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Informing Canada's commitment to biodiversity conservation: A science-based framework to help guide protected areas designation through Target 1 and beyond

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Abstract

Biodiversity is intrinsically linked to the health of our planet—and its people. Yet, increasingly, human activities are causing the extinction of species, degrading ecosystems, and reducing nature's resilience to climate change and other threats. As a signatory to the Convention on Biological Diversity, Canada has a legal responsibility to protect 17% of land and freshwater by 2020. Currently, Canada has protected ~10% of its terrestrial lands, requiring a marked increase in the pace and focus of protection over the next three years.

Given the distribution, extent, and geography of Canada's current protected areas, systematic conservation planning would provide decision-makers with a ranking of the potential for new protected area sites to stem biodiversity loss and preserve functioning ecosystems. Here, we identify five key principles for identifying lands that are likely to make the greatest contribution to reversing biodiversity declines and ensuring biodiversity persistence into the future. We identify current gaps and integrate principles of protecting (i) species at risk, (ii) representative ecosystems, (iii) intact

wilderness, (*iv*) connectivity, and (*v*) climate refugia. This spatially explicit assessment is intended as an ecological foundation that, when integrated with social, economic and governance considerations, would support evidence-based protected area decision-making in Canada.

Key words: protected areas, conservation planning, gap analysis, Aichi Target 11, threat reduction, governance

Introduction

The world's biological diversity is facing a substantial threat of loss due to human activity (Barnosky et al. 2011; Ceballos et al. 2015; De Vos et al. 2015; Urban 2015; Ceballos et al. 2017). Globally, it is estimated that humans have raised the rate of species' extinction 1000 times over background rates (Ceballos et al. 2015; De Vos et al. 2015), with these rates expected to rise with future climate change (Thomas et al. 2004; Urban 2015). Protected areas—national parks, reserves, special management zones—are one effective tool to protect biodiversity (Chape et al. 2005; Le Saout et al. 2013). Protected areas reduce the scale or intensity of negative human activities and are most effective when identified through ecological assessment (Locke 2015; Belote et al. 2017; Saura et al. 2017). The decision-making criteria and processes used to locate new protected areas dramatically affect biodiversity outcomes (Svancara et al. 2005; Venter et al. 2017), future land-use patterns (Ellis and Ramankutty 2008; Ellis et al. 2010; Venter et al. 2016), and human well-being (e.g., where tied to ecosystem services such as pollination and flood control; see Naidoo et al. 2006; Kaplan-Hallam and Bennett 2017), thereby altering conservation efficacy.

One hundred and sixty-eight countries have signed and ratified the Convention on Biological Diversity (CBD), which enshrines national commitments to conservation of biodiversity. Of these signatories, Canada is the second-largest country and is in a strong position to create positive biodiversity outcomes. Following adoption of the CBD Strategic Plan for Biodiversity and the Aichi Biodiversity Targets 2011–2020, Canada set 19 specific national targets related to biodiversity conservation in the 2020 Biodiversity Goals and Targets for Canada (ECCC 2016a). Canada Target 1 is a restatement of quantitative aspects of Aichi Target 11, namely protection of 17% (1.70 million km²) of terrestrial and freshwater areas by 2020. As of June 2017, 10.6% (1.05 million km²) of Canada's lands had received such protection (GC 2017). From an ecological perspective, the proportion of protected area required to ensure the persistence of biodiversity is substantially greater, with estimates varying from 25%–75% (Svancara et al. 2005; Noss et al. 2012; Locke 2015; Dinerstein et al. 2017). Protected areas, in and of themselves, are not sufficient to reverse biodiversity declines but must be complemented by appropriate governance and careful management of lands (Geldmann et al. 2015) in and out of protected areas. We acknowledge the importance of additional measures to reverse biodiversity decline but focus here on ecological criteria to select protected areas.

Specific, critical elements of Aichi Target 11 state that protected area conservation should include areas of particular importance for biodiversity and ecosystem services that are ecologically representative and well connected and integrated into the broader landscape and seascape. These qualitative elements (for a discussion see Rees et al. 2017) are vital to evidence-based efforts to reverse biodiversity decline and, although not included in written text for Canada Target 1, have been represented as part of Canada Target 1 (McKenna 2017). As such, we hereafter refer interchangeably to Aichi Target 11 and Canada Target 1 to encompass Canada's commitment to reduce biodiversity decline through establishment of protected areas.

Achieving Aichi Target 11 will require a marked increase in both the pace and focus of protection both globally (Butchart et al. 2010; Watson et al. 2016b) and in Canada (Standing Committee on

[Environment and Sustainable Development 2017](#)). Protected area planning that explicitly incorporates biophysical science into decision-making produces better protection outcomes than processes that do not ([Watson et al. 2011](#); [Bottrill and Pressey 2012](#)) and can increase the quality of protected areas ([Svancara et al. 2005](#); [Ruckelshaus et al. 2015](#)). Recently, the Canadian government formed a National Advisory Panel (NAP 2017) with the goal to “develop a pathway, grounded in science and traditional knowledge, to achieve Canada Target 1” (conservation2020canada.ca/the-pathway/), but there is no transparent process by which this grounding in science occurs. Nor is there public information about an overarching framework used to incorporate the different scientific principles that could guide an evidence-based decision process.

Here, we use biophysical science to help identify priority areas for protection under Canada’s Target 1 and, ultimately, to reduce biodiversity loss. Our focus is solely on terrestrial protected areas. We do not consider freshwater protected areas, which require different management approaches and involve a different suite of biophysical processes (see [Chu et al. 2003](#); [Chessman 2013](#); [Chu et al. 2014](#); [Grantham et al. 2017](#)). Marine protected areas are dealt with in a separate, parallel policy process and are similarly excluded. Many candidate sites for expanding Canada’s protected area network have already been identified through a variety of processes and plans (e.g., Parks Canada’s system plan, Key Biodiversity Areas, Indigenous and community-conserved areas, land-trust acquisition plans, regional land-use plans, provincial and territorial protected area strategies). Such sites have been put forth based on differing criteria, however, and could benefit from being placed in a common framework to reach national conservation goals. An operational policy for the Minister of the Environment and Climate Change is needed to move Canada forward along the Pathway to Target 1. Ideally, to increase consistency of conservation decision-making, such a policy would be based on a transparent and objective approach where biophysical science is considered explicitly and then integrated with socioeconomic and governance criteria. Below, we develop such a scientific framework, which can form a base for integration of community, socio-economic, and governance issues to achieve Target 1 (see section: A framework to guide Canada’s protected area planning).

The Canadian context for protected areas: threats to biodiversity in Canada

Canadians across political and demographic lines generally support effective environmental management: nearly all Canadians (97%) consider the protection of Canada’s endangered biodiversity important¹ ([McCune et al. 2017](#)). Human pressures on the environment have had profound detrimental impacts on species across the globe ([Ceballos et al. 2015](#); see [Box S1](#)). Even within Canada, a country with vast remaining wilderness and an international reputation for natural resources ([Watson et al. 2016a](#)), human-dominated regions show extensive biodiversity loss (see [Fig. 1](#); [Fig. 2](#); [Coristine and Kerr 2011](#); [McCune et al. 2013](#)). The populations of hundreds of wildlife species have declined rapidly in Canada over the past 150 years, placing them at risk of extinction (canada.ca/en/environment-climate-change/services/committee-status-endangered-wildlife.html). Although the precise causes are often species specific ([McCune et al. 2013](#)), habitat loss and destruction explain most declines for endangered terrestrial species ([Venter et al. 2006](#)). Areas of intensive agriculture and urbanization ([Kerr and Cihlar 2004](#); [Coristine and Kerr 2011](#)), transportation networks ([Robillard et al. 2015](#)), industrial operations such as mining and smelting ([Bayne et al. 2008](#); [Kelly et al. 2009](#); [Hebblewhite 2017](#)), and development of wetlands ([van Asselen et al. 2013](#)) put intense pressure on ecosystems. A warming climate

¹64% very, 33% somewhat ([Ipsos Reid 2012](#))

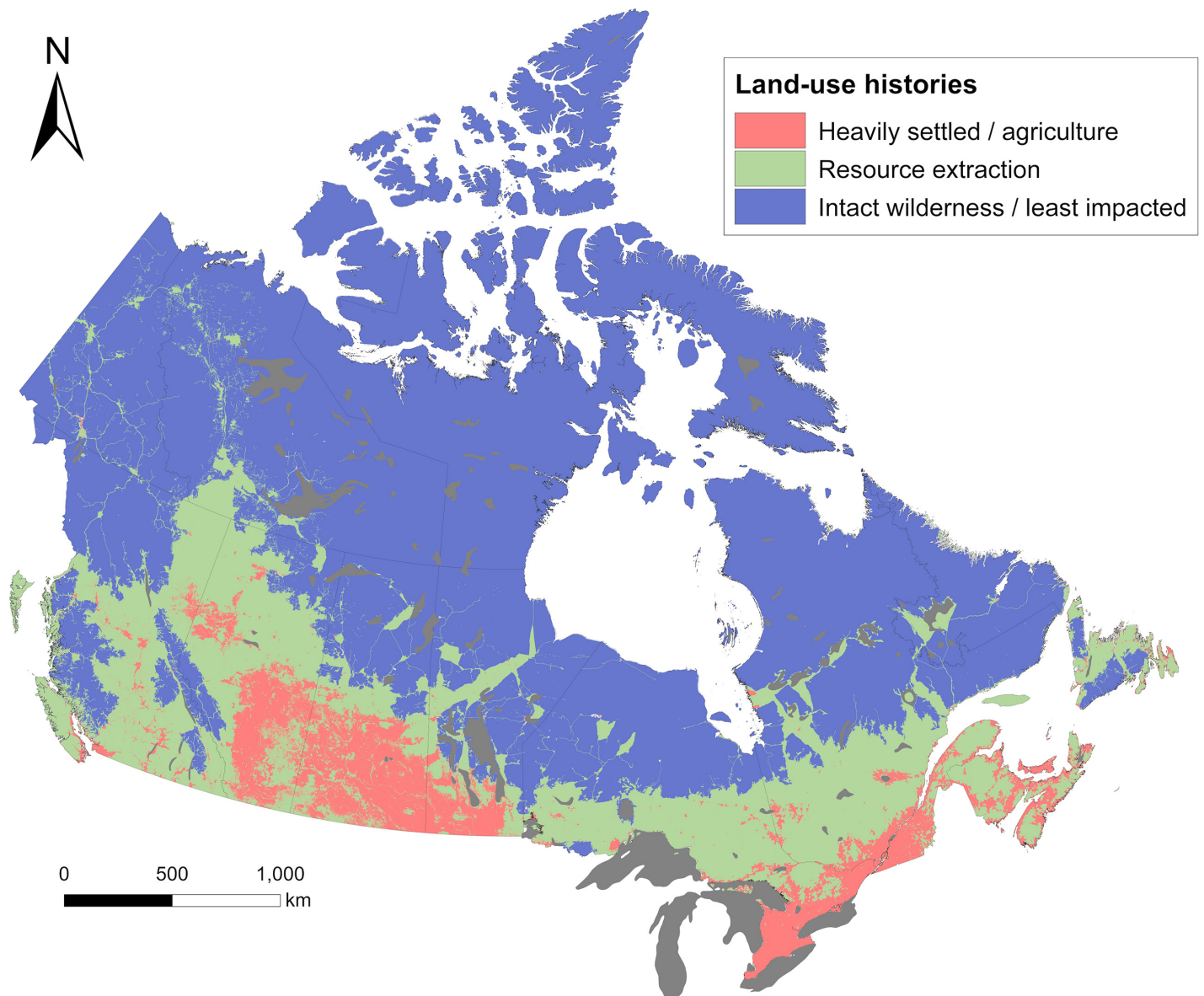


Fig. 1. Current and historic land-use legacies in Canada. See [Supplement S1](#) for data sources. Differing land-use legacies represent distinct conservation challenges for biodiversity ([Locke 2017](#)).

further threatens organisms, species, communities, and ecosystems in a myriad of unanticipated ways ([Urban et al. 2016](#)), particularly when populations must shift poleward through fragmented and degraded habitats to track suitable climates ([Robillard et al. 2015](#)).

The cumulative effects of extinction threats can be far more devastating than expected from the component threats alone ([Schindler and Lee 2010](#); [Cristine and Kerr 2011](#)). The interactions of multiple extinction threats are most apparent in southern Canada where the highest concentration of land-use changes ([Kerr and Cihlar 2004](#)) and greatest loss of species habitat occur ([Kerr and Deguise 2004](#)). Unfortunately, ecological thresholds of cumulative effects are poorly understood

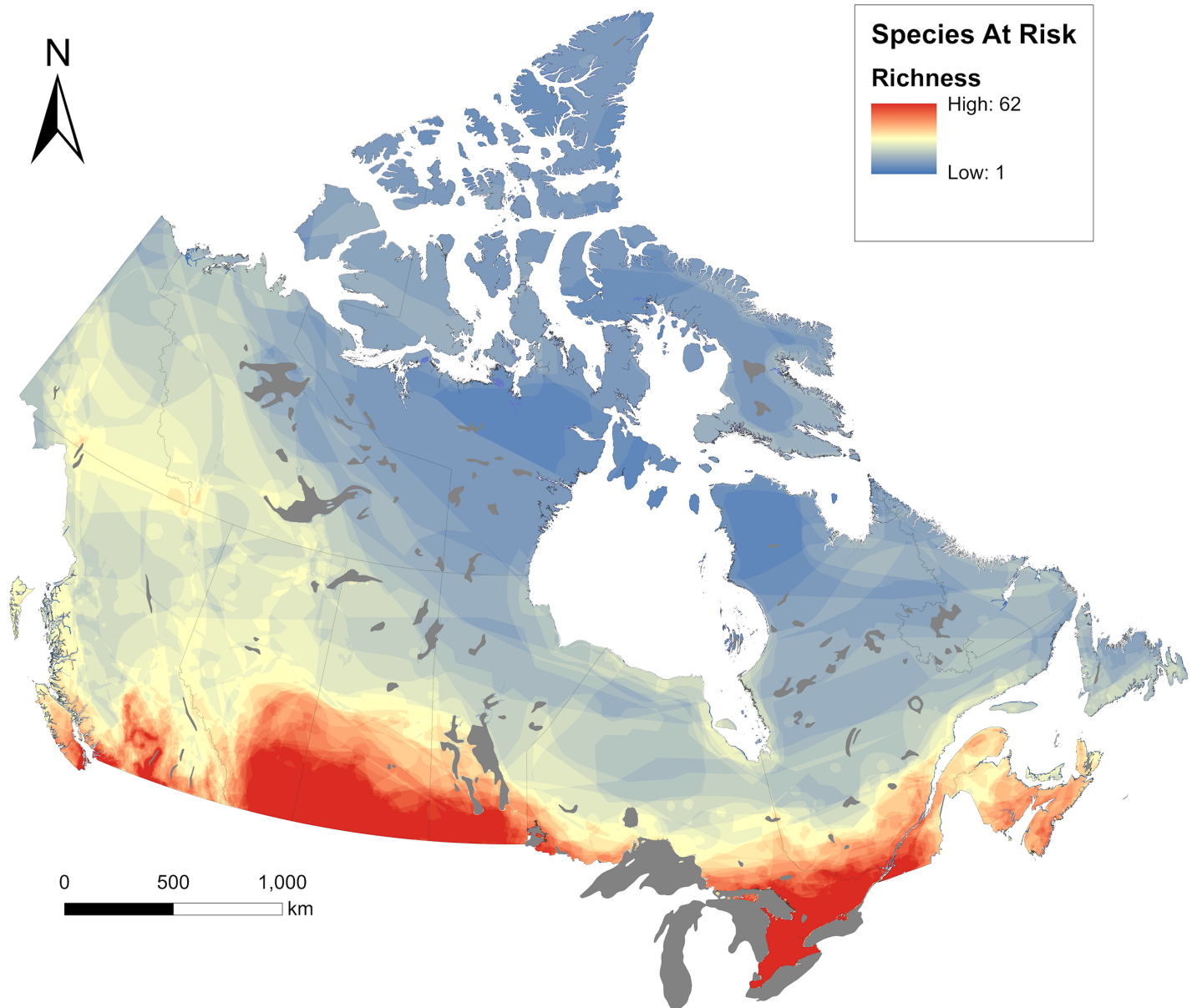


Fig. 2. Range overlap of species at risk within Canada (data from [ECCC 2016c](#)). Southern Canada, with the greatest numbers of species at risk, coincides with the most developed areas.

([Kreutzweiser et al. 2013](#)). A precautionary approach to conservation planning and land-use management is needed to guard against these cumulative extinction threats ([Gonzalez-Suarez and Revilla 2014](#)).

Key principles of biodiversity conservation

In this paper, we discuss five key biodiversity conservation principles that can be used to facilitate an evidence-based approach to the establishment of protected areas under Target 1. We identify gaps in protection in Canada and illustrate how these principles can be integrated to identify areas with greatest potential to improve biodiversity prospects.

Principle 1: protect species at risk

Protection of species at risk is essential to biodiversity conservation. Areas with the greatest loss of biodiversity tend to occur in highly developed southern portions of Canada and represent regions where the greatest strides can be made to reverse biodiversity decline.

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assesses the status of wildlife species or other designatable units and has identified 735 species at risk of extinction. Three-quarters of these species are legally listed under the Species At Risk Act (SARA) (ECCC 2017) and protected against intentional harming or killing. SARA does not automatically protect the habitat of these species (Bird and Hodges 2017), which is only legally designated once a recovery strategy is finalized. Critical habitat protection generally only applies on federal land (~5% of land within the provinces) unless the species is aquatic or a migratory bird or an emergency order is issued. Climatic requirements are not currently included in critical habitat designations, making it difficult to plan for future habitat needs.

Indeed, there is clear evidence that current protection for Canadian species at risk is not sufficient; even after being designated under COSEWIC, the status of many species at risk in Canada continues to decline. Where species have been reassessed by COSEWIC, declines outnumber improvements by more than two to one (Favaro et al. 2014). Further, one-quarter of the observed improvements were driven by increased sampling effort, not intensified conservation efforts (Favaro et al. 2014). Increasing protected areas within regions where species are currently threatened is central to reducing biodiversity loss (Fig. 2). Ecological restoration will often be needed to ensure that these already impacted landscapes increase local biodiversity (Benayas et al. 2009) and effectively connect populations (see Principle 4; M’Gonigle et al. 2015; Foster et al. 2017). Canada Target 1 has the potential to dramatically improve conservation for species at risk through well-situated protected areas (Venter et al. 2014) that include critical habitat and restoration of degraded lands. To prevent further erosion of Canada’s biodiversity, this principle should be prioritized.

Principle 2: represent ecosystem diversity

Minimum protection targets for each Canadian ecoregion can ensure persistence of a variety of ecosystem services (e.g., flood control, carbon sequestration), as well as preserve diverse ecological communities.

Canada is home to a diversity of biological communities with unique interacting species in habitats ranging from the desert of southern British Columbia to the tundra of the Arctic territories. Preserving biodiversity across this array of habitats is only possible if functional ecosystems remain intact in each (see Principles 1 and 4). Aichi Target 11 recommends protecting a minimum of 10% in each “ecoregion” to ensure representativeness (cbd.int/sp/targets/rationale/target-11). Thus, a second principle when prioritizing candidate protected areas for Target 1 is representativity.

Maintaining representative areas of Canada’s diverse ecosystems allows people to benefit from the various ecosystem services that these regions provide (de Groot et al. 2002; Carpenter et al. 2009). Ecosystem services are place specific, so preserving large, well-connected, representative areas for major ecosystems of Canada is similar to an insurance policy against losing these services.

The scale and criteria used to specify “ecoregions” can dramatically influence conservation decisions around representativeness. Ecoregions are defined as “large units of land containing a distinct assemblage of natural communities and species, with boundaries that approximate the original extent of natural communities prior to major land-use change” (Olson et al. 2001, p. 933). We recommend Canada’s 194 terrestrial ecoregions, as developed by the National Ecological Framework for Canada (NEFC) (ESWG 1995), as an appropriate scale for defining representativeness in Canada rather than

the coarser ecozones currently considered by Environment Canada (e.g., [ECCC 2016b](#); see [Fig. S1](#)) or the parks planning regions considered by [Parks Canada \(2014\)](#). For example, one of 18 terrestrial ecozones ([ccea.org/ecozones-introduction/](#)), the Boreal Shield, is massive, extending from Alberta to Newfoundland (1.8 million km²) and encompassing a wide variety of ecosystems (from the sand dunes of the Athabasca plains to the heathlands of the Maritime barrens). Using too coarse a scale for ecological representativeness could result in the loss of unique biological communities that are excluded from protected area conservation targets. This is especially true when there are limited data available regarding community structure and risk of extirpation of component species (see [Table 1](#)).

The current extent of protection varies widely among Canadian ecoregions. Several ecoregions have no protection (e.g., Takijua Lake Upland, Mackenzie Delta), whereas others are almost entirely protected (e.g., Mount Logan, Nahanni Plateau). Only 67 of Canada’s 194 ecoregions meet the Aichi Target 11 minimum of 10% protection by ecoregion ([Fig. 3](#)). Furthermore, for many ecoregions, protected areas are in small and isolated parcels; few ecoregions have large contiguous protected areas ([Fig. 3\(b\)](#)).

Table 1. Data availability and outstanding data needs for each of the five conservation principles.

Principle	Data used	Priority	Outstanding data requirements
Species at risk	Range maps for 490 species at risk ^a	Greatest overlap for species at risk	Range maps for unmapped species at risk
			Critical habitat maps for species at risk
			Climatic habitat maps for species at risk
			Backlogged species awaiting listing decisions
			Global responsibility for species
Representativeness	Protected areas meeting Aichi Target 11 ^b	Ecoregions with least protected areas	Environmental diversity
	Ecoregion boundaries ^c	—	Ecosystem services
Wilderness	Human population density 2015 ^d	Least human impact	—
	Global Forest Watch, Access 2010 ^e	—	—
	Land Cover 2015 ^f	—	—
Connectivity	Current connectivity initiatives ^{g-j}	Pre-existing connectivity effort	Migration routes for diverse species
	Riparian buffer zone ^k	0–1500 m buffer on major rivers and lakes	Structural connectivity assessments
Climate change resilience	Climate change resilience map ^l	Areas with lowest velocity, fewest extremes, and consistent seasonal and annual changes	Climate connectivity

^aECCC, SARA database.

^b[ccea.org/download-carts-data/](#).

^cNEFC (1996).

^dCenter for International Earth Science Information Network (CIESIN)—Columbia University (2016).

^eGlobal Forest Watch Canada (2014, 2016).

^fEuropean Space Agency Climate Change Initiative (2017).

^g[y2y.net/](#).

^h[programs.wcs.org/2c1forest/](#).

ⁱ[a2acollaborative.org/](#).

^j[borealbirds.org/](#).

^kCANVEC (2013).

^lCoristine et al. 2016; derived from climate data at [cfs.nrcan.gc.ca/projects/3/4](#) (including [McKenney et al. 2011](#)).

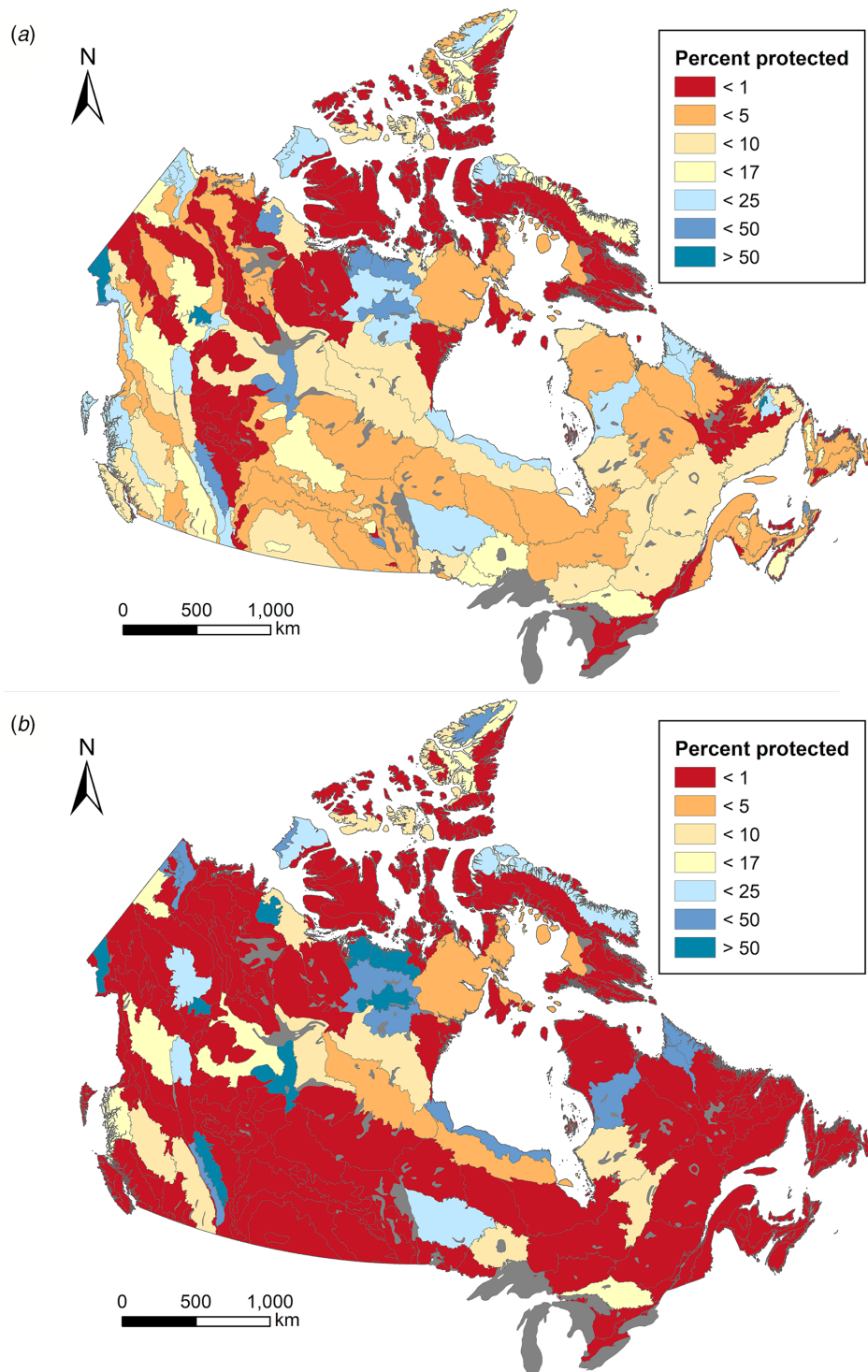


Fig. 3. The current extent of protection within each of Canada’s 194 terrestrial ecoregions. Percent of each ecoregion that (a) is protected and (b) contains protected areas >5000 km² (CCEA 2016). Ecoregions are based on the National Ecological Framework for Canada (NEFC 1996; ESWG 1995).

Principle 3: conserve remaining wilderness

Intact wilderness areas are the least impacted by human activities; their protection preserves more natural ecological communities. Protected wilderness areas should be large to minimize human impacts from outside the protected area and retain natural processes such as fire regimes and long-distance migration.

The third principle protects large, intact land, which in Canada remains mainly in the north (Fig. 1). Canada has the ability and, arguably, a global responsibility to preserve much of the world's remaining wilderness. Protecting large undisturbed areas ensures that the complete suite of biological processes remain relatively unperturbed and retains future potential for ecological and evolutionary adaptation (Turner et al. 2007; Wilson et al. 2009; Pereira et al. 2010; but for a dissenting view, see Bush et al. 2017). For example, the Canadian boreal has a high density of carbon storage, and its protection would also reduce carbon release (Bala et al. 2007; Bonan 2008). Further, intact wilderness areas are less likely to be affected by human-introduced diseases (Foley et al. 2005) or invasive species (Didham et al. 2005) and provide improved biodiversity outcomes for species impacted by climate change (Martin and Watson 2016; Principle 5). Protecting northern ecosystems is also important for maintaining and strengthening Indigenous governance in land stewardship (Murray and King 2012), in a region that is disproportionately threatened by climate change (Durkalec et al. 2015).

Tracts of ecologically intact wilderness have been lost across the globe; less than 25% of non-barren ice-free land remains free from anthropogenic use (Ellis and Ramankutty 2008; Venter et al. 2016; Watson et al. 2016a). Yet intact wilderness supports high levels of biodiversity (Gurd et al. 2001; Pollock et al. 2017), diverse communities (see Crooks 2002; Ferraz et al. 2003; Gibson et al. 2013), ecosystem services (Bala et al. 2007), and processes such as fire regimes (Gill et al. 2013; Stephens et al. 2014). Canada contains fully one-third of the world's remaining non-barren wilderness areas (Fig. S2; Ellis and Ramankutty 2008) and almost one-quarter of the world's intact forests (Potapov et al. 2017). Much of Canada remains isolated from transportation infrastructure, human land-use change, and other development (Venter et al. 2016).

To ensure wilderness areas remain intact and to allow natural processes such as fire and long-distance migration to occur within them, areas protected under this principle should be large in size. Long-term persistence of species (Principle 1) is compromised when insufficient area is protected due to the risk of local extinction and the difficulty of recolonization when populations are unconnected (Haddad et al. 2015; Belote et al. 2016; Principle 4). Although the minimum area for an effective reserve depends on the ecosystem and organism assemblage, assessments of mammalian data from contiguous and fragmented areas found that reserves > 5 000 km² would likely conserve the historic assemblage of species (Gurd et al. 2001). Within Canada, relatively few protected areas exceed this size (Fig. 3(b)).

Principle 4: ensure connectivity and resilience

Ecological connectivity is important at local, regional, and national scales, promoting opportunities for species' natural movements. Resilience of populations and species can be fostered through strategic protection of areas that increase connectivity.

The fourth principle, connectivity, promotes natural movements for wide-ranging species (see Di Minin et al. 2016), prevents breeding populations from becoming isolated (Haddad et al. 2015; Belote et al. 2016), and facilitates south-to-north and elevational movement of individuals that are shifting geographically in response to changing climates (Coristine and Kerr 2015; Robillard et al. 2015). Long-term experiments have shown that fragmentation of landscapes reduces biodiversity by 13%–75%, lowering species' abundance and persistence times (Haddad et al. 2015,

but see [Fahrig 2003](#)). Additionally, connecting fragmented landscapes through corridors reduces species loss (Principle 1; see [Crooks et al. 2017](#); [Thompson and Gonzalez 2017](#)), improves core ecosystem functions (Principle 2; see [Hauer et al. 2016](#)), and can contribute to the provision of some ecosystem services ([Mitchell et al. 2013](#)), such as pollination ([M’Gonigle et al. 2015](#)).

Unfortunately, there is no current analysis on the connectivity needs of diverse species in Canada. Nevertheless, Canada Target 1 can be guided by existing initiatives that have highlighted priority areas for connectivity planning. For example, at a large landscape level, the Yellowstone to Yukon Conservation Initiative (Y2Y) aims to protect and connect habitat over 1.3 million km² across the western United States and Canada to increase connectivity between core areas for wide-ranging species such as caribou (e.g., *Rangifer tarandus* (Linnaeus, 1758)), wolverines (e.g., *Gulo gulo* (Linnaeus, 1758)), wolves (e.g., *Canis lupus* Linnaeus, 1758), and grizzly bears (e.g., *Ursus arctos* Linnaeus, 1758) ([Chester et al. 2012](#); [Fig. S4](#)). Furthermore, migratory songbirds have been used to define corridors (e.g., Boreal Songbird Initiative). Although connectivity initiatives may focus on specific taxa, these often serve as “umbrella species” to protect connectivity for non-focal taxa ([Carroll et al. 2003](#); [Steenweg 2016](#)). For example, the Boreal Songbird Initiative encompasses the range of the threatened boreal woodland caribou (e.g., *Rangifer tarandus caribou* (Gmelin, 1788)), so efforts to increase protection and connectivity for songbirds would also benefit caribou.

In addition to previously identified connectivity priorities, connectivity can be improved by protecting land around waterways ([Hilty and Merenlender 2004](#); [Hauer et al. 2016](#)). Besides facilitating wildlife movement, setbacks around streams reduce threats to semiaquatic species ([Saunders et al. 2002](#)), integrate freshwater and terrestrial communities ([Adams et al. 2014](#)), and protect water quality ([Dosskey et al. 2010](#); [Hauer et al. 2016](#)). Federal and provincial guidelines (e.g., minimum 30 m riparian strips on each side of a stream; [Chilibeck et al. 1992](#); [Environment Canada 2013](#)) are a start, but they are not mandated for all land and are typically too small to gain the full benefits of riparian buffers. Indeed, research indicates that terrestrial species preferentially use vegetated riparian land up to 1500 m from freshwater streams ([Hilty and Merenlender 2004](#)). Prioritizing the protection of larger riparian buffers would thus contribute to improved connectivity and biodiversity health across watersheds.

Principle 5: preserve climate refugia

Protecting areas with milder climate change reduces the risk to species from extreme climatic events (such as heat waves, hurricanes, and drought) and from insufficient tracking of preferred environmental conditions.

The risks of climate change to biodiversity can be reduced by preferentially protecting areas that currently—or are predicted to—experience less climate change and fewer extreme climatic events ([Moritz and Agudo 2013](#); [Coristine et al. 2016](#); see also [Table 1](#)). Climatically stable areas (“climate refugia”) foster the persistence of biological communities ([Iwamura et al. 2010](#)) and facilitate population movement from current to future suitable habitat ([Robillard et al. 2015](#); [Coristine et al. 2016](#); [McGuire et al. 2016](#)).

Climate change is expected to have ever increasing negative impacts for the majority of species as geographic distributions diverge from climatically suitable habitat and resource regions. In songbirds, asynchrony between food availability and migration arrival has led to population declines ([Mayor et al. 2017](#)). Inadequate expansion of range limits in response to climate change has caused compression of species’ ranges ([Coristine and Kerr 2015](#)). Extreme climatic events are linked to reproductive failure ([Bolger et al. 2005](#)) and population loss ([Williams et al. 2013](#); [Oliver et al. 2015](#)). Given Canada’s large area, position as a polar country, and the number of species whose ranges have already shifted, from birds ([Foden et al. 2013](#); [Coristine and Kerr 2015](#)) to trees ([Aitken et al. 2008](#)),

Canada may well witness more biodiversity redistribution in the face of climate change than most other countries. Both protecting climate refugia (Coristine et al. 2016) and ensuring habitat connectivity (see Principle 4) reduce the threat to biodiversity from climate change (Saura et al. 2014; Saura et al. 2017).

A framework to guide Canada's protected area planning

We call for a framework, illustrated in Fig. 4, to govern protected area identification, which uses systematic conservation planning (Margules and Pressey 2000) to guide decisions in a way that explicitly incorporates both biophysical and socio-economic evidence. As a preliminary step, we identify conservation gaps and discuss candidate areas based on the five scientific ecological principles. Subsequent work must next incorporate site-specific ecological analysis and socio-economic and governance considerations into the planning process for protected area prioritization.

Identify conservation deficits

Because existing protected area networks are biased towards particular ecoregions (Dinerstein et al. 2017; Fig. 3) and are unequally distributed with respect to taxa (Rodrigues et al. 2004b), an important first stage in any protected area selection process is to identify conservation deficits (Fig. 4). These “gap analyses” allow quantitative comparisons between biodiversity targets and protected area performance and identify missing components in protection (e.g., Table 1; Scott et al. 1993; Jennings 2000; Rodrigues et al. 2004a). Gaps and opportunities were identified for each of the five principles. We used geographic information system (GIS) methods to map the number of species at risk according to their range maps (Principle 1, Fig. 2), quantify the amount of protected area in each ecoregion (Principle 2, Fig. 3), measure wilderness according to the absence of intense human pressure and assign a higher rank to areas of at least 5000 km² of contiguous wilderness (Principle 3), highlight areas that have been previously identified as important for connectivity or that improve connectivity along waterways (Principle 4), and evaluate areas with the greatest climatic stability (Principle 5; see Supplement S1 for further details on methodology).

Although not performed here, gap analyses can also identify deficits in protected area governance structures and management regimes. As an example, the lack of formal recognition in Canadian law for tribal parks and other Indigenous models of stewardship (TRCC 2015), so that very few protected areas are governed by Indigenous peoples (Table 2, Canadian Protected Area Status Report 2012–2015), represents a governance-related gap within Canadian protected areas currently being addressed by the Pathway to Canada Target 1 Indigenous Circle of Experts².

Identify candidate areas

Following the identification of gaps, a second stage involves integrating the five principles to identify candidate protected area sites with the highest rankings. We integrated the data on gaps and opportunities for the five conservation principles to identify areas with broad potential to stem biodiversity decline and preserve biodiversity into the future. For illustration purposes, we used two distinct weighting procedures: equal weighting across each of the five principles (Fig. 5(a)); and a relative weighting according to land-use legacy in Canada (Fig. 5(b); Locke 2017): within the heavily settled/agricultural regions in the south, the areas of heavy resource extraction in middle latitudes, and the least impacted areas to the north (Fig. 1; see also Foster et al. 2003). A relative weighting reduces the likelihood that highly developed regions will be overlooked based on ecological principles that can no longer be attained due to land-use legacy (e.g., wilderness). This relative weighting may be

²conservation2020canada.ca/ice/

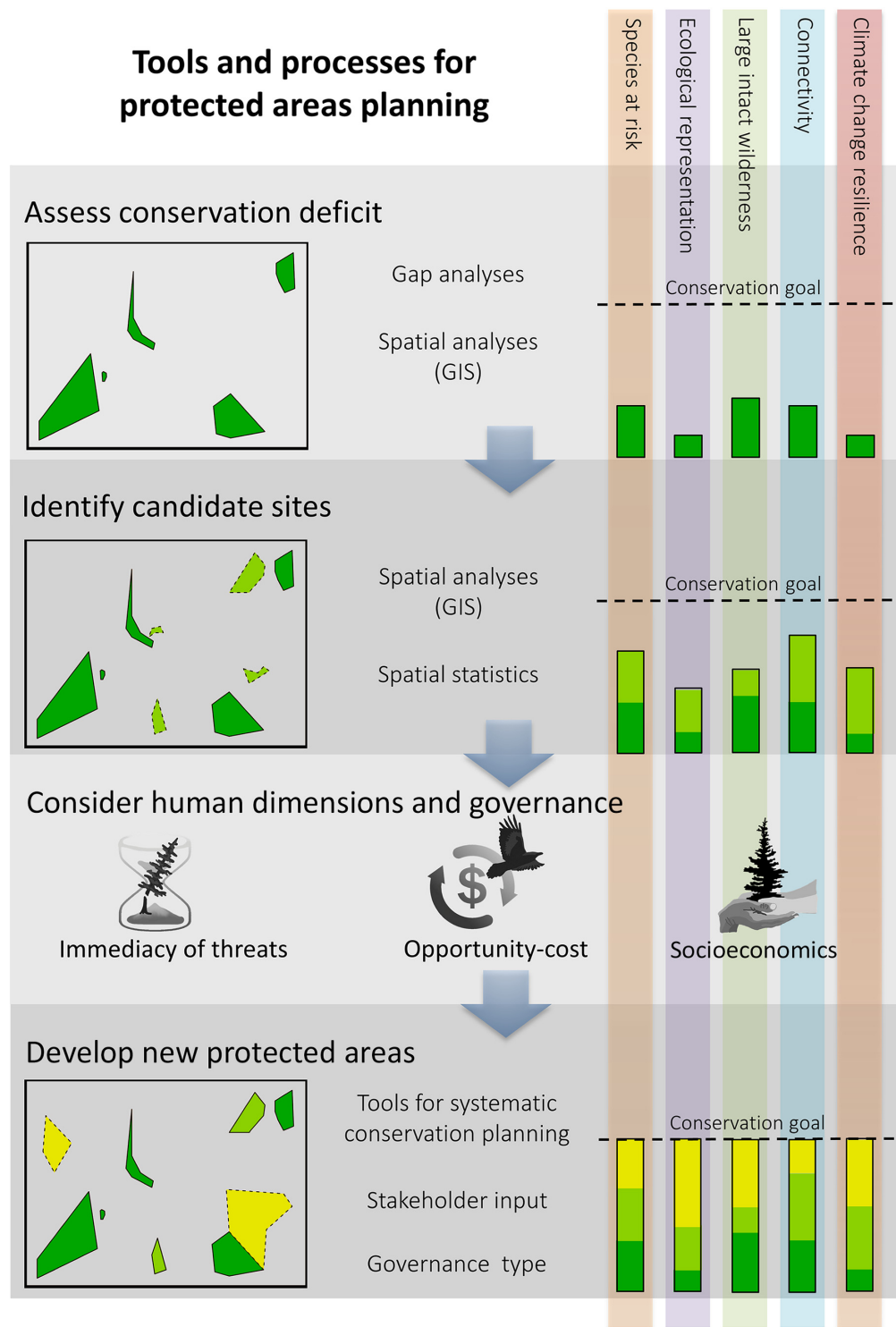


Fig. 4. Description of scientific tools and processes for systematic conservation decision-making. The columns on the right indicate hypothetical progress towards conservation goals according to the five conservation principles. Governance, economic, social, and cultural values, as well as immediacy of threat and opportunity costs, are integrated into the process of identifying protected areas, building upon an initial assessment of conservation gaps. GIS, geographic information system.

Table 2. The total area protected and counting towards Aichi 11 under each governance type within Canada.

Governance type	Examples	Area protected under Aichi 11 (ha)
Federal	National parks, national wildlife areas, and migratory bird sanctuaries	64 193 509
Provincial	Provincial parks, nature reserves, and conservation reserves	37 794 901
Indigenous peoples	Indigenous Protected and Conserved Areas, tribal parks, Indigenous and Community Conserved Areas, and Indigenous Protected Areas	97 682
Non-profit organization	Conservation easements and private lands that qualify as other effective area-based conservation measures	12 079
Shared governance	Territorial parks, co-management board	2 315 087
Not reported	—	880 737

Note: Data source: Canadian Council on Ecological Areas (ceea.org/download-carts-data/, data accessed: 30 November 2016). Data for the protected areas in Quebec were requested from Directorate of Protected Areas of the Ministry of Sustainable Development, Environment and Climate Change, Quebec (data version: 2 December 2016).

useful in developing a balanced conservation approach across Canada, protecting wilderness where available but also protecting biodiversity where it is most at risk (e.g., the mixed-wood plains of southern Ontario; see [Table S1](#) for a list of ecoregions containing sites with the highest composite score).

Not all of the above principles can be simultaneously optimized in any process to designate protected areas. Different approaches to protected areas may be necessary depending on context, for instance preserving wilderness areas that remain relatively intact (a proactive approach) versus preserving areas under threat from past and ongoing human development (a reactive approach) ([Brooks et al. 2006](#); [Watson et al. 2016b](#)). Prioritizing ecologically representative areas (proactive) will tend to protect areas that do not currently contain neighboring protected areas, whereas areas that improve connectivity (reactive) will tend to fill in gaps between adjacent protected areas. Optimization methods can be used to identify which additional protected areas would satisfy the most principles and can allow regionally relevant priorities to be incorporated ([Gjertsen and Barrett 2004](#); [Kujala et al. 2013](#); [Ekroos et al. 2014](#); [Setälä et al. 2014](#)). We developed a web-based application that allows the data to be explored more fully and that allows users to identify candidate areas based on different weightings of the conservation principles (climaterefugia.ca/research/canada-target-1/conservation-planning-tool).

Consider human dimensions

Ultimately, the environmental principle that is most important in any given region depends not only on the distribution of species and ecosystems at risk but also on socio-economic and governance considerations (i.e., which are infrequently incorporated as spatial data; [Mangubhai et al. 2015](#)). For instance, information on immediacy of threats (not included in our analyses) would likely enhance the importance of regions where species at risk occur, notably in the Okanagan, prairies and mixed-wood plains or regions at risk of imminent development such as the Peace Lowland (see [Table S1](#)).

Nevertheless, separating environmental scientific criteria as illustrated above from social, economic, and governance considerations provides clarity in conservation decision-making processes, offering a clear delineation between what biophysical science indicates and the other key aspects that must enter into policy decisions ([Mooers et al. 2010](#)). Moving forward, input from local communities and other stakeholder groups needs to be integrated ([Brooks et al. 2012](#); [Bennett et al. 2017](#); [Charnley et al. 2017](#)). Numerous considerations inform decision-making at this stage including: immediacy of

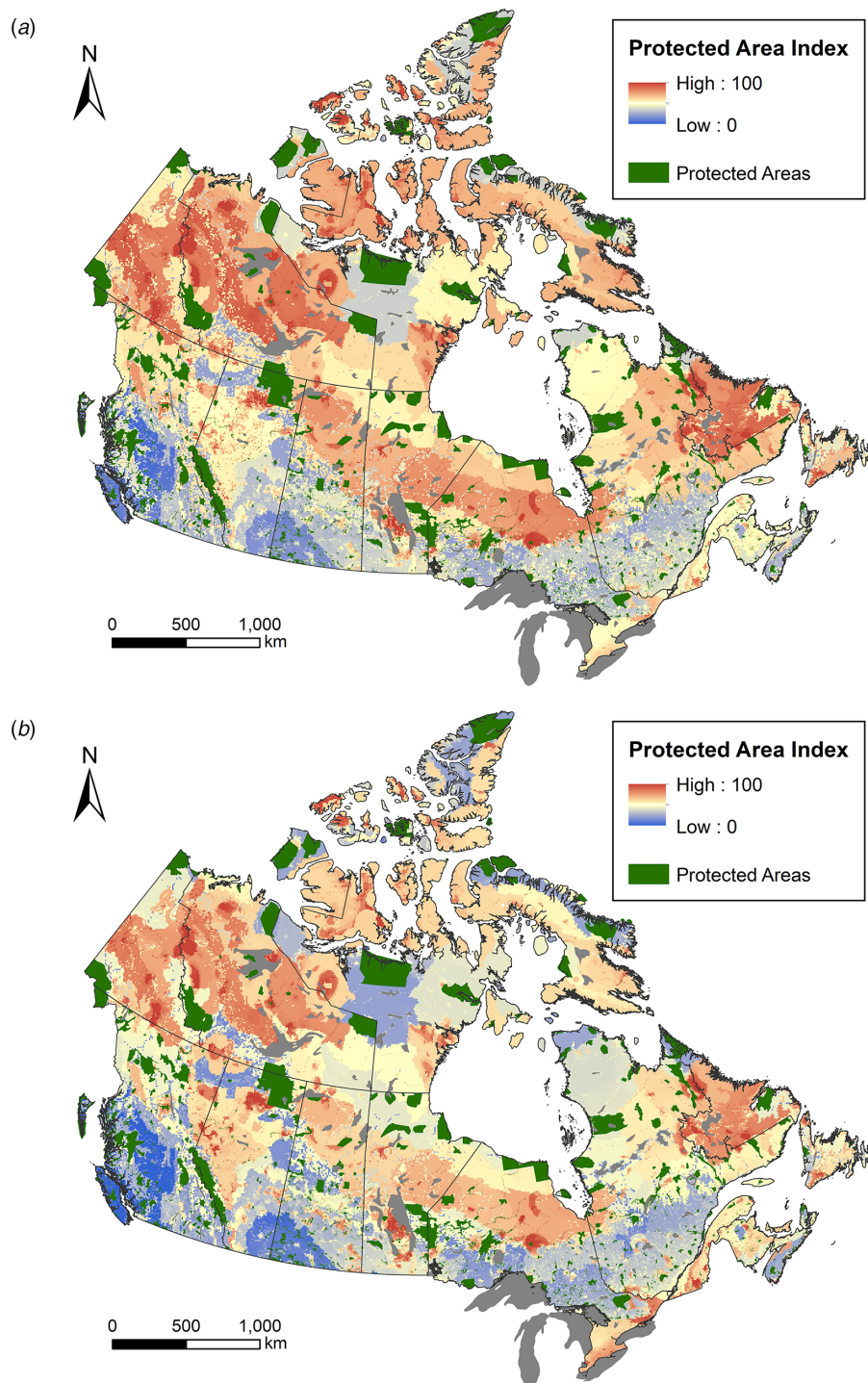


Fig. 5. Hotspots for candidate Canadian protected areas based on scientific ecological principles of (i) species at risk, (ii) current representativeness within ecoregions, (iii) wilderness, (iv) connectivity, and (v) climate change resilience. Maps are (a) based on equal weighting of principles across Canada and (b) relative to Canada's historical land-use legacies (see Foster et al. 2003; Fig. 1) of urbanization, resource extraction, and wilderness. Warmer colours represent areas with the potential to make a greater contribution to reversing biodiversity decline and preserving biodiversity for future generations. Note that these hotspots do not incorporate considerations such as social, political, economic, immediacy of threat, or opportunity costs. Alternative methods to combine scientific ecological principles are possible through an online web application (see climaterefugia.ca/research/canada-target-1/conservation-planning-tool).

threats, implications of biodiversity loss for future generations, evaluation of social and economic constraints and opportunity costs, community conservation practices, historical use, local livelihoods, cultural values (particularly for Indigenous communities), and input of expertise across a variety of knowledge systems. Integrating these considerations through an open and transparent process can increase public acceptance and support for protected areas.

Identify new protected areas

With a framework in place that incorporates both scientific evidence and social, cultural, and economic factors that influence protected area support and viability, quantitative modelling of alternative scenarios can rank areas that best protect biodiversity and have the greatest community support (Margules and Pressey 2000; Game et al. 2013; Mantyka-Pringle et al. 2016; Martin et al. 2017). These methods can account for economic considerations (such as land acquisition and management costs or costs of lost economic development opportunities; see Naidoo et al. 2006) as well as incorporate a wide range of values derived from consultations and rigorous social science to understand the needs and perspectives of diverse stakeholders (Bennett et al. 2017). Spatial decision-making methods rely on a quantitative set of rules to generate priorities for allocating limited conservation resources in service of specified objectives (Margules and Pressey 2000, Margules and Sarkar 2007). Such spatial conservation planning tools (e.g., Marxan, Zonation, C-Plan) (Moilanen et al. 2009) have been used by a variety of conservation organizations and governments (Groves et al. 2002; Fernandes et al. 2005; Kremen et al. 2008).

Designate appropriate governance

A final important step in this process is to identify the type of protected area governance that is appropriate, feasible, and can be effectively implemented (Borrini-Feyerabend et al. 2013). Terrestrial conservation in Canada is complicated by the fact that multiple jurisdictions, with distinct laws and priorities, must work together to identify, establish, and manage protected areas. There are multiple legal designations for protected areas (Table 2), including those under the jurisdiction of the federal government, provincial or territorial governments, Indigenous peoples, as well as privately protected areas without formal legal designation. Choosing the appropriate type of governance may influence the efficacy of protected area establishment and management (Lockwood 2010; Borrini-Feyerabend et al. 2013; Bennett and Dearden 2014) and should be evaluated in relation to protected area targets under Aichi Target 11. For example, approaches that foster cooperation with neighbouring communities (Fraser et al. 2006) and among agencies and jurisdictions (Dearden and Rollins 2016; Reed 2016) result in more functional and robust conservation initiatives. In some places, the designation of “other effective area-based conservation measures” may be more desirable than protected areas under national or provincial jurisdiction.

Putting the pieces together: establishing protected areas in Canada

Using a framework to evaluate the biodiversity value of areas for protection can help guard against protected areas with little value for either development (e.g., agriculture) or species protection (Venter et al. 2017). For example, biases have historically led to protected areas being located on lands with higher elevations and steeper slopes (Margules and Pressey 2000; Joppa and Pfaff 2009). Conservation planning, based on a suite of complementary approaches that encompass both proactive and reactive management principles (Brooks et al. 2006), is needed to avoid protection bias and to promote resilience into the future (Margules and Pressey 2000; Hannah et al. 2007; Beier and Brost 2010). Prioritizing protected area planning across multiple conservation principles would provide the additional benefit of balancing Canada’s conservation portfolio to counter the loss of

biodiversity where impacts are highest while also maximizing wilderness while the opportunity still remains (Pouzols et al. 2014).

The urgency to identify and protect areas remains high across all regions of Canada, yet the rationale and the available mechanisms for protection will differ depending on the region. In the south, protected area conservation and ecological restoration are needed to protect species most at risk from human activities and to improve connectivity among isolated habitat patches. Although adding protected areas to locations with greatest numbers of species at risk should be a priority, additional measures are needed to incentivize protection on private lands, such as through conservation agreements, easements, or tax incentives. For example, a tax-shifting strategy rewards protection of biodiversity features on private lands by off-setting property taxes to lands without protection. Tax shifting could limit ongoing and future threats to species at risk in regions with limited non-private land (Schuster et al. 2017).

By contrast, in the north, we have the greatest opportunities for protecting areas that have experienced lower development and human impact pressure (Venter et al. 2016). The north includes the extensive Canadian boreal (Brandt 2009), which experiences a dynamic fire (natural disturbance) cycle (Davies et al. 2013). Protected areas must be large enough to encompass disturbance regimes while maintaining metapopulation dynamics. For instance, the necessary reserve area to encompass dynamic processes in northern Canada is estimated at ~ 5000 km², but requirements may be much higher (for details see Leroux et al. 2007), under the expectation that climate change will drive increased intensity and frequency of fires in northern Canada (Kasischke and Turetsky 2006; Davies et al. 2013; de Groot et al. 2013).

Contributing to global efforts: identifying key biodiversity areas

Canada, in deciding which areas to protect, should also seek to contribute to international efforts to preserve biodiversity. The International Union for Conservation of Nature (IUCN) has established criteria to identify globally significant areas for biodiversity protection (IUCN 2016; and see Supplement S2). These locations have not yet been fully identified but play a key role for the persistence of a specific species or ecosystem (e.g., holding at least 20% of the global population of a species or being one of a limited number of areas (≤ 2) representing an ecoregion). These exceptional areas for biodiversity on a global scale are known as Key Biodiversity Areas (KBAs). The thresholds used to trigger a KBA listing, although more stringent in requiring global biodiversity importance, are consistent with the ecological principles listed above. A national approach could build upon global KBAs by expanding the standards to include species and ecosystems of significance in Canada.

By highlighting regions of outstanding biological significance, KBAs can focus attention on regions deserving of protection, instill public pride in protecting a globally important resource, and support the development of conservation economies (e.g., ecotourism). To align with global efforts for biodiversity protection, Canada should contribute to global KBA protection, setting aside KBAs that protect species that only Canada can save (e.g., musk ox, Vancouver Island marmot, among others; see Appendix C of Cannings et al. 2005) and ecoregions that only Canada has (e.g., areas within the Northwest Territories Taiga, including the currently unprotected Mackenzie Delta).

Challenges

Not just area, effective management

Area alone is not sufficient for achieving Aichi Target 11. Under each governance category, the extent to which protected areas contribute towards Aichi Target 11 varies significantly. Each type of protected area may allow different human uses and activities according to its IUCN management categories (see Dudley 2008), thereby influencing the type and quality of contribution towards reduction in

biodiversity loss. Further, area-based conservation decisions must be economically feasible as well as socially and politically acceptable. The effective management of protected areas also requires such factors as adequate financing, capacity, enforcement, outreach, and adaptive management (Hockings et al. 2006; Watson et al. 2014). Changes in governance can also weaken protection, altering priorities for protection. For example, the community pastures of Saskatchewan are included as a current protected area (here and in CCEA 2016), despite plans to shift management of these areas to local producers. This recent change would strongly alter the relative priority of grassland protection in these areas.

Protected areas, in and of themselves, are key approaches to ensure biodiversity persistence in to the future. Adequate planning, regulation, and management of land-use activities outside of protected areas are also necessary to foster effective biodiversity conservation (for discussion on these points, see Polasky et al. 2005; Wood et al. 2014). Long-term planning can be used to forecast acceptable levels of development that are consistent with biodiversity targets (e.g., regarding species diversity and abundance), taking into account cumulative effects of all human activities on species and ecosystems at risk.

Data availability and uncertainty

Insufficient data can limit the ability of science to inform conservation decisions. Biodiversity data are notoriously incomplete: distributions, relative abundance, population structure, and species interactions are almost never known for all species in an ecosystem. In particular, recorded data on biodiversity is extremely sparse in northern Canada (Fig. S3). Furthermore, although temporal data sets are critical for generating baseline information and assessing rates of change, such data sets are often incomplete (e.g., due to gaps in funding, shifts in monitoring platforms, etc.) or simply not available (Table 1). Although there is a greater certainty for trends in threats to biodiversity, failure to account for all risks compounds data uncertainty. For instance, there is a tendency for protected area analyses to discount species' and populations' poleward movement as climates change thereby generating estimates of optimal protected area locations that become increasingly inaccurate as climate change progresses. Representativeness in particular assumes species, population, communities, and ecosystems will remain spatially static over long time frames. The development of novel statistical and technological techniques (e.g., near-real-time biodiversity indicators through remote sensing) represents promising approaches to address incomplete data (Ovaskainen and Soininen 2011; Deblauwe et al. 2016; Santini et al. 2016; Bush et al. 2017). Increased data availability would also increase the accuracy of efforts to prioritize areas for protection. However, making decisions with incomplete data is preferable to delaying decision-making and can reduce overall biodiversity decline (Martin et al. 2017).

Another major data gap concerns identifying priority regions for ensuring connectivity. As Canada-wide data on home ranges and dispersal routes is currently lacking for many species, we measured importance to connectivity based on an area's proximity to waterways and on existing connectivity initiatives under the assumption that these initiatives were motivated to identify and protect locations that promote migratory routes and dispersal (see Brown and Harris 2005; Badiou et al. 2013). A more direct metric would collate the movement data and measure functional connectivity needs for a broad array of species across Canada, including plants.

Climate change is a significant driver of current and future biodiversity decline (Urban 2015; Coristine and Kerr 2015). Although our fifth principle selects regions that are predicted to be relatively stable in the face of future climate change (Principle 5), this could be augmented through data on "pinch-points": areas that are predicted to provide limiting habitat or climate at some point in the future as species move from where they live today to where they are predicted to live under changing climatic conditions. More research is needed to identify and increase certainty around estimates of future climatic connectivity in Canada (for a US example see McGuire et al. 2016). Including climate connectivity in our analyses would build upon efforts to map future ecosystem distributions (e.g., in British Columbia: Wang et al. 2012).

Although we outlined a way to identify candidate areas for protection in Canada based on five key conservation principles, these principles are not mutually exclusive of other considerations nor do they represent an absolute prioritization. For instance, we did not explicitly consider biodiversity richness, although the principle of protecting species at risk accounts for the local richness of such species (Fig. 2). We did not include richness because native species richness is not well mapped across Canada and because it is affected by invasive species and habitat fragmentation in ways that complicate the assessment of protected area value for biodiversity (Dornelas et al. 2014; see Table 1 and Fig. S3).

Conclusion

Spatial analyses and maps provide an important set of tools to make and evaluate decisions about conservation and can enhance current protected area selection by highlighting key gaps (i.e., species at risk, governance; see Fig. 2, Table 2) and identifying priorities for action (Fig. 5). Ultimately, decisions on site selection for protected areas should have an objective foundation in ecological criteria prior to balancing a suite of trade-offs and conflicting priorities arising from social, economic, political, cultural, and land-use legacies (Fig. 4). To achieve the stated Aichi Target 11 goals of reducing biodiversity loss and preserving biodiversity into the future, environmental science principles should be used to identify areas with the greatest potential to make a difference.

Based on five key principles, we identified regions with potential to both reduce biodiversity loss and preserve biodiversity into the future (Fig. 5). In particular, species within highly urbanized and developed portions of Canada are disproportionately threatened; we recommend that protected areas should be designed and prioritized relative to the land-use legacy within the region (Fig. 5(b)). We also identified locations that are low priority (viz. with low species at risk, high representativity, degraded ecosystems, and low connectivity potential), which would not substantially contribute to reducing the rate of biodiversity loss; Canada should avoid protecting such areas without providing a scientifically grounded justification. Biodiversity priorities are based on a number of factors and all levels of government should be transparent and explicit about using biodiversity priorities in systematic conservation planning. This spatially explicit mapping of key principles for biodiversity conservation is a step toward identifying protected areas based on ecological principles and evidence as Canada strives to achieve Target 1.

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Author contributions

LEC, ALJ, RS, and SPO conceived and designed the study. LEC and RS performed the experiments/collected the data. LEC analyzed and interpreted the data. LEC, ALJ, RS, SPO, NEB, NJB, SJB, CD, BF, AF, LN, DO, WJP, JLP, DSS, OV, and SW contributed resources. LEC, ALJ, RS, SPO, NEB, NJB, SJB, CD, BF, AF, LN, DO, WJP, JLP, DSS, OV, and SW drafted or revised the manuscript.

Competing interests

BF is currently serving as a Subject Editor for FACETS, but was not involved in review or editorial decisions regarding this manuscript.

Data accessibility statement

All relevant data are within the paper, the Supplementary Material, and the underlying spatial data are available through Environment and Climate Change Canada, NatureServe, Global Forest Watch, Canadian Council on Ecological Areas—Conservation Areas Reporting and Tracking System, Natural Resources Canada, Canadian Soil Information Service—National Ecological Framework, and the Socioeconomic Data and Applications Center (refer to the references section for details).

Supplementary Materials

The following Supplementary Material is available with the article through the journal website at doi:[10.1139/facets-2017-0102](https://doi.org/10.1139/facets-2017-0102).

Supplementary Material 1

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