response scores. They are generally located in the more intact northern and western portions of the study area, and along the east coast. Many of these ecoregions score very high for intactness, habitat diversity and congregatory species.

There are 13 ecoregions that score higher for threat but lower for biodiversity, these ecoregions represent a total of 301,365 km<sup>2</sup> or 10.3% of the study area. Of these ecoregions, two (Pacific Ranges and Okanagan Range) have higher total conservation response scores with over 17% in parks and protected areas.

The remaining 34 ecoregions that represent  $1,169,625 \text{ km}^2$  or 39.9% of the study area fall in the lower left quadrant with lower biodiversity and lower threat. Four of these ecoregions, all located in western Canada, have over one-quarter of their lands and inland waters in protected areas. These ecoregions also score the highest category for representation of landform features in protected areas.

Ecoregion/provinces	Description
Aspen Parkland Alberta, Saskatchewan, Manitoba	Almost 80% of the natural cover has been converted to cropland and other land uses. Only 4% is included in conserved/protected areas and of this 0.7% is designated as community pasture. The rate of land conversion (2000–2010) in this ecoregion is one of the highest in southern Canada. The total population is 2,496,162 (2016), with a growth of over 47.5% in the last 20 years
Eastern Vancouver Island British Columbia	Just over 93% of this ecoregion remains in natural cover and 13.8% is within conserved/protected areas. Land use change in this ecoregion (2000–2010) was moderate. The land uses with the greatest net gain are settlement and roads. Major urban centres include Victoria, Nanaimo, Campbell River and Courtenay. The total population is 730,655 (2016), with a growth of 20% in the last 20 years
Lake Erie Lowland Ontario	Only 14% of this ecoregion remains in natural cover and only 1% is within conserved/protected areas. The Lake Erie Lowlands ecoregion has experienced historic rates of habitat loss to agriculture and urban areas that are among the highest in Canada. Remaining habitat patches are generally small, highly fragmented and degraded. The total population is 8,324,391 (2016), with a growth of just over 29% in the last 20 years
<b>Lower Mainland</b> British Columbia	Approximately 58% of this ecoregion remains in natural cover and 5.2% is within conserved/protected areas. There has been a moderate and steady expansion of urban areas in this ecoregion. The expansion of settlements has mostly occurred in areas that were previously forested, with a smaller amount expanding into croplands. The total population is 2,786,670 (2016), with a growth of 34% in the last 20 years
Manitoulin-Lake Simcoe Ontario	Almost 40% of this ecoregion remains in natural cover and only 1.9% is within conserved/protected areas. The ecoregion has experienced high historic rates of conversion of natural habitats to agriculture and urban areas. These have generally stabilized for the ecoregion, although there are still significant land use change pressures in some areas. The total population is 2,828,114 (2016), with a growth of just over 26% in the last 20 years
Mixed Grassland Alberta, Saskatchewan	Approximately 42% of this ecoregion remains in natural cover and almost 11% is conserved/protected areas including 4% in community pastures. The rate of land conversion (2000–2010) in this ecoregion is one of the highest in southern Canada. This is primarily native managed grasslands being converted to cropland. The area of these grasslands decreased by 30%, while the area of crop increased by about the same percentage. The total population (2016) is 204,767, with a growth rate of 7.8% since 1996
Northern Continental Divide British Columbia, Alberta	The Northern Continental Divide ecoregion is characterized by natural cover (97%) with forestry dominating the working landscape. This ecoregion has one of the highest amounts of protected areas in southern Canada (29%). The most significant threat to this ecoregion is habitat fragmentation that is caused by roads urban areas, and for some species, forestry. The total population is 46,694 (2016), with a growth of just under 20% in the last 20 years
Prince Edward Island Prince Edward Island	Prince Edward Island has 56.4% natural cover; however, many of the forests are now even-aged stands. Approximately 3% of this ecoregion is within conserved/protected areas. The rate of land conversion (2000–2010) in this ecoregion is relatively low. There was an increase in the area of settlements (approximately 5.4%) and while some cropland areas have expanded, others have reverted back to forest. The total population is 142,907 (2016), with a growth of just over 6% in the last 20 years

Ecoregion/provinces	Description	
St. Lawrence Lowlands Ontario, Quebec	Almost 42% of this ecoregion remains in natural cover and only 3.7% is within conserved/protected areas. The St. Lawrence Lowlands ecoregion has experienced high historic rates of conversion of natural habitats to agriculture and urban areas. These have generally stabilized for the ecoregion as a whole, although there are still significant land use change pressures particularly around major urban areas and where soils are productive for agriculture. The total population is 7,210,863 (2016), with a growth of just over 17% in the last 20 years	



Fig. 6 Map of study area showing final categories of ecoregions based on total biodiversity and total threat score

# Discussion

Our assessment supports conservation in Canada by providing a systematic framework to categorize ecoregions based on biodiversity, threat and conservation response. Although ecoregions with higher biodiversity and threat levels are generally known for southern Canada, and some have been identified in global and North American assessments (Olson and Dinerstein 2002; Ricketts et al. 1999), our analysis provides the first framework that assesses all ecoregions in southern Canada using a standardized approach.

Canada's nine crisis ecoregions have higher biodiversity and threats scores compared to other ecoregions in southern Canada and will be particularly challenging to manage for conservation. Five of the nine crisis ecoregions have less than 5% of their lands and inland waters in protected areas and the high level of threat represents the many competing land

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uses including agriculture, urban areas and resource development. Some of the existing protected areas within the crisis ecoregions may be too small or fragmented to maintain the biodiversity values for which they were established (e.g. Browne and Hecnar 2007). Many protected areas in the crisis ecoregions will also require active management and restoration to maintain their biodiversity and mitigate threats associated with small, fragmented nature reserves.

Results from our analysis can be used to help identify key regions to build clusters of effective habitat (Wiersma and Simonson 2010; Wiersma et al. 2004). Traditional government led protected areas can play and important role in these ecoregions but will need to be supported by Privately Protected Areas and Other Effective Area-based Conservation Measures, including conservation management agreements with landowners to maintain and restore biodiversity.

Only one of the nine crisis ecoregion that we identify, Northern Continental Divide, has over 17% of its lands and inland waters in protected and conserved areas. However, much of this protection is focussed in higher elevations and connectivity in the valley lands is highly restricted and under threat. The Northern Continental Divide and six of the other crisis ecoregions are located along Canada's southern border with the U.S., and conservation of species, ecosystems and connectivity will require transboundary conservation.

The analysis also identifies ecoregions in southern Canada that have higher biodiversity values but lower overall threat. Because these ecoregions often have a higher proportion of public lands and protected areas, many of them offer an opportunity to protect large and intact conservation networks. Some of these ecoregions include the 23% of the Earth's terrestrial surface that has not been significantly modified by the direct effects of human activities (Watson et al. 2018), including the Central Laurentians and Columbia Mountains and Highlands ecoregions. Protecting 17% has already been achieved in several higher biodiversity and lower threat ecoregions. In other ecoregions this can be accomplished through private and public land protection and Indigenous Protected and Conserved Areas.

The results of our assessment provide conservation practitioners with a framework to better contextualize conservation projects and to track progress toward national, regional and organizational conservation goals. It can provide a foundation to explore the feasibility, constraints, and opportunities to set and strive toward ecoregional-based conservation objectives and ensure that progress in meeting national targets occurs not just in the ecoregions where conservation can happen, but in the ecoregions where conservation must happen to protect Canadian biodiversity.

This assessment also provides a framework that could be applied to update Canada's 2010 Ecosystem Status and Trends Reporting (Federal Provincial and Territorial Governments of Canada 2010). The data and results are also complementary to existing national-scale monitoring initiatives including Canadian Environmental Sustainability Indicators, such as Canada's conserved areas (ECCC 2018b) and the World Wildlife Fund Living Planet Index for Canada (WWF Canada 2017) on national wildlife declines. The results support the identification of "shared priority places" under Canada's 2019–2022 Federal Sustainable Development Strategy (ECCC 2018a), and can help guide Canada's post-2020 biodiversity framework, including targets for the 2021–2030 UN Decade of Ecological Restoration.

In addition to monitoring and reporting at the ecoregional scale, the criteria used in the assessment could be used to develop new indicators for monitoring conservation in Canada. In particular, a conservation assessment can support Canada in reporting on key elements of Aichi Target 11, including connectivity, representation and 'areas of particular

importance for biodiversity, and in developing post-2020 targets that focus on qualitative conservation measures (Lemieux et al. 2019).

The lens of ecoregions can help identify local actions that will contribute to biodiversity conservation from a Canadian context. Regional governments, land trusts and other conservation organizations can use this assessment to help coordinate conservation efforts in priority areas and demonstrate that resources are being directed to the areas that are of greatest importance and urgency for biodiversity conservation in Canada.

This assessment builds on past ecoregional assessments in southern Canada (e.g. Gratton 2010) and studies that have identified geographical gaps in conservation nationally (Iacobelli et al. 2006; Wiersma et al. 2009) and provincially (Freemark et al. 2006; Gauthier and Wiken 2003). The results can also support the current initiative to identify Key Biodiversity Areas (KBAs) in Canada (IUCN 2016). Ecoregions that have the highest score for species of global conservation concern and nationally endemic species have high probability of containing sites that could qualify under the KBA criterion for threatened species and geographically restricted biodiversity. These ecoregions include Appalachians, Fundy Coast and Eastern Vancouver Island. Ecoregions that have large habitat blocks, or large areas of natural cover compared could qualify as Key Biodiversity Areas the criterion for ecological integrity.

There are important elements of biodiversity that were not included in this study because they lack spatial information, occur at smaller geographical scales or have not yet been identified. Systematic biological surveys have not been conducted in many regions of the study area. The scoring system developed for this assessment was designed to be flexible and accommodate new measures and updated data. Additional measures that could be incorporated in the assessment as better data becomes available includes concentrations of migratory mammals or insects, range maps for additional species, richness of freshwater biodiversity and intact faunal assemblages for groups other than mammals. Information on nationally and globally rare or endemic vegetation communities does not yet exist because Canada's national vegetation classification system is incomplete, and vegetation communities are not tracked and ranked by many Conservation Data Centres. Better information on the distribution and status of vegetation communities, including current initiatives to identify Red List ecosystems (Ferrer-Paris et al. 2018; Rodríguez et al. 2015), would help support future iterations of this assessment.

Integration of additional socio-economic information into the analysis, such as forecasts on population trends, land value, and household income, could help to refine levels of risk and identify conservation opportunities. For example, Ontario's population is projected to increase by 38% by 2046, with much of that growth focussed around the urban areas in the Lake Erie Lowland ecoregion (Ontario Ministry of Finance 2019).

Additional climate change models could be also considered to identify ecoregions most likely to continue to experience rapid changes in temperature, precipitation and other variables. Forecasting and mapping these potential future threats would help to identify those ecoregions that have the highest probability of experiencing future change and are in need of conservation action.

Our connectivity analysis did not incorporate models of potential species movements and habitat shifts due to climate change (e.g. Lawler et al. 2013). As additional information on projected species' range shifts, climate stability and potential climate refugia (Iwamura et al. 2010) become available and the certainty of these predictions increases, such data could help to refine the scoring of ecoregions.

Expanding our assessment to all of Canada would provide a more complete picture of biodiversity, threats and conservation needs, and national context for conservation actions.

This assessment examines Canada's southern landscapes that have already been significantly altered and where conservation and often restoration are urgently needed. While parts of Canada's north are under pressure from industrial activities and climate change is rapidly altering the ecology of this region, there remains a globally significant opportunity to work with Indigenous Peoples to conserve large, intact landscapes. Although biodiversity data for some criteria is poorly documented in the north, there is information that would support the initial identification of important sites and networks. For example, the Athabasca sand dunes and the Beringia region of the Yukon are known to have high concentrations of at-risk, endemic and globally rare species.

Assessing the relative importance of biodiversity conservation over large scales is complex and depends on the measures and criteria that are applied (Brooks et al. 2006). Alternative approaches to our analysis could combine top scores based only on species measures or stratify the final scores based on ecological boundaries or a grid would refine the ecoregional results and help to pinpoint key sites for conservation action in each ecoregion. For example, Manitoba's Interlake Plain ecoregion has relatively higher biodiversity values, but lower threat. However, within a small area of this ecoregion are some of the world's best remaining remnants of tallgrass prairie. Other well-known areas of conservation concern were split between multiple ecoregions in our analysis, such as central British Columbia's South Okanagan Similkameen. These areas have very high numbers of species at risk and are critical to conserve biodiversity in Canada. Stepping down the scale of the analysis would support the identification of priority areas within all ecoregions will be an important next step.

Selecting priority places for conservation is difficult and is ultimately based on the species and ecosystems that we chose to value. Conserving biodiversity everywhere is also important. Protecting habitats and species across regional geographies protects representative biodiversity and is often critical in maintaining ecological services. But in a rapidly changing world with limited conservation resources, conservation requires decision making that is based on an assessment of priorities. This conservation assessment provides a framework to direct conservation actions to the ecoregions in southern Canada that have the highest levels of biodiversity and are under the greatest risk.

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**Data availability** The datasets generated and analyzed for this study are available from the Nature Conservancy of Canada at: https://arcg.is/Cuz9n0.

#### Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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