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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 km^2) of terrestrial and freshwater areas by 2020. As of June 2017, 10.6% (1.05 million km^2) 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 important[1] (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

[1] 64% very, 33% somewhat (Ipsos Reid 2012)

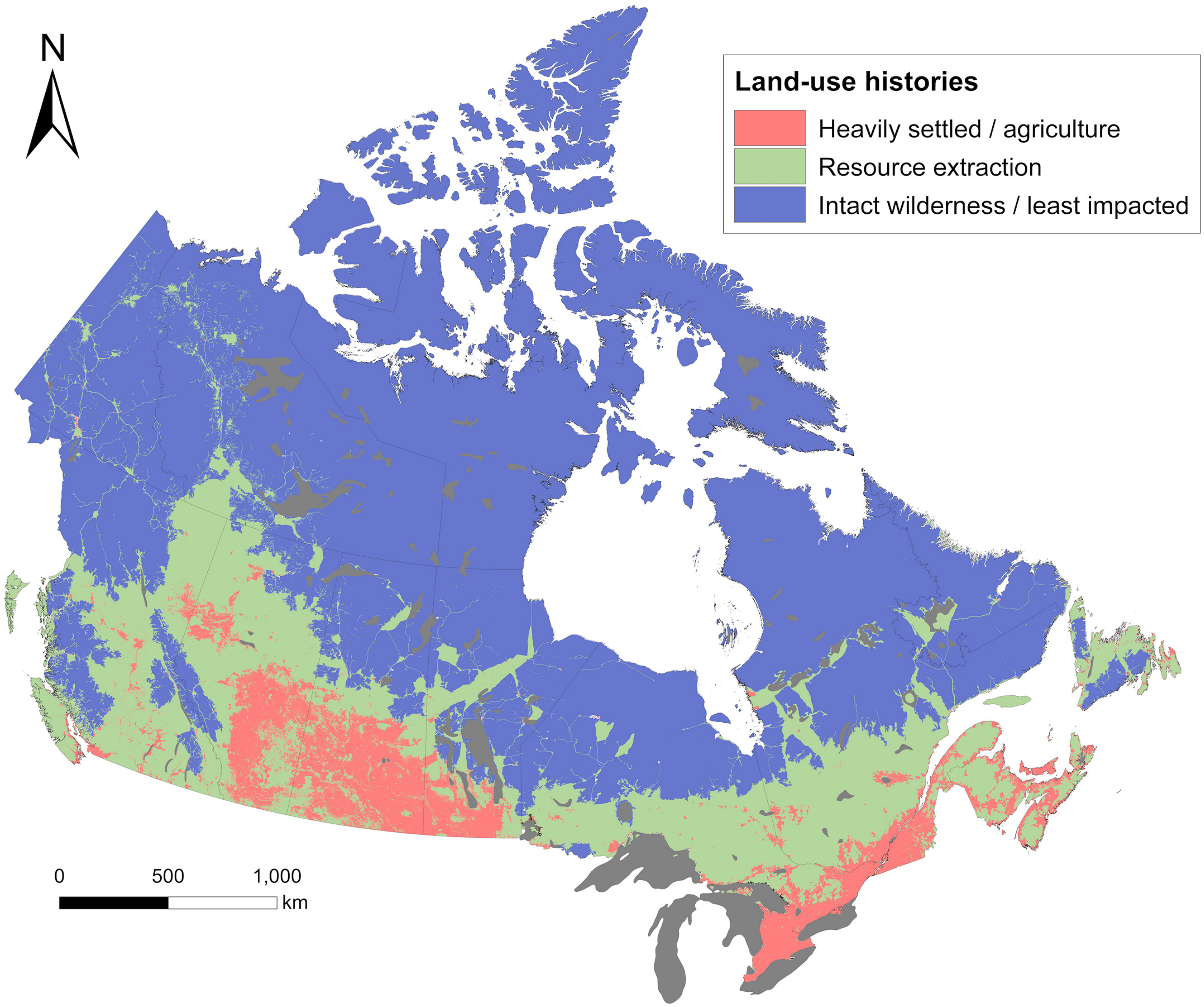

Fig. 1. Current and historic land-use legacies in Canada. See **Supplement S1** for data sources. Differing land-use legacies represent distinct conservation challenges for biodiversity (Locke 2017).

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; Coristine 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

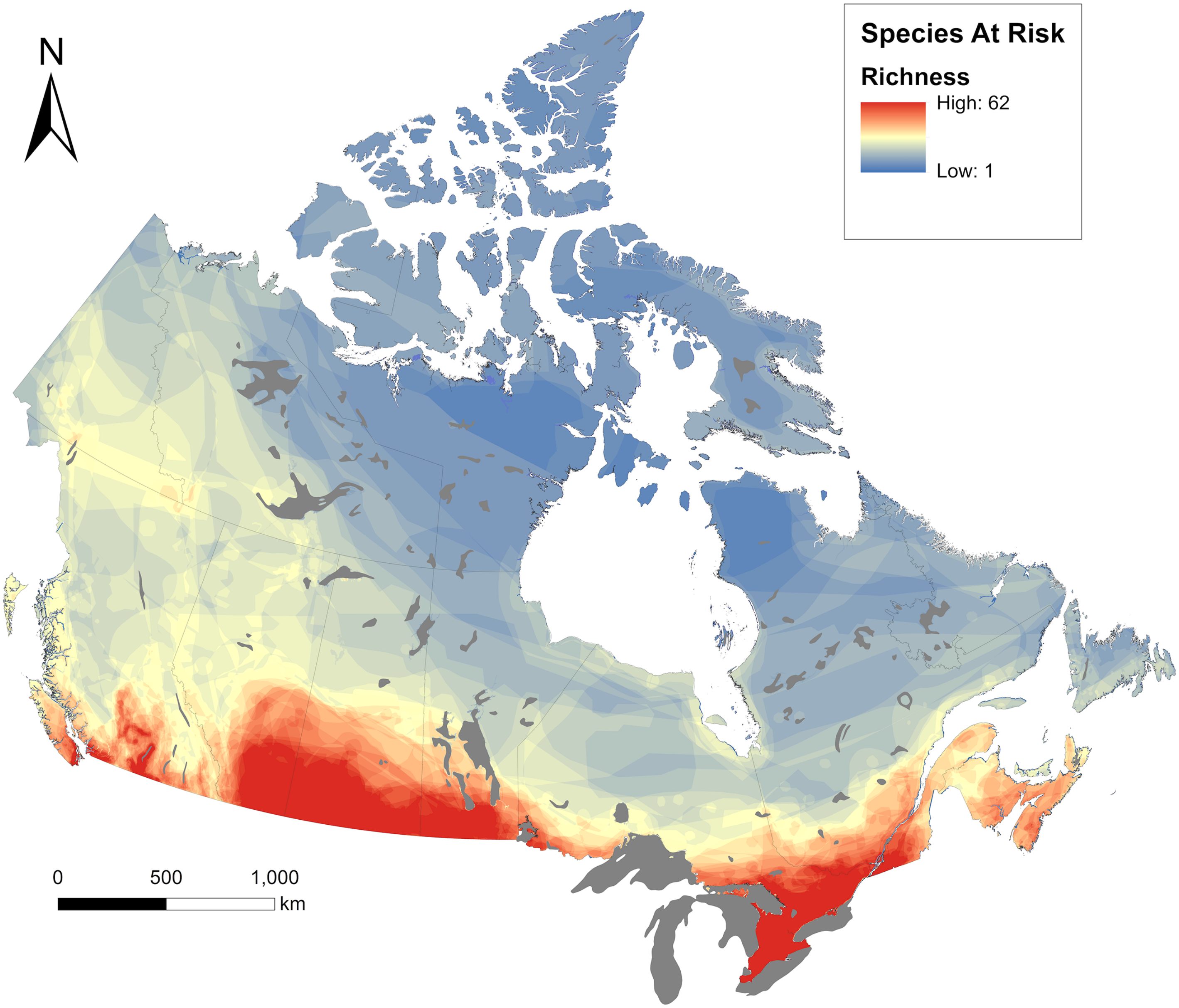

Fig. 2. Range overlap of species at risk within Canada (data from ECCC 2016c). Southern Canada, with the greatest numbers of species at risk, coincides with the most developed areas.

(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 km^2) 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

[a]ECCC, SARA database.
[b]ccea.org/download-carts-data/.
[c]NEFC (1996).
[d]Center for International Earth Science Information Network (CIESIN)—Columbia University (2016).
[e]Global Forest Watch Canada (2014, 2016).
[f]European Space Agency Climate Change Initiative (2017).
[g]y2y.net/.
[h]programs.wcs.org/2c1forest/.
[i]a2acollaborative.org/.
[j]borealbirds.org/.
[k]CANVEC (2013).
[l]Coristine et al. 2016; derived from climate data at cfs.nrcan.gc.ca/projects/3/4 (including McKenney et al. 2011).

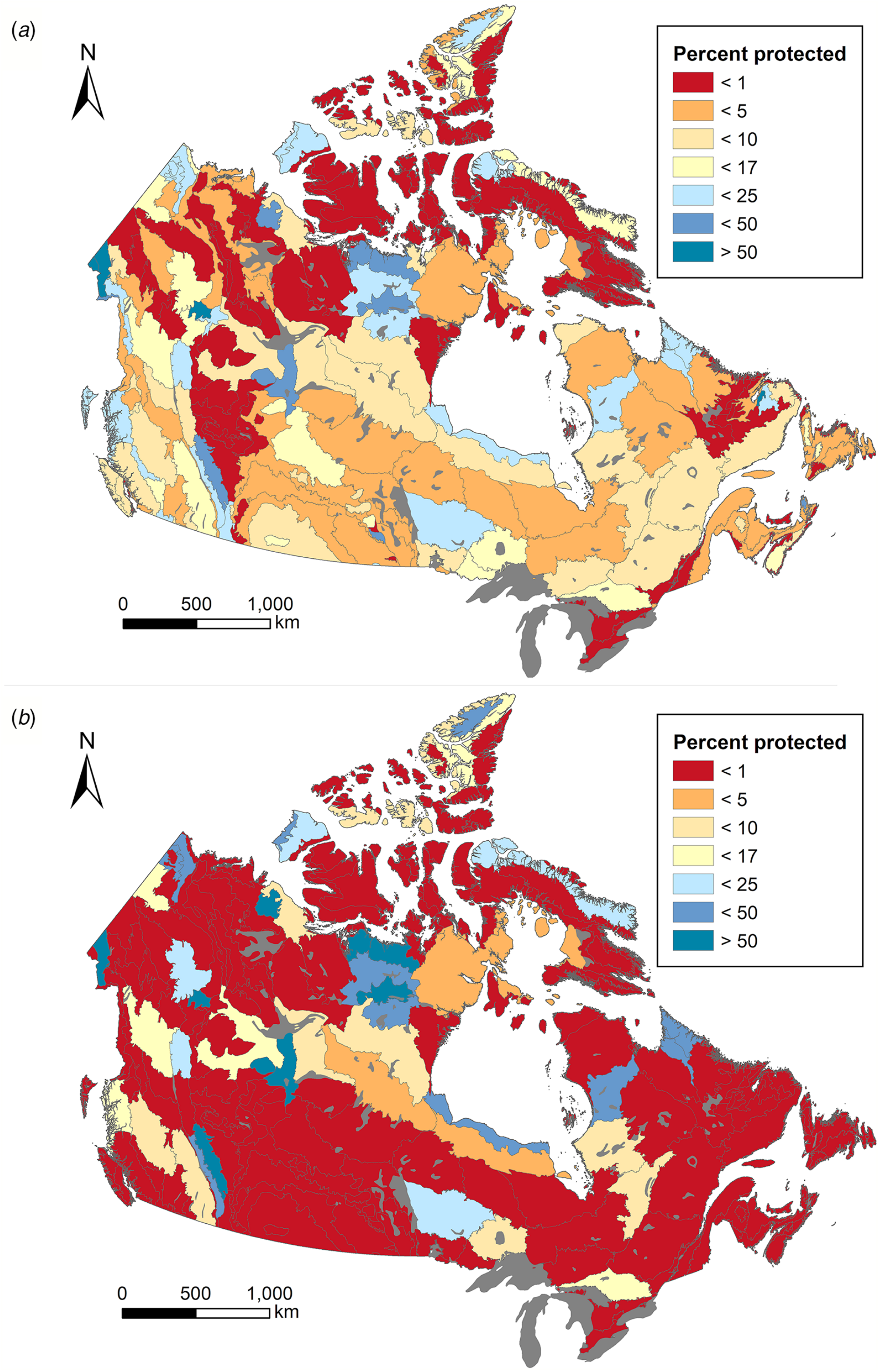

Fig. 3. The current extent of protection within each of Canada's 194 terrestrial ecoregions. Percent of each ecoregion that (*a*) is protected and (*b*) contains protected areas >5000 km^2 (CCEA 2016). Ecoregions are based on the National Ecological Framework for Canada (NEFC 1996; ESWG 1995).

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 km^2 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 km^2 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 km^2 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 Experts[2].

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

[2] conservation2020canada.ca/ice/

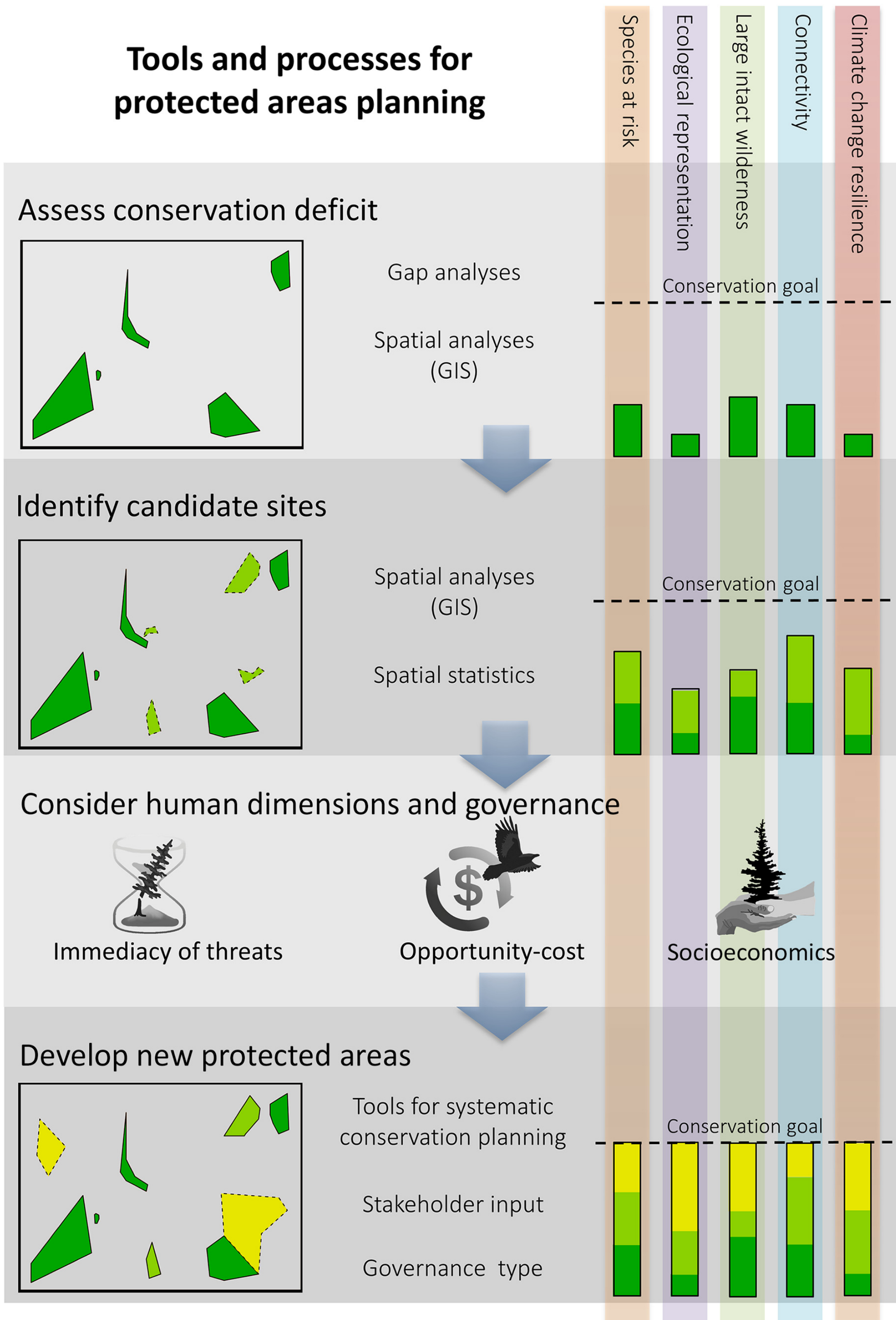

Fig. 4. Description of scientific tools and processes for systematic conservation decision-making. The columns on the right indicate hypothetical progress towards conservation goals according to the five conservation principles. Governance, economic, social, and cultural values, as well as immediacy 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 (ccea.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

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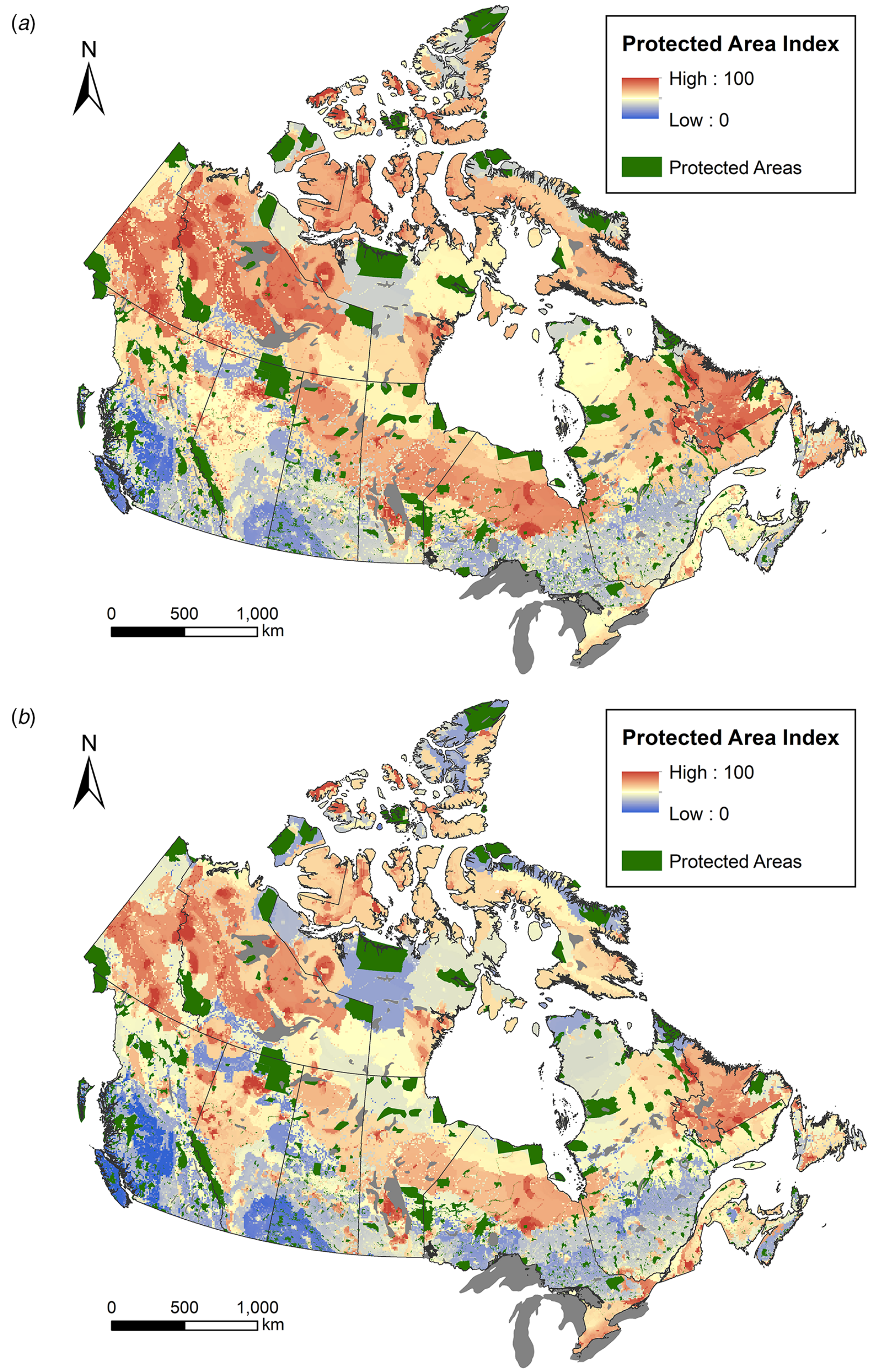

Fig. 5. Hotspots for candidate Canadian protected areas based on scientific ecological principles of (*i*) species at risk, (*ii*) current representativeness within ecoregions, (*iii*) wilderness, (*iv*) connectivity, and (*v*) climate change resilience. Maps are (*a*) based on equal weighting of principles 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 km^2, 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.

Supplementary Material 1

References

Adams VM, Álvarez-Romero JG, Carwardine J, Cattarino L, Hermoso V, Kennard MJ, et al. 2014. Planning across freshwater and terrestrial realms: cobenefits and tradeoffs between conservation actions. Conservation Letters, 7: 425–440. DOI: 10.1111/conl.12080

Aitken SN, Yeaman S, Holliday JA, Wang T, and Curtis-McLane S. 2008. Adaptation, migration or extirpation: climate change outcomes for tree populations. Evolutionary Applications, 1: 95–111. PMID: 25567494 DOI: 10.1111/j.1752-4571.2007.00013.x

Badiou P, Baldwin R, Carlson M, Darveau M, Drapeau P, Gaston K, et al. 2013. Conserving the world's last great forest is possible: here's how. International Boreal Conservation Science Panel: briefing note.

Bala G, Caldeira K, Wickett M, Phillips TJ, Lobell DB, Delire C, et al. 2007. Combined climate and carbon-cycle effects of large-scale deforestation. Proceedings of the National Academy of Sciences of the USA, 104: 6550–6555. PMID: 17420463 DOI: 10.1073/pnas.0608998104

Barnosky AD, Matzke N, Tomiya S, Wogan GOU, Swartz B, Quental TB, et al. 2011. Has the Earth's sixth mass extinction already arrived? Nature, 471: 51–57. PMID: 21368823 DOI: 10.1038/nature09678

Bayne EM, Habib L, and Boutin S. 2008. Impacts of chronic anthropogenic noise from energy-sector activity on abundance of songbirds in the boreal forest. Conservation Biology, 22: 1186–1193. PMID: 18616740 DOI: 10.1111/j.1523-1739.2008.00973.x

Beier P, and Brost B. 2010. Use of land facets to plan for climate change: conserving the arenas, not the actors. Conservation Biology, 24: 701–710. PMID: 20067491 DOI: 10.1111/j.1523-1739.2009.01422.x

Belote RT, Dietz MS, McRae BH, Theobald DM, McClure ML, Irwin GH, et al. 2016. Identifying corridors among large protected areas in the United States. PLoS ONE, 11: e0154223. PMID: 27104683 DOI: 10.1371/journal.pone.0154223

Belote RT, Dietz MS, Jenkins CN, McKinley PS, Irwin GH, Fullman TJ, et al. 2017. Wild, connected, and diverse: building a more resilient system of protected areas. Ecological Applications, 27: 1050–1056. PMID: 28263450 DOI: 10.1002/eap.1527

Benayas JMR, Newton AC, Diaz A, and Bullock JM. 2009. Enhancement of biodiversity and ecosystem services by ecological restoration: a meta-analysis. Science, 325: 1121–1124. DOI: 10.1126/science.1172460

Bennett NJ, and Dearden P. 2014. From measuring outcomes to providing inputs: governance, management, and local development for more effective marine protected areas. Marine Policy, 50: 96–110. DOI: 10.1016/j.marpol.2014.05.005

Bennett NJ, Roth R, Klain SC, Chan KMA, Christie P, Clark DA, et al. 2017. Conservation social science: Understanding and integrating human dimensions to improve conservation. Biological Conservation, 205: 93–108. DOI: 10.1016/j.biocon.2016.10.006

Bird SC, and Hodges KE. 2017. Critical habitat designation for Canadian listed species: slow, biased, and incomplete. Environmental Science & Policy, 71: 1–8. DOI: 10.1016/j.envsci.2017.01.007

Bolger DT, Patten MA, and Bostock DC. 2005. Avian reproductive failure in response to an extreme climatic event. Oecologia, 142: 398–406. PMID: 15549403 DOI: 10.1007/s00442-004-1734-9

Bonan GB. 2008. Forests and climate change: forcings, feedbacks, and the climate benefits of forests. Science, 320: 1444–1449. PMID: 18556546 DOI: 10.1126/science.1155121

Borrini-Feyerabend G, Dudley N, Jaeger T, Lassen B, Pathak Broome N, Philips A, et al. 2013. Governance of protected areas: from understanding to action, Best Practice Protected Area Guideline Series. IUCN, Gland, Switzerland.

Bottrill M, and Pressey R. 2012. The effectiveness and evaluation of conservation planning. Conservation Letters, 5: 407–420. DOI: 10.1111/j.1755-263X.2012.00268.x

Brandt JP. 2009. The extent of the North American boreal zone. Environmental Reviews, 17: 101–161. DOI: 10.1139/A09-004

Brooks JS, Waylen KA, and Mulder MB. 2012. How national context, project design, and local community characteristics influence success in community-based conservation projects. Proceedings of the National Academy of Sciences of the USA, 109: 21265–21270. DOI: 10.1073/pnas.1207141110

Brooks TM, Mittermeier RA, da Fonseca GA, Gerlach J, Hoffmann M, Lamoreux JF, et al. 2006. Global biodiversity conservation priorities. Science, 313: 58–61. PMID: 16825561 DOI: 10.1126/science.1127609

Brown R, and Harris G. 2005. Comanagement of wildlife corridors: the case for citizen participation in the Algonquin to Adirondack proposal. Journal of Environmental Management, 74: 97–106. PMID: 15627463 DOI: 10.1016/j.jenvman.2004.08.005

Bush A, Sollmann R, Wilting A, Bohmann K, Cole B, Balzter H, et al. 2017. Connecting Earth observation to high-throughput biodiversity data. Nature Ecology & Evolution, 1: 0176. DOI: 10.1038/s41559-017-0176

Butchart SH, Walpole M, Collen B, Van Strien A, Scharlemann JP, Almond RE, et al. 2010. Global biodiversity: indicators of recent declines. Science, 328: 1164–1168. PMID: 20430971 DOI: 10.1126/science.1187512

Canadian Council on Ecological Areas. 2016. Conservation Areas Reporting and Tracking System (CARTS) data [online]: Available from ccea.org/download-carts-data/, for the Quebec portions of the dataset we requested data directly from Registre des aires protégées au Québec.

Cannings S, Anions M, Rainer R, and Stein B. 2005. Our home and native land: Canadian species of global conservation concern. NatureServe Canada, Ottawa, Ontario.

CANVEC. 2013. CANVEC 15 Meter hydro features of Canada. A joint initiative from the national topographic data base, the mapping the north process conducted by the Canada Center for Mapping and Earth Observation, the Atlas of Canada, and the GeoBase initiative [online]: Available from ftp.maps.canada.ca/pub/nrcan_rncan/vector/canvec/shp/Hydro/.

Carpenter SR, Mooney HA, Agard J, Capistrano D, DeFries RS, Díaz S, et al. 2009. Science for managing ecosystem services: beyond the Millennium Ecosystem Assessment. Proceedings of the National Academy of Sciences of the USA, 106: 1305–1312. DOI: 10.1073/pnas.0808772106

Carroll C, Noss RF, Paquet PC, and Schumaker NH. 2003. Use of population viability analysis and reserve selection algorithms in regional conservation plans. Ecological Applications, 13: 1773–1789. DOI: 10.1890/02-5195

Ceballos G, Ehrlich PR, Barnosky AD, García A, Pringle RM, and Palmer TM. 2015. Accelerated modern human-induced species losses: entering the sixth mass extinction. Science Advances, 1: e1400253. PMID: 26601195 DOI: 10.1126/sciadv.1400253

Ceballos G, Ehrlich PR, and Dirzo R. 2017. Biological annihilation via the ongoing sixth mass extinction signaled by vertebrate population losses and declines. Proceedings of the National Academy of Sciences of the USA, 114(30): E6089–E6096. PMID: 28696295 DOI: 10.1073/pnas.1704949114

Center for International Earth Science Information Network (CIESIN)—Columbia University. 2016. Gridded Population of the World, Version 4 (GPWv4): population density. NASA Socioeconomic Data and Applications Center (SEDAC), Palisades, New York. DOI: 10.7927/H4NP22DQ

Chape S, Harrison J, Spalding M, and Lysenko I. 2005. Measuring the extent and effectiveness of protected areas as an indicator for meeting global biodiversity targets. Philosophical Transactions of the Royal Society B: Biological Sciences, 360: 443–455. PMID: 15814356 DOI: 10.1098/rstb.2004.1592

Charnley S, Carothers C, Satterfield T, Levine A, Poe MR, Norman K, et al. 2017. Evaluating the best available social science for natural resource management decision-making. Environmental Science & Policy, 73: 80–88. DOI: 10.1016/j.envsci.2017.04.002

Chessman BC. 2013. Do protected areas benefit freshwater species? A broad-scale assessment for fish in Australia's Murray–Darling Basin. Journal of Applied Ecology, 50: 969–976. DOI: 10.1111/1365-2664.12104

Chester CC, Hilty JA, and Francis WL. 2012. Yellowstone to Yukon, North America. *In* Climate and conservation. *Edited by* JA Hilty, CC Chester, and MS Cross. Island Press, Washington, DC. pp. 240–252.

Chilibeck B, Chislett G, and Norris G. 1992. Land development guidelines for the protection of aquatic habitat. Copublished by Ministry of Environment, Lands and Parks and Department of Fisheries and Oceans, British Columbia.

Chu C, Minns CK, and Mandrak NE. 2003. Comparative regional assessment of factors impacting freshwater fish biodiversity in Canada. Canadian Journal of Fisheries and Aquatic Sciences, 60: 624–634. DOI: 10.1139/f03-048

Chu C, Minns CK, Lester NP, and Mandrak NE. 2014. An updated assessment of human activities, the environment, and freshwater fish biodiversity in Canada. Canadian Journal of Fisheries and Aquatic Sciences, 72: 135–148. DOI: 10.1139/cjfas-2013-0609

Coristine LE, and Kerr JT. 2011. Habitat loss, climate change, and emerging conservation challenges in Canada. Canadian Journal of Zoology, 89: 435–451. DOI: 10.1139/z11-023

Coristine LE, and Kerr JT. 2015. Temperature-related geographical shifts among passerines: contrasting processes along poleward and equatorward range margins. Ecology & Evolution, 5(22): 5162–5176. DOI: 10.1002/ece3.1683

Coristine LE, Soares RN, Soroye P, Robillard C, and Kerr JT. 2016. Dispersal limitation, climate change, and practical tools for butterfly conservation in intensively used landscapes. Natural Areas Journal, 36: 440–452. DOI: 10.3375/043.036.0410

Crooks KR. 2002. Relative sensitivities of mammalian carnivores to habitat fragmentation. Conservation Biology, 16(2): 488–502. DOI: 10.1046/j.1523-1739.2002.00386.x

Crooks KR, Burdett CL, Theobald DM, King SR, Di Marco M, Rondinini C, et al. 2017. Quantification of habitat fragmentation reveals extinction risk in terrestrial mammals. Proceedings of the National Academy of Sciences of the USA, 114(29): 7635–7640. PMID: 28673992 DOI: 10.1073/pnas.1705769114

Davies GM, Gray A, Rein G, and Legg CJ. 2013. Peat consumption and carbon loss due to smouldering wildfire in a temperate peatland. Forest Ecology and Management, 308: 169–177. DOI: 10.1016/j.foreco.2013.07.051

Dearden P, and Rollins R (Eds.). 2016. Parks and protected areas in Canada: planning and management. 4th edition. Oxford University Press, Oxford, UK.

Deblauwe V, Droissart V, Bose R, Sonké B, Blach-Overgaard A, Svenning JC, et al. 2016. Remotely sensed temperature and precipitation data improve species distribution modelling in the tropics. Global Ecology and Biogeography, 25: 443–454. DOI: 10.1111/geb.12426

de Groot RS, Wilson MA, and Boumans RM. 2002. A typology for the classification, description and valuation of ecosystem functions, goods and services. Ecological Economics, 41: 393–408. DOI: 10.1016/S0921-8009(02)00089-7

de Groot WJ, Flannigan MD, and Cantin AS. 2013. Climate change impacts on future boreal fire regimes. Forest Ecology and Management, 294: 35–44. DOI: 10.1016/j.foreco.2012.09.027

De Vos JM, Joppa LN, Gittleman JL, Stephens PR, and Pimm SL. 2015. Estimating the normal background rate of species extinction. Conservation Biology, 29: 452–462. PMID: 25159086 DOI: 10.1111/cobi.12380

Didham RK, Tylianakis JM, Hutchison MA, Ewers RM, and Gemmell NJ. 2005. Are invasive species the drivers of ecological change? Trends in Ecology & Evolution, 20: 470–474. PMID: 16701420 DOI: 10.1016/j.tree.2005.07.006

Di Minin E, Slotow R, Hunter LT, Pouzols FM, Toivonen T, Verburg PH, et al. 2016. Global priorities for national carnivore conservation under land use change. Scientific Reports, 6: 23814. PMID: 27034197 DOI: 10.1038/srep23814

Dinerstein E, Olson D, Joshi A, Vynne C, Burgess ND, Wikramanayake E, et al. 2017. An ecoregion-based approach to protecting half the terrestrial realm. Bioscience, 67: 534–545. PMID: 28608869 DOI: 10.1093/biosci/bix014

Dornelas M, Gotelli NJ, McGill B, Shimadzu H, Moyes F, Sievers C, et al. 2014. Assemblage time series reveal biodiversity change but not systematic loss. Science, 344(6181): 296–299. PMID: 24744374 DOI: 10.1126/science.1248484

Dosskey MG, Vidon P, Gurwick NP, Allan CJ, Duval TP, and Lowrance R. 2010. The role of riparian vegetation in protecting and improving chemical water quality in streams. JAWRA Journal of the American Water Resources Association, 46: 261–277. DOI: 10.1111/j.1752-1688.2010.00419.x

Dudley N (Ed.). 2008. Guidelines for applying protected area management categories. IUCN, Gland, Switzerland. 86 p.

Durkalec A, Furgal C, Skinner MW, and Sheldon T. 2015. Climate change influences on environment as a determinant of Indigenous health: relationships to place, sea ice, and health in an Inuit community. Social Science & Medicine, 136: 17–26. PMID: 25974138 DOI: 10.1016/j.socscimed.2015.04.026

Ecological Stratification Working Group (ESWG). 1995. A national ecological framework for Canada. Agriculture and Agri-Food Canada, Research Branch, Centre for Land and Biological Resources Research and Environment Canada, State of the Environment Directorate, Ecozone Analysis Branch, Hull, Ottawa.

Ekroos J, Olsson O, Rundlöf M, Wätzold F, and Smith HG. 2014. Optimizing agri-environment schemes for biodiversity, ecosystem services or both? Biological Conservation, 172: 65–71. DOI: 10.1016/j.biocon.2014.02.013

Ellis EC, and Ramankutty N. 2008. Putting people in the map: anthropogenic biomes of the world. Frontiers in Ecology and the Environment, 6: 439–447. DOI: 10.1890/070062

Ellis EC, Klein Goldewijk K, Siebert S, Lightman D, and Ramankutty N. 2010. Anthropogenic transformation of the biomes, 1700 to 2000. Global Ecology and Biogeography, 19: 589–606. DOI: 10.1111/j.1466-8238.2010.00540.x

Environment and Climate Change Canada (ECCC). 2016a. 2020 Biodiversity goals and targets for Canada [online]: Available from publications.gc.ca/collections/collection_2016/eccc/CW66-524-2016-eng.pdf.

Environment and Climate Change Canada (ECCC). 2016b. Canadian protected areas status report 2012–2015. 129 p.

Environment and Climate Change Canada (ECCC). 2016c. Species at Risk range dataset for species that are either an ECCC responsibility or a joint Parks Canada—ECCC responsibility, and that were SARA Schedule 1 listed as of March 28th 2013. SARA Management and Regulatory Affairs.

Environment and Climate Change Canada (ECCC). 2017. Species at risk listed on Schedule 1 of SARA [online]: Available from sararegistry.gc.ca/species/schedules_e.cfm?id=1.

Environment Canada. 2013. How much habitat is enough? 3rd edition. Environment Canada, Toronto, Ontario. [online]: Available from ec.gc.ca/nature/default.asp?lang=En&n=E33B007C-1.

European Space Agency Climate Change Initiative. 2017. Land cover project 2014–2017. Land Cover map 2015 [online]: Available from maps.elie.ucl.ac.be/CCI/viewer/download.php.

Fahrig L. 2003. Effects of habitat fragmentation on biodiversity. Annual Review of Ecology, Evolution, and Systematics, 34: 487–515. DOI: 10.1146/annurev.ecolsys.34.011802.132419

Favaro B, Claar DC, Fox CH, Freshwater C, Holden JJ, and Roberts A. 2014. Trends in extinction risk for imperiled species in Canada. PLoS ONE, 9: e113118. PMID: 25401772 DOI: 10.1371/journal.pone.0113118

Fernandes L, Day JON, Lewis A, Slegers S, Kerrigan B, Breen DAN, et al. 2005. Establishing representative no-take areas in the Great Barrier Reef: large-scale implementation of theory on marine protected areas. Conservation Biology, 19(6): 1733–1744. DOI: 10.1111/j.1523-1739.2005.00302.x

Ferraz G, Russell GJ, Stouffer PC, Bierregaard RO, Pimm SL, and Lovejoy TE. 2003. Rates of species loss from Amazonian forest fragments. Proceedings of the National Academy of Sciences of the USA, 100: 14069–14073. DOI: 10.1073/pnas.2336195100

Foden WB, Butchart SH, Stuart SN, Vié J-C, Akçakaya HR, Angulo A, et al. 2013. Identifying the world's most climate change vulnerable species: a systematic trait-based assessment of all birds, amphibians and corals. PLoS ONE, 8: e65427. PMID: 23950785 DOI: 10.1371/journal.pone.0065427

Foley JA, DeFries R, Asner GP, Barford C, Bonan G, Carpenter SR, et al. 2005. Global consequences of land use. Science, 309: 570–574. PMID: 16040698 DOI: 10.1126/science.1111772

Foster D, Swanson F, Aber J, Burke I, Brokaw N, Tilman D, et al. 2003. The importance of land-use legacies to ecology and conservation. BioScience, 53: 77–88. DOI: 10.1641/0006-3568(2003)053[0077:TIOLUL]2.0.CO;2

Foster E, Love J, Rader R, Reid N, and Drielsma MJ. 2017. Integrating a generic focal species, metapopulation capacity, and connectivity to identify opportunities to link fragmented habitat. Landscape Ecology, 32: 1837–1847. DOI: 10.1007/s10980-017-0547-2

Fraser ED, Dougill AJ, Mabee WE, Reed M, and McAlpine P. 2006. Bottom up and top down: analysis of participatory processes for sustainability indicator identification as a pathway to community empowerment and sustainable environmental management. Journal of Environmental Management, 78: 114–127. PMID: 16095806 DOI: 10.1016/j.jenvman.2005.04.009

Game ET, Kareiva P, and Possingham HP. 2013. Six common mistakes in conservation priority setting. Conservation Biology, 27: 480–485. PMID: 23565990 DOI: 10.1111/cobi.12051

Geldmann J, Coad L, Barnes M, Craigie ID, Hockings M, Knights K, et al. 2015. Changes in protected area management effectiveness over time: a global analysis. Biological Conservation, 191: 692–699. DOI: 10.1016/j.biocon.2015.08.029

Gibson SY, Van der Marel RC, and Starzomski BM. 2009. Climate change and conservation of leading-edge peripheral populations. Conservation Biology, 23: 1369–1373. PMID: 20078636 DOI: 10.1111/j.1523-1739.2009.01375.x

Gibson L, Lynam AJ, Bradshaw CJA, He F, Bickford DP, Woodruff DS, et al. 2013. Near-complete extinction of native small mammal fauna 25 years after forest fragmentation. Science, 341(6153): 1508–1510. DOI: 10.1126/science.1240495

Gill AM, Stephens SL, and Cary GJ. 2013. The worldwide "wildfire" problem. Ecological Applications, 23: 438–454. PMID: 23634593 DOI: 10.1890/10-2213.1

Gjertsen H, and Barrett CB. 2004. Context-dependent biodiversity conservation management regimes: theory and simulation. Land Economics, 80: 321–339. DOI: 10.2307/3654724

Global Forest Watch Canada. 2014. Canada Access 2010 [online]: Available from data.globalforestwatch.org/.

Global Forest Watch Canada. 2016. Canada's Intact Forest Landscapes 2013 Dataset [online]: Available from data.globalforestwatch.org/.

Gonzalez-Suarez M, and Revilla E. 2014. Generalized drivers in the mammalian endangerment process. PLoS ONE, 9: e90292. PMID: 24587315 DOI: 10.1371/journal.pone.0090292

Government of Canada. 2017. Press release: Federal and Provincial Governments Create National Advisory Panel on Canada's biodiversity conservation initiative [online]: Available from canada.ca/en/parks-canada/news/2017/06/federal_and_provincialgovernmentscreatenationaladvisorypanelonca.html.

Grantham TE, Fesenmyer KA, Peek R, Holmes E, Quiñones RM, Bell A, et al. 2017. Missing the boat on freshwater fish conservation in California. Conservation Letters, 10: 77–85. DOI: 10.1111/conl.12249

Groves CR, Jensen DB, Valutis LL, Redford KH, Shaffer ML, Scott JM, et al. 2002. Planning for biodiversity conservation: putting conservation science into practice: a seven-step framework for developing regional plans to conserve biological diversity, based upon principles of conservation biology and ecology, is being used extensively by the nature conservancy to identify priority areas for conservation. BioScience, 52: 499–512. DOI: 10.1641/0006-3568(2002)052[0499:PFBCPC]2.0.CO;2

Gurd DB, Nudds TD, and Rivard DH. 2001. Conservation of mammals in eastern North American wildlife reserves: how small is too small? Conservation Biology, 15: 1355–1363. DOI: 10.1111/j.1523-1739.2001.00188.x

Haddad NM, Brudvig LA, Clobert J, Davies KF, Gonzalez A, Holt RD, et al. 2015. Habitat fragmentation and its lasting impact on Earth's ecosystems. Science Advances, 1: e1500052. PMID: 26601154 DOI: 10.1126/sciadv.1500052

Hannah L, Midgley G, Andelman S, Araújo M, Hughes G, Martinez-Meyer E, et al. 2007. Protected area needs in a changing climate. Frontiers in Ecology and the Environment, 5: 131–138. DOI: 10.1890/1540-9295(2007)5[131:PANIAC]2.0.CO;2

Hauer FR, Locke H, Dreitz VJ, Hebblewhite M, Lowe WH, Muhlfeld CC, et al. 2016. Gravel-bed river floodplains are the ecological nexus of glaciated mountain landscapes. Science Advances, 2: e1600026. PMID: 27386570 DOI: 10.1126/sciadv.1600026

Hebblewhite M. 2017. Billion dollar boreal woodland caribou and the biodiversity impacts of the global oil and gas industry. Biological Conservation, 206: 102–111. DOI: 10.1016/j.biocon.2016.12.014

Hilty JA, and Merenlender AM. 2004. Use of riparian corridors and vineyards by mammalian predators in northern California. Conservation Biology, 18: 126–135. DOI: 10.1111/j.1523-1739.2004.00225.x

Hockings M, Stolton S, Leverington F, Dudley N, and Courrau J. 2006. Evaluating effectiveness: a framework for assessing the management effectiveness of protected areas. 2nd edition. IUCN, Gland, Switzerland.

International Union for Conservation of Nature (IUCN). 2016. A global standard for the identification of key biodiversity areas, version 1.0. 1st edition. IUCN, Gland, Switzerland.

Ipsos Reid. 2012. Three in five Canadians (62%) say the federal government is doing too little to protect species at risk. News release, December 13, 2012 [online]: Available from ipsos-na.com/news-polls/pressrelease.aspx?id=5926.

Iwamura T, Wilson KA, Venter O, and Possingham HP. 2010. A climatic stability approach to prioritizing global conservation investments. PLoS ONE, 5: e15103. DOI: 10.1371/journal.pone.0015103

Jennings MD. 2000. Gap analysis: concepts, methods, and recent results. Landscape Ecology, 15: 5–20. DOI: 10.1023/A:1008184408300

Joppa LN, and Pfaff A. 2009. High and far: biases in the location of protected areas. PLoS ONE, 4: e8273. DOI: 10.1371/journal.pone.0008273

Kaplan-Hallam M, and Bennett NJ. 2017. Adaptive social impact management for conservation and environmental management. Conservation Biology, 32(2): 304–314.

Kasischke ES, and Turetsky MR. 2006. Recent changes in the fire regime across the North American boreal region—spatial and temporal patterns of burning across Canada and Alaska. Geophysical Research Letters, 33: L09703. DOI: 10.1029/2006GL025677

Kelly EN, Short JW, Schindler DW, Hodson PV, Ma M, Kwan AK, et al. 2009. Oil sands development contributes polycyclic aromatic compounds to the Athabasca River and its tributaries. Proceedings of the National Academy of Sciences of the USA, 106: 22346–22351. PMID: 19995964 DOI: 10.1073/pnas.0912050106

Kerr JT, and Cihlar J. 2004. Patterns and causes of species endangerment in Canada. Ecological Applications, 14: 743–753. DOI: 10.1890/02-5117

Kerr JT, and Deguise I. 2004. Habitat loss and the limits to endangered species recovery. Ecology Letters, 7: 1163–1169. DOI: 10.1111/j.1461-0248.2004.00676.x

Kremen C, Cameron A, Moilanen A, Phillips S, Thomas C, Beentje H, et al. 2008. Aligning conservation priorities across taxa in Madagascar with high-resolution planning tools. Science, 320: 222–226. PMID: 18403708 DOI: 10.1126/science.1155193

Kreutzweiser D, Beall F, Webster K, Thompson D, and Creed I. 2013. Impacts and prognosis of natural resource development on aquatic biodiversity in Canada's boreal zone 1. Environmental Reviews, 21: 227–259. DOI: 10.1139/er-2013-0044

Kujala H, Burgman MA, and Moilanen A. 2013. Treatment of uncertainty in conservation under climate change. Conservation Letters, 6: 73–85. DOI: 10.1111/j.1755-263X.2012.00299.x

Leroux SJ, Schmiegelow FK, Lessard RB, and Cumming SG. 2007. Minimum dynamic reserves: a framework for determining reserve size in ecosystems structured by large disturbances. Biological Conservation, 138: 464–473. DOI: 10.1016/j.biocon.2007.05.012

Le Saout S, Hoffmann M, Shi Y, Hughes A, Bernard C, Brooks TM, et al. 2013. Protected areas and effective biodiversity conservation. Science, 342: 803–805. PMID: 24233709 DOI: 10.1126/science.1239268

Locke H. 2015. Nature needs (at least) half: a necessary new Agenda for protected areas. *In* Protecting the wild. *Edited by* G Wuerthner, E Crist, and T Butler. Island Press, Washington, DC. pp. 3–15.

Locke H. 2017. Personal submission to Parks Canada Minister's Roundtable. 8 p.

Lockwood M. 2010. Good governance for terrestrial protected areas: a framework, principles and performance outcomes. Journal of Environmental Management, 91: 754–766. PMID: 19896262 DOI: 10.1016/j.jenvman.2009.10.005

Mangubhai S, Wilson JR, Rumetna L, and Maturbongs Y. 2015. Explicitly incorporating socioeconomic criteria and data into marine protected area zoning. Ocean & Coastal Management, 116: 523–529. DOI: 10.1016/j.ocecoaman.2015.08.018

Mantyka-Pringle CS, Martin TG, Moffatt DB, Udy J, Olley J, Saxton N, et al. 2016. Prioritizing management actions for the conservation of freshwater biodiversity under changing climate and land-cover. Biological Conservation, 197: 80–89. DOI: 10.1016/j.biocon.2016.02.033

Margules CR, and Pressey RL. 2000. Systematic conservation planning. Nature, 405: 243–253. PMID: 10821285 DOI: 10.1038/35012251

Margules CR, and Sarkar S. 2007. Systematic conservation planning. Cambridge University Press, Cambridge, UK.

Martin TG, and Watson JE. 2016. Intact ecosystems provide best defence against climate change. Nature Climate Change, 6: 122–124. DOI: 10.1038/nclimate2918

Martin TG, Camaclang AE, Possingham HP, Maguire LA, and Chadès I. 2017. Timing of protection of critical habitat matters. Conservation Letters, 10: 308–316. DOI: 10.1111/conl.12266

Mayor SJ, Guralnick RP, Tingley MW, Otegui J, Withey JC, Elmendorf SC, et al. 2017. Increasing phenological asynchrony between spring green-up and arrival of migratory birds. Scientific Reports, 7: 1902. DOI: 10.1038/s41598-017-02045-z

McCune JL, Harrower WL, Avery-Gomm S, Brogan JM, Csergő A-M, Davidson LN, et al. 2013. Threats to Canadian species at risk: an analysis of finalized recovery strategies. Biological Conservation, 166: 254–265. DOI: 10.1016/j.biocon.2013.07.006

McCune JL, Carlsson AM, Colla S, Davy C, Favaro B, Ford AT, et al. 2017. Assessing public commitment to endangered species protection: a Canadian case study. FACETS, 2: 178–194. DOI: 10.1139/facets-2016-0054

McGuire JL, Lawler JJ, MCrae BH, Nuñez TA, and Theobald DM. 2016. Achieving climate connectivity in a fragmented landscape. Proceedings of the National Academy of Sciences of the USA, 113(26): 7195–7200. DOI: 10.1073/pnas.1602817113

McKenna C. 2017. Letter to: Ms. Debrah Schulte, Chair of the Standing Committee on Environment and Sustainable Development. Minister of Environment and Climate Change Canada, Government of Canada, Ottawa, Ontario [online]: Available from ourcommons.ca/content/Committee/421/ENVI/GovResponse/RP9056718/421_ENVI_Rpt05_GR/421_ENVI_Rpt05_GR-e.pdf.

McKenney DW, Hutchinson MF, Papadopol P, Lawrence K, Pedlar J, Campbell K, et al. 2011. Customized spatial climate models for North America. Bulletin of the American Meteorological Society, 92: 1611–1622. DOI: 10.1175/2011BAMS3132.1

M'Gonigle LK, Ponisio LC, Cutler K, and Kremen C. 2015. Habitat restoration promotes pollinator persistence and colonization in intensively managed agriculture. Ecological Applications, 25: 1557–1565. DOI: 10.1890/14-1863.1

Mitchell MG, Bennett EM, and Gonzalez A. 2013. Linking landscape connectivity and ecosystem service provision: current knowledge and research gaps. Ecosystems, 16: 894–908. DOI: 10.1007/s10021-013-9647-2

Moilanen A, Wilson KA, and Possingham HP. 2009. Spatial conservation prioritization: quantitative methods and computational tools. Oxford University Press, Oxford, UK.

Mooers AO, Doak DF, Findlay CS, Green DM, Grouios C, Manne LL, et al. 2010. Science, policy, and species at risk in Canada. BioScience, 60: 843–849. DOI: 10.1525/bio.2010.60.10.11

Moritz C, and Agudo R. 2013. The future of species under climate change: resilience or decline? Science, 341: 504–508. PMID: 23908228 DOI: 10.1126/science.1237190

Murray G, and King L. 2012. First Nations values in protected area governance: Tla-o-qui-aht tribal parks and Pacific Rim National Park Reserve. Human Ecology, 40: 385–395. DOI: 10.1007/s10745-012-9495-2

Naidoo R, Balmford A, Ferraro PJ, Polasky S, Ricketts TH, and Rouget M. 2006. Integrating economic costs into conservation planning. Trends in Ecology & Evolution, 21: 681–687. PMID: 17050033 DOI: 10.1016/j.tree.2006.10.003

National Advisory Panel. 2017. Pathway to Canada Target 1 [online]: Available from conservation2020canada.ca/who-we-are#NAP.

National Ecological Framework for Canada (NEFC). 1996. Ecoregions of Canada 1996 [online]: Available from sis.agr.gc.ca/cansis/nsdb/ecostrat/gis_data.html.

Noss RF, Dobson AP, Baldwin R, Beier P, Davis CR, Dellasala DA, et al. 2012. Bolder thinking for conservation. Conservation Biology, 26: 1–4. PMID: 22280321 DOI: 10.1111/j.1523-1739.2011.01738.x

Oliver TH, Marshall HH, Morecroft MD, Brereton T, Prudhomme C, and Huntingford C. 2015. Interacting effects of climate change and habitat fragmentation on drought-sensitive butterflies. Nature Climate Change, 5: 941–945. DOI: 10.1038/nclimate2746

Olson DM, Dinerstein E, Wikramanayake ED, Burgess ND, Powell GV, Underwood EC, et al. 2001. Terrestrial Ecoregions of the World: A New Map of Life on Earth: a new global map of terrestrial ecoregions provides an innovative tool for conserving biodiversity. BioScience, 51: 933–938. DOI: 10.1641/0006-3568(2001)051[0933:TEOTWA]2.0.CO;2

Ovaskainen O, and Soininen J. 2011. Making more out of sparse data: hierarchical modeling of species communities. Ecology, 92: 289–295. PMID: 21618908 DOI: 10.1890/10-1251.1

Parks Canada. 2014. Evaluation of Parks Canada National Park Establishment and Expansion Sub-program. Office of Internal Audit and Evaluation.

Pereira HM, Leadley PW, Proenca V, Alkemade R, Scharlemann JPW, Fernandez-Manjarres JF, et al. 2010. Scenarios for global biodiversity in the 21st century. Science, 330: 1496–1501. PMID: 20978282 DOI: 10.1126/science.1196624

Polasky S, Nelson E, Lonsdorf E, Fackler P, and Starfield A. 2005. Conserving species in a working landscape: land use with biological and economic objectives. Ecological Applications, 15: 1387–1401. DOI: 10.1890/03-5423

Pollock LJ, Thuiller W, and Jetz W. 2017. Large conservation gains possible for global biodiversity facets. Nature, 546: 141–144. PMID: 28538726 DOI: 10.1038/nature22368

Potapov P, Hansen MC, Laestadius L, Turubanova S, Yaroshenko A, Thies C, et al. 2017. The last frontiers of wilderness: tracking loss of intact forest landscapes from 2000 to 2013. Science Advances, 3: e1600821. PMID: 28097216 DOI: 10.1126/sciadv.1600821

Pouzols FM, Toivonen T, Di Minin E, Kukkala AS, Kullberg P, Kuusterä J, et al. 2014. Global protected area expansion is compromised by projected land-use and parochialism. Nature, 516: 383–386. DOI: 10.1038/nature14032

Reed MG. 2016. Conservation (in)action: renewing the relevance of UNESCO biosphere reserves. Conservation Letters, 9: 448–456. DOI: 10.1111/conl.12275

Rees SE, Foster NL, Langmead O, Pittman S, and Johnson DE. 2017. Defining the qualitative elements of Aichi Biodiversity Target 11 with regard to the marine and coastal environment in order to strengthen global efforts for marine biodiversity conservation outlined in the United Nations Sustainable Development Goal 14. Marine Policy.

Robillard CM, Coristine LE, Soares RN, and Kerr JT. 2015. Facilitating climate-change induced range shifts across continental land use barriers. Conservation Biology, 29: 1586–1595. PMID: 26193759 DOI: 10.1111/cobi.12556

Rodrigues AS, Akcakaya HR, Andelman SJ, Bakarr MI, Boitani L, Brooks TM, et al. 2004a. Global gap analysis: priority regions for expanding the global protected-area network. BioScience, 54: 1092–1100. DOI: 10.1641/0006-3568(2004)054[1092:GGAPRF]2.0.CO;2

Rodrigues AS, Andelman SJ, Bakarr MI, Boitani L, Brooks TM, Cowling RM, et al. 2004b. Effectiveness of the global protected area network in representing species diversity. Nature, 428: 640–643. DOI: 10.1038/nature02422

Ruckelshaus M, McKenzie E, Tallis H, Guerry A, Daily G, Kareiva P, et al. 2015. Notes from the field: lessons learned from using ecosystem service approaches to inform real-world decisions. Ecological Economics, 115: 11–21. DOI: 10.1016/j.ecolecon.2013.07.009

Santini L, Cornulier T, Bullock JM, Palmer SC, White SM, Hodgson JA, et al. 2016. A trait-based approach for predicting species responses to environmental change from sparse data: how well might terrestrial mammals track climate change? Global Change Biology, 22: 2415–2424. PMID: 27073017 DOI: 10.1111/gcb.13271

Saunders D, Meeuwig J, and Vincent A. 2002. Freshwater protected areas: strategies for conservation. Conservation Biology, 16: 30–41. DOI: 10.1046/j.1523-1739.2002.99562.x

Saura S, Bodin Ö, and Fortin MJ. 2014. Stepping stones are crucial for species' long-distance dispersal and range expansion through habitat networks. Journal of Applied Ecology, 51: 171–182. DOI: 10.1111/1365-2664.12179

Saura S, Bastin L, Battistella L, Mandrici A, and Dubois G. 2017. Protected areas in the world's ecoregions: how well connected are they? Ecological Indicators, 76: 144–158. PMID: 28469529 DOI: 10.1016/j.ecolind.2016.12.047

Schindler D, and Lee P. 2010. Comprehensive conservation planning to protect biodiversity and ecosystem services in Canadian boreal regions under a warming climate and increasing exploitation. Biological Conservation, 143: 1571–1586. DOI: 10.1016/j.biocon.2010.04.003

Schuster R, Law EA, Rodewald AD, Martin TG, Wilson KA, Watts M, et al. 2017. Tax shifting and incentives for biodiversity conservation on private lands. Conservation Letters, 11(2): 1–7. DOI: 10.1111/conl.12377

Scott JM, Davis F, Csuti B, Noss R, Butterfield B, Groves C, et al. 1993. Gap analysis: a geographic approach to protection of biological diversity. Wildlife Monographs, 123: 3–41.

Setälä H, Bardgett R, Birkhofer K, Brady M, Byrne L, De Ruiter P, et al. 2014. Urban and agricultural soils: conflicts and trade-offs in the optimization of ecosystem services. Urban Ecosystems, 17: 239–253. DOI: 10.1007/s11252-013-0311-6

Standing Committee on the Environment and Sustainable Development. 2017. Taking action today: establishing protected areas for Canada's future [online]: Available from ourcommons.ca/DocumentViewer/en/42-1/ENVI/report-5/page-5.

Steenweg RW. 2016. Large-scale camera trapping and large-carnivore monitoring, occupancy-abundance relationships, and food-webs. Dissertation, University of Montana, Missoula, Montana. 221 p.

Stephens SL, Burrows N, Buyantuyev A, Gray RW, Keane RE, Kubian R, et al. 2014. Temperate and boreal forest mega-fires: characteristics and challenges. Frontiers in Ecology and the Environment, 12: 115–122. DOI: 10.1890/120332

Svancara LK, Brannon JR, Scott M, Groves CR, Noss RF, and Pressey RL. 2005. Policy-driven versus evidence-based conservation: a review of political targets and biological needs. Bioscience, 55: 989–995. DOI: 10.1641/0006-3568(2005)055[0989:PVECAR]2.0.CO;2

Thomas CD, Cameron A, Green RE, Bakkenes M, Beaumont LJ, Collingham YC, et al. 2004. Extinction risk from climate change. Nature, 427: 145–148. PMID: 14712274 DOI: 10.1038/nature02121

Thompson PL, and Gonzalez A. 2017. Dispersal governs the reorganization of ecological networks under environmental change. Nature Ecology & Evolution, 1: 0162. PMID: 28812626 DOI: 10.1038/s41559-017-0162

Truth and Reconciliation Commission of Canada. 2015. Honouring the truth, reconciling for the future: summary of the final report of the Truth and Reconciliation Commission of Canada. Truth and Reconciliation Commission of Canada, National Centre for Truth and Reconciliation, Winnipeg, Manitoba.

Turner WR, Brandon K, Brooks TM, Costanza R, Da Fonseca GA, and Portela R. 2007. Global conservation of biodiversity and ecosystem services. BioScience, 57: 868–873. DOI: 10.1641/B571009

Urban MC. 2015. Accelerating extinction risk from climate change. Science, 348: 571–573. PMID: 25931559 DOI: 10.1126/science.aaa4984

Urban MC, Bocedi G, Hendry AP, Mihoub JB, Pe'er G, Singer A, et al. 2016. Improving the forecast for biodiversity under climate change. Science, 353: aad8466. PMID: 27609898 DOI: 10.1126/science.aad8466

Van Asselen S, Verburg PH, Vermaat JE, and Janse JH. 2013. Drivers of wetland conversion: a global meta-analysis. PLoS ONE, 8: e81292. PMID: 24282580 DOI: 10.1371/journal.pone.0081292

Venter O, Brodeur NN, Nemiroff L, Belland B, Dolinsek IJ, and Grant JWA. 2006. Threats to endangered species in Canada. Bioscience, 56: 903–910. DOI: 10.1641/0006-3568(2006)56[903:TTESIC]2.0.CO;2

Venter O, Fuller RA, Segan DB, Carwardine J, Brooks T, Butchart SHM, et al. 2014. Targeting global protected area expansion for imperiled biodiversity. PLoS Biology, 12: e1001891. PMID: 24960185 DOI: 10.1371/journal.pbio.1001891

Venter O, Sanderson EW, Magrach A, Allan JR, Beher J, Jones KR, et al. 2016. Global terrestrial Human Footprint maps for 1993 and 2009. Scientific Data, 3: 160067. PMID: 27552448 DOI: 10.1038/sdata.2016.67

Venter O, Magrach A, Outram N, Klein CJ, Marco MD, and Watson JE. 2017. Bias in protected-area location and its effects on long-term aspirations of biodiversity conventions. Conservation Biology, 32: 127–134. DOI: 10.1111/cobi.12970

Wang T, Campbell EM, O'Neill GA, and Aitken SN. 2012. Projecting future distributions of ecosystem climate niches: uncertainties and management applications. Forest Ecology and Management, 279: 128–140. DOI: 10.1016/j.foreco.2012.05.034

Watson JEM, Grantham HS, Wilson KA, and Possingham HP. 2011. Systematic conservation planning: past, present and future. Conservation Biogeography, 1: 136–160. DOI: 10.1002/9781444390001.ch6

Watson JEM, Dudley N, Segan DB, and Hockings M. 2014. The performance and potential of protected areas. Nature, 515(7525): 67–73. PMID: 25373676 DOI: 10.1038/nature13947

Watson JEM, Danielle M, Shanahan F, Di Marco M, William JA, Laurance F, et al. 2016a. Catastrophic declines in wilderness areas undermine global environment targets. Current Biology, 26: 2929–2934. PMID: 27618267 DOI: 10.1016/j.cub.2016.08.049

Watson JEM, Darling ES, Venter O, Maron M, Walston J, Possingham HP, et al. 2016b. Bolder science needed now for protected areas. Conservation Biology, 30: 243–248. PMID: 26486683 DOI: 10.1111/cobi.12645

Williams AP, Allen CD, Macalady AK, Griffin D, Woodhouse CA, Meko DM, et al. 2013. Temperature as a potent driver of regional forest drought stress and tree mortality. Nature Climate Change, 3: 292–297. DOI: 10.1038/nclimate1693

Wilson KA, Carwardine J, and Possingham HP. 2009. Setting conservation priorities. Annals of the New York Academy of Sciences, 1162: 237–264. PMID: 19432651 DOI: 10.1111/j.1749-6632.2009.04149.x

Wood EM, Pidgeon AM, Radeloff VC, Helmers D, Culbert PD, Keuler NS, et al. 2014. Housing development erodes avian community structure in US protected areas. Ecological Applications, 24: 1445–1462. PMID: 29160666 DOI: 10.1890/12-1992.1