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Transformational changes for achieving the Post-2020 Global Biodiversity Framework ecological connectivity goals

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Abstract

The first draft of the United Nations Convention on Biological Diversity (CBD) Post-2020 Global Biodiversity Framework (GBF) includes an unprecedented call for states that have ratified the treaty (Parties) to implement measures to maintain and enhance ecological connectivity as urgent actions to abate further biodiversity loss and ecosystem decline. Considering the challenges that lie ahead for Parties to the CBD, we highlight the ways in which effective and equitable connectivity conservation can be achieved through four transformative changes, including: (1) mainstreaming connectivity retention and restoration within biodiversity conservation sector and influencing sectors (e.g., transportation, energy, agriculture, forestry); (2) mainstreaming financial resources and incentives to support effective implementation; (3) fostering collaboration with a focus on cross-sector collective action; and (4) investing in diverse forms of knowledge (co-)production and management in support of adaptive governance. We detail 15 key actions that can be used to support the implementation of these transformative changes. While ambitious, the transformative changes and associated key actions recommended in this perspective will need to be put in place with unprecedented urgency, coherency, and coordination if Parties to the CBD truly aspire to achieve the goals and targets of the forthcoming Post-2020 GBF in this new decade of biodiversity.

Key words: conservation, biodiversity, protected areas, convention on biological diversity, corridors, evidence, mainstreaming

Introduction

In 1993, the United Nations (UN) Convention on Biological Diversity (CBD) entered into force. It is the international legal instrument for "the conservation of biological diversity, the sustainable use of the components of biodiversity, and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources" (CBD n.d.a). There are 196 Parties to the CBD, comprising the European Union and 195 nation states, including Canada, which have ratified the treaty (CBD n.d.b). In 2010, the CBD adopted a 10-year strategic plan for biodiversity that included

20 Aichi Biodiversity Targets (CBD 2010). Target 11 recognized that to abate further biodiversity loss and achieve its 2050 vision of "living in harmony with nature" it was necessary for Parties to the CBD to expand the area of "well connected" systems of protected areas and other effective area-based conservation measures (OECMs).

Ecological connectivity, defined as "the unimpeded movement of species and the flow of natural processes that sustain life on Earth" (Convention on Migratory Species (CMS) 2020), is fundamental to retaining ecological processes across all ecosystems, promoting both persistence and resilience of biodiversity through the dispersal of species across populations, communities, and ecosystems (Baldwin et al. 2018; Oppler et al. 2021). Connectivity is also necessary to support climate change mitigation and adaptation, allowing species and ecosystems to respond with range shifts (Littlefield et al. 2019).

Despite the recognized importance of connectivity to the long-term persistence of biodiversity, there was little progress toward achieving the connectivity element of Target 11 (Gannon et al. 2019; Maxwell et al. 2020). The Protected Planet Report 2020, which provided the final report on the status of Target 11 as per the CBD's Strategic Plan for Biodiversity 2011–2020, revealed that while 17% of the world's terrestrial surface is considered protected, only 7% is both protected and connected, falling well short of the target (UNEP-WCMC IUCN and NGS 2021). Recently, Brennan et al. (2022) have shown that the most globally important areas for mammal movement remain unprotected, with 71% of these overlapping with global biodiversity priority areas.

A new Post-2020 Global Biodiversity Framework (hereafter, the Post-2020 GBF) is being negotiated and will be finalized at the fifteenth meeting of the Conference of the Parties (COP) to the CBD in Kunming, China, in 2022. The significantly elevated profile of connectivity is evident throughout the overarching 2050 Goals and 2030 Milestones included in its first draft. To achieve the goals will require nothing short of transformational change across technological, economic, and social systems (Open-Ended Working Group on the Post-2020 GBF 2021). A clearer picture of what will be required to implement effective ecological connectivity will help governments around the world to deliver on these unprecedented and ambitious conservation commitments.

Nations such as Canada, Russia, Brazil, the Democratic Republic of Congo, Peru, and the United States have globally significant connectivity conservation contexts, harbouring both some of the planet's most intact and most altered ecosystems (Venter et al. 2016; Carroll and Ray 2020; Reid and Lovejoy 2021; Allan et al. 2022). They are in unique positions to further their efforts and contribute to the global challenges of abating biodiversity loss and supporting climate change mitigation through more effective mainstreaming of connectivity. Brazil and the Democratic Republic of Congo had the largest losses of primary tropical forest in 2020 (Weisse and Goldman n.d.). In Canada, the boreal forest region is experiencing significant forest loss from mining and forestry activities, as well as fires resulting from anthropogenic climate change (Watson et al. 2016; Hirsh-Pearson et al. 2022). While much of northern Canada includes large, intact, and carbon-rich areas (Venter et al. 2016; Carroll and Ray 2020) that are *de facto* connected by virtue of its relatively undisturbed land cover at present (Robertson et al. 2017), there are no measures to keep it that way, and the northward expansion of mining, energy development, forestry, tourism, and associated roads is already evident (Watson et al. 2016; Hirsh-Pearson et al. 2022). In fact, a recent study by Allan et al. (2022) revealed that 84% of Canada should be targeted for protection to safeguard biodiversity against future habitat conversion, largely because of the nation's extensive ecologically intact areas. In contrast, southern and eastern regions of Canada have been heavily altered by urban, industrial, and agricultural land uses, and many protected and conserved areas are isolated (Hirsh-Pearson et al. 2022). Despite commitments by the federal government to protect 25% of land and marine area by 2025 and 30% by 2030 (Trudeau 2019), much of Canada remains subject to ongoing tensions between

conservation and development, with many threats to biodiversity intensifying in recent years (World Wildlife Fund (WWF)-Canada 2020).

Consequently, there is a strong need to protect intact and connected areas in Canada and similar nations from increasing pressures and to restore degraded areas to help conserve biodiversity and ecosystem services. At the same time, recognitions of the rights of Indigenous Peoples to govern and steward their territories, including within protected and conserved areas, have increased substantially both globally and within Canada (The Truth and Reconciliation Commission of Canada 2015; Indigenous Circle of Experts (ICE) 2018; Tran et al. 2020). Most of the world's remaining intact ecosystems are Indigenous lands (Garnett et al. 2018), and there is a need to understand approaches to support the full and effective participation of Indigenous Peoples in the implementation of the CBD and its Post-2020 GBF (Zurba et al. 2019). This includes recognizing the interdependence between ecological and social connectivity for food, travel, and lifeways and biocultural integrity that are reflective of Indigenous worldviews, natural laws, and stewardship practices (M'sit No'kmaq et al. 2021).

Within this context, we detail the key challenges related to the ecological connectivity goals and targets included in the Post-2020 GBF. We then present **four transformative changes** and **15 key actions** necessary to enable concerted action focused on effective and equitable conservation outcomes that can meaningfully reverse worsening trends for biodiversity. Ultimately, our aim is to highlight the ways in which evidence-based connectivity conservation can become more mainstreamed by means of developing or revising legislation and policy, providing incentives to retain and restore connectivity, and implementing disincentives for activities that degrade or ignore connectivity in decision-making processes related to conservation (e.g., parks and protected areas, wildlife management) and other influencing sectors (e.g., agriculture, infrastructure development, forestry, energy, mining, recreation). While the interrelated transformations and actions we propose focus on enabling implementation of connectivity conservation in the Canadian policy and management context, the challenges are not unique to Canada. Therefore, the suggested transformative changes and key actions may be considered by other Parties to the CBD working to address conservation challenges within their own unique ecological and socioeconomic contexts.

Key challenges

Human pressures on ecosystems are having profound implications for the planet's biodiversity through extraction of natural resources, the expansion of infrastructures, and conversion of habitat to production-oriented land uses (Kareiva et al. 2007; Venter et al. 2016). It has been estimated that 75% the planet's land surface is experiencing measurable human pressures, and human pressures on ecosystems remain intense, widespread, and rapidly intensifying in many regions (Venter et al. 2016). Although the overall global quantitative component of Target 11 to protect at least 17% terrestrial and inland water areas was met at a global level, progress is uneven with less than half of the world's 821 terrestrial ecoregions meeting the protection target (UNEP-WCMC IUCN and NGS 2021).

In Canada, agriculture and urbanization are the most common human activities causing habitat loss and fragmentation that threaten species at risk (Venter et al. 2006). Forestry, energy, mining, and infrastructure development remain as significant and accelerating challenges to effective conservation of biodiversity, including retaining intact ecosystems (Venter et al. 2014; Maron et al. 2018; Watson et al. 2018; Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) 2019; Hirsh-Pearson et al. 2022; Allan et al. 2022) (**Fig. 1**). While most resource and infrastructure development expansions in Canada will occur in southern and mid-latitude parts of the country, which are also the most biodiverse and threatened (Kraus and Hebb 2020), federal and

Fig. 1. Pronghorn (*Antilocapra americana*) crossing a highway near Val Marie, southwestern Saskatchewan, Canada (photo by Ryan Brook). Forestry, agriculture, urban development, mining, energy, and infrastructure development such as that related to transportation remain significant and growing threats to the effective conservation of biodiversity, including the retention of intact ecosystems.

provincial/territorial governments are supporting increased economic development and resource extraction in Canada's more intact, northern regions (Infrastructure Canada 2021).

Given these challenges, Parties to the CBD are beginning to acknowledge that the traditional piecemeal approach to conserving biodiversity is failing (Watson et al. 2021). In particular, maintaining and enhancing ecosystem connectivity across socio-ecologically diverse regions of Canada will require new and transformative approaches that transcend traditional conservation practices. Connectivity is reflected in the Post-2020 GBF Goal A for 2050, which unprecedently calls on Parties to enhance conservation, "... with an increase of at least 15 per cent in the area, **connectivity** and integrity of natural ecosystems...", and the corresponding Milestone (1A) for 2030, that calls for a "Net gain in the area, **connectivity** and integrity of natural systems of at least 5 per cent" (Open-Ended Working Group on the Post-2020 GBF 2021). Like the Aichi Biodiversity Targets included in the Strategic Framework for Biodiversity 2011–2020, the Post-2020 GBF includes a list of targets for urgent action over the decade, to 2030. The retention of connectivity is implicit in Target 1 and explicit in Targets 2 and 3, which call on Parties to:

> **Target 1.** Ensure that all land and sea areas globally are under integrated biodiversity-inclusive spatial planning addressing land- and sea-use change, retaining existing **intact** and wilderness areas.
>
> **Target 2.** Ensure that at least 20% of degraded freshwater, marine and terrestrial ecosystems are under restoration, **ensuring connectivity** among them and focusing on priority ecosystems.

> **Target 3.** Ensure that at least 30% globally of land areas and of sea areas, especially areas of particular importance for biodiversity and its contributions to people, are conserved through effectively and equitably managed, ecologically representative and **well-connected systems of protected areas and other effective area-based conservation measures**, and integrated into the wider landscapes and seascapes (Open-Ended Working Group on the Post-2020 GBF 2021).

Considering that virtually no progress was made on (the vaguely worded) connectivity-focused targets detailed under the former Strategic Plan for Biodiversity 2011–2020 and its associated Targets, achieving the heightened connectivity goals, targets, and milestones contained within the Post-2020 GBF will require nothing short of transformational change across governance, economic, and social systems. Indeed, ambition needs to be equalled by action (Watson et al. 2021). While recent commitments by several Parties to the CBD to protect 30% of land and marine area by 2030 (Target 2) should be lauded, there is overwhelming evidence to suggest that agencies and organizations responsible for protected and conserved areas face significant, often systemic, human and financial resource constraints (Lemieux et al. 2021a). The outfall of these constraints has been significant, with documented widespread understaffing, underfunding or outright termination of biodiversity inventory and monitoring programs, a lack of resources to complete protected areas management effectiveness assessments, and challenges using various forms of evidence to support management decisions (Auditor General of British Columbia 2010; Office of the Auditor General of British Columbia 2013; Office of the Auditor General of Ontario 2020). Furthermore, challenges have been encountered in reconciling Indigenous governance and knowledge systems within bureaucratic information systems and decision-making processes (Reid et al. 2021). Consequently, contributions to positive biodiversity outcomes by Indigenous Peoples may be overlooked and displaced by more damaging activities, to the detriment of both the environment and human well-being (Loring and Moola 2020).

Finally, achieving the connectivity goals and targets of the CBD's Post-2020 GBF will not be possible without mainstreaming biodiversity in the sectors that influence it the most. This includes sectors that are directly dependent on biodiversity (agriculture, forests, fisheries, and tourism) as well as those that have traditionally been not compatible with conservation, such as energy and mining, infrastructure development, and agriculture and forestry (as per decisions XIII/3 (COP-CBD 2016) and 14/3 (COP-CBD 2018)). It has become clear that a portfolio of actions to support transformative change, including whole-of-society and whole-of-government approaches, will be required to support more effective mainstreaming and implementation of connectivity conservation (Open-Ended Working Group on the Post-2020 GBF 2021). These actions will need to be supported by enabling conditions and adequate means of implementation, including financial resources and capacity development, some of which we detail below.

Solutions to the connectivity conservation challenge

With this backdrop, we adopt a pragmatic, solutions-oriented lens and identify four transformative changes and 15 key actions that nations may take to support the mainstreaming of evidence-based connectivity conservation. We acknowledge the inherent interconnectedness of many of the proposed transformative changes and key actions, and the necessity of broad collaboration in their implementation, so we have identified linkages where appropriate. A summary of our solutions is presented in **Fig. 2**.

Transformative change 1: mainstream connectivity retention and restoration across influencing sectors and within conservation organizations

A key lesson that emerged from global progress on the Aichi Biodiversity Targets is that it will be essential to make biodiversity conservation a far stronger part of terrestrial, freshwater, and marine

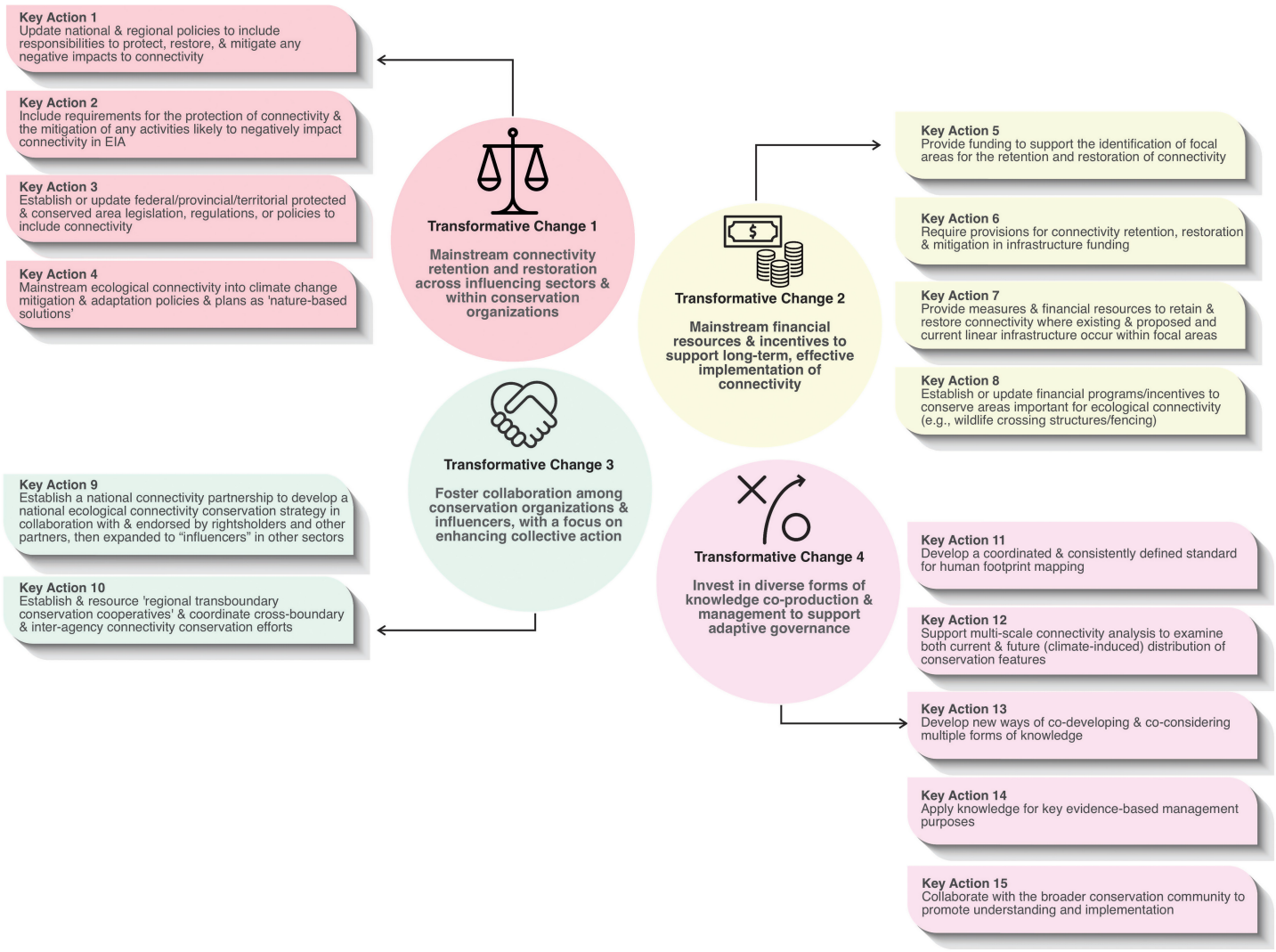

Fig. 2. Schematic illustration of the four transformative changes and 15 key actions that can be used to support effective mainstreaming of connectivity conservation in line with the goals and targets of the Post-2020 GBF.

management policies beyond those focused primarily on protected areas expansion (Maxwell et al. 2020). This is evident in the first draft of Post-2020 GBF, which emphasizes that successful implementation "... requires governance and whole-of-government approaches to ensure policy coherence and effectiveness, political will and recognition at the highest levels of government" (Open-Ended Working Group on the Post-2020 GBF 2021), and Target 14, which focuses on implementation and mainstreaming and calls on Parties to: "Fully integrate biodiversity values into policies, regulations, planning, development processes, poverty reduction strategies, accounts, and assessments of environmental impacts at all levels of government and across all sectors of the economy, ensuring that all activities and financial flows are aligned with biodiversity values" (Open-Ended Working Group on the Post-2020 GBF 2021).

While mainstreaming has appeared in the text of the goals and targets of the CBD in recent years, Parties have struggled to find ways forward. As Addison et al. noted (Milner-Gulland et al. 2021),

"... the 'mainstreaming' of biodiversity can help address these challenges by translating high-level goals into meaningful and inclusive actions at multiple scales throughout society." According to Huntley and Redford (2014), biodiversity mainstreaming is "the process of embedding biodiversity considerations into policies, strategies, and practices of key public and private actors that impact or rely on biodiversity, so that biodiversity is conserved, and sustainably used, both locally and globally." It is now clear that mainstreaming connectivity will have to occur within the economic sectors of society that exert the strongest pressures on biodiversity such as agriculture, forestry, transportation, energy, and mining.

> **Key Action 1:** Update federal (national) and provincial/territorial (regional) legislation, regulations and (or) policies to include responsibilities (including financial responsibility) to protect, restore, and mitigate any negative impacts to ecological connectivity in the mandates of agencies whose activities impact it the most (e.g., transportation, forestry, agriculture, energy, and mining). Such mechanisms could be new, stand-alone laws to address specific federal/provincial/territorial issues, or mainstreamed within existing ones, where appropriate.

Related to Key Action 1, a recent global assessment of connectivity conservation initiatives revealed that the existence of enabling legislation and policy enhanced the effective implementation of such initiatives (Keeley et al. 2019). Recent studies focused on Canada revealed large gaps and fragmented approaches across more than 200 federal, provincial, and territorial laws related to biodiversity (Ray et al. 2021), and very few include provisions for connectivity conservation (Lemieux et al. 2021b), laying bare the scale of the challenge that lies ahead over the next decade. These challenges are not unique to Canada, as laws and policies on transportation, wildlife, and land use planning in many countries do not specifically address connectivity conservation (Lausche et al. 2013; Keeley et al. 2019). However, Keeley et al. (2019) found that connectivity conservation is done most effectively when it is legislatively mandated and tied to funding. The integration of connectivity in various laws and policies are also important for accountability, as explicit recognition of connectivity as a conservation goal or target would trigger accountability assessments, reporting, and review by both state (e.g., government accountability offices) and nonstate (e.g., Canadian Parks and Wilderness Society) actors alike.

To more effectively mainstream connectivity, the alignment of policies, plans, and practices between various governmental departments (e.g., environment, finance) and levels (national, sub-national, and local), will be needed. For example, treatment of biodiversity in Canadian federal, provincial, and territorial environmental impact assessments (EIA) has been largely inadequate, let alone at the scale required to ensure connected landscapes over the long term (Gannon 2021). Several challenges have recently been associated with attempts to integrate biodiversity information into federal, provincial, and territorial EIAs, including a lack of consideration of alternatives and mitigation activities and their respective impacts on biodiversity (Gannon 2021). And, because species are interactively or cumulatively affected by multiple stressors (e.g., agriculture, urbanization, extraction, pollution), with the number of threats increasing with the level of endangerment (Venter et al. 2006), effective EIA must be able to address multiple threats simultaneously.

> **Key Action 2:** Include requirements for the protection of connectivity and the mitigation of any activities likely to negatively impact connectivity in federal and provincial/territorial environmental impact assessment legislation and associated regulations. This includes for infrastructure and other projects proposed both outside and inside protected and conserved area boundaries.

It will also be critical that ecological connectivity be integrated in the enabling legislation for protected and conserved area network planning when such strategies are developed or updated. Established goals should identify the appropriate spatial and temporal scales of connectivity (e.g., timeframes for implementation), and improve regional (cross-jurisdictional) knowledge of connectivity patterns

and associated conservation needs (including those related to mitigating and restoring degraded connectivity).

> **Key Action 3:** Establish or update federal and provincial/territorial protected and conserved area legislation, regulations, or policies to prioritize conservation of ecological networks, including ecological corridors of national, sub-national and cross-border importance.

To support policy coherence with climate change-related initiatives, connectivity nodes and corridors can be used to support national and sub-national climate change mitigation and adaptation policy goals by storing and sequestering carbon and enabling species' dispersal and migration under changing climatic and ecological conditions. The designation of ecological corridors within and between protected and conserved areas can thereby enhance the resilience and integrity of regional ecosystems with benefits for both people and biodiversity.

> **Key Action 4:** Mainstream ecological connectivity into national and sub-national climate change mitigation and adaptation policies and plans as "nature-based solutions" in efforts aiming to keep temperatures within a limit of 1.5° C as per the Paris Agreement.

Mainstreaming ecological connectivity into national and sub-national climate change mitigation and adaptation policies can also be used to identify and support synergies with other multi-lateral environmental agreements and goals, such as the UN Sustainable Development Goals (SDGs), the Paris Agreement, and others, to streamline national reporting requirements.

Transformational change 2: mainstream financial resources and incentives to support long-term, effective implementation of connectivity conservation

As noted above, the expanding footprint of land-use change and infrastructure development has profound impacts on ecosystems worldwide. Habitat loss and fragmentation, overexploitation, native species interactions, introduced species, pollution, and other stressors can interact to open what has been referred to as a "Pandora's Box" of direct and indirect ecosystem impacts (Laurance et al., 2015).

Within this, the intersection of habitat loss, wildlife, and roads is of particular concern for the future of biodiversity. Road development has been shown to have significant effects on landscape permeability with corresponding effects on wildlife habitat use, home range selection, movements, population fragmentation, survival, and reproductive rates (Newbold et al. 2015; Bennett 2017; Tucker et al. 2018). With the length of roads projected to increase by >60% globally from 2010 to 2050 (Dulac 2013), and because roads can facilitate further development in previously remote areas (such as in Canada's northern regions) (Ibisch et al. 2016), there is an urgent need to understand and quantify spatial patterns of where current and future human pressures overlap with key ecological corridors to improve our ability to prioritise actions to prevent and mitigate negative impacts on connectivity (**Fig. 3**). Taken collectively, policies and planning processes will require financial and budgetary mainstreaming, including incentive alignment to reward net positive impacts on biodiversity including connectivity conservation, in sectors with the most significant impacts on, and dependencies from, biodiversity.

> **Key Action 5:** Provide funding to support the identification of focal areas for the retention and restoration of ecological networks and corridors of national, sub-national, and cross-border importance. This should include prioritizing the protection of remaining roadless areas that are regarded as important for biodiversity and (or) ecosystem functionality.

> **Key Action 6:** Require provisions for connectivity retention, restoration, and mitigation in federal and provincial/territorial infrastructure funding. Such provisions should include climate

Fig. 3. The Right Honorable Herb Gray Parkway, located in one of Canada's most highly altered and busiest gateways between Canada and the U.S. (Windsor–Detroit corridor, Ontario). The ecosystem-based restoration and landscaping undertaken as part of Parkway implementation, including the development of several eco-passages over two major highways, is designed to provide numerous benefits to biodiversity, places of refuge for rare and endangered species, recreation, and traditional ecological knowledge (Photo by Windsor-Essex Mobility Group).

change considerations where appropriate (e.g., oversized culverts to address potential flooding and facilitate wildlife movement).

Key Action 7: Provide appropriate measures and financial resources to retain and restore connectivity where existing and proposed linear infrastructural developments occur within focal areas and corridors of national and regional importance (e.g., wildlife crossing structures, associated fencing, and securement of adjacent corridor lands).

Key Action 8: Establish or update financial programs for federal and provincial/territorial Crown (i.e., government) lands and financial incentives for non-Crown lands to conserve areas important for ecological connectivity.

Transformational change 3: foster collaboration among conservation organizations and connectivity influencers, with a focus on enhancing collective action

The act of simply designating an ecological corridor under any governance system does not guarantee positive biodiversity outcomes (Maxwell et al. 2020). At just about any scale, connectivity conservation can only be effectively implemented with collaboration across areas that cover a mixture of land and resource owners and uses and involves a broad range of stakeholders and rightsholders (Guerrero et al. 2015; Kark et al. 2015). Fortunately, lessons are being learned on the ways and means to strengthen social engagement and the representation and capacity of the diverse conservation community, civil society, and others in implementing action to effectively and equitably manage connected areas (Keeley et al. 2018; Hilty et al. 2020; Beazley et al. 2021; Lemieux et al. 2021b).

Fig. 4. Ts'udé Niljné Tuyeta (Tsoo-den-ee-len Too-yuh-ta), an Indigenous and territorial protected area in the Northwest Territories, Canada. Crucial to connectivity conservation advancements are provisions to ensure Indigenous Peoples are socially connected to, and have the right to govern, their territories (Photo by Julien Schroeder, Government of Northwest Territories).

These lessons illustrate how a culture of collaboration is a key ingredient of partnership and how it provides the necessary social foundation for sound governance and successful implementation of connectivity conservation initiatives (Keeley et al. 2019).

> **Key Action 9:** Establish a government-led national connectivity partnership to develop a national ecological connectivity conservation strategy in collaboration with and endorsed by rightsholders (Indigenous Peoples) and other partners (e.g., conservation organizations or "promoters"), then expanded to "influencers".

Partnerships that center local concerns and communities as well as encourage knowledge coproduction and shared governance arrangements are needed to work towards transformative pathways for connectivity conservation (Armitage et al. 2020). Global and national criteria to support ecoregional (and sub-ecoregional) representation, for example, have been developed and are now being applied in Canada and elsewhere, including the United States where Landscape Conservation Cooperatives (LCCs) were developed using ecoregion boundaries to coordinate conservation strategies applicable to large landscapes (Jacobson and Haubold 2014). Other criteria that could be applied to identify important areas for connectivity include watershed boundaries and ecological integrity, and those of importance to Indigenous Peoples, including biocultural pathways for food and lifeways (**Fig. 4**).

> **Key Action 10:** Establish and provide resources for "regional transboundary conservation cooperatives" (RTCCs) throughout Canada and coordinate cross-boundary and inter-agency conservation efforts, especially connectivity conservation efforts. The purpose of the network would be to support natural and social science and Indigenous research on connectivity, harness the capacities and abilities of all partners in support of common conservation outcomes, and serve as a strategic forum for collegial collaboration and coordination.

Regardless of the type of global or national designation, providing a boundary and name to an area for connectivity is an essential step to develop and coordinate governance and monitor success, but other

provisions are needed to ensure that such governance is socially just, and corridors are effective. A key consideration in socially just governance and other equitable collaborations for connectivity conservation is meaningful engagement with Indigenous Peoples, communities, and governments. Canada is situated on unceded and traditional territory and (or) subject to treaty or land agreements, and Indigenous Peoples are sovereign nations with rights to self-governance of their communities and territories, and in nation-to-nation relations with Canada. Crucial to connectivity conservation advancements are provisions to ensure Indigenous Peoples relate to their territories and recognize Indigenous rights to govern their territories (Artelle et al. 2019; Zurba et al. 2019). Collaborative approaches such as Two-Eyed Seeing (Bartlett et al. 2012), Two-Row Wampum (McGregor 2008), learning together (Polfus et al. 2016), Strong Like Two People (e.g., Chief Jimmy Bruneau School 2020), and Ethical Space (Ermine 2007) respect diverse knowledge systems and encourage the use of both Indigenous and non-Indigenous approaches in respectful engagement, knowledge coproduction, and decision-making (ICE 2018; M'sit No'kmaq et al. 2021).

Transformational change 4: invest in diverse forms of knowledge coproduction and management in support of adaptive governance

Effective connectivity conservation initiatives that result in the protection and (or) restoration of ecosystems require access to and use of robust natural and social science data, evidence-based scientific knowledge, Indigenous Knowledge, and local knowledge. Knowledge management and exchange is directly linked to management effectiveness and is associated with an organization's (or nation's) capacity to improve, transfer, share, and apply knowledge (Lemieux et al. 2021a). The knowledge and expertise requirements for connectivity conservation initiatives can encompass a broad range of activities, including: identifying key areas for connectivity conservation; creating effective governance arrangements; engaging in outreach and communication with different groups; estimating restoration, administrative, and management costs; coping with legal issues; monitoring and reporting on biodiversity outcomes; managing for changing socio-economic conditions; and implementing remediation programs and enforcement.

To facilitate our understanding of connectivity barriers, "pinch-points", and priorities, Canada would benefit from better mapping of biodiversity values and tracking of the human footprint and (or) human modification of the environment (Venter et al. 2016; Theobald et al. 2020). At present, human footprint mapping in Canada is incomplete and, where such work has been undertaken, many significant impacts to connectivity and fragmentation remain unmapped and quantified (e.g., resource roads, seismic lines, forest harvesting) (e.g., Hirsh-Pearson et al. 2022). Consequently, the extent of fragmentation and loss of connectivity is significantly under-reported.

> **Key Action 11:** Develop a coordinated and consistently defined standard for mapping the human footprint and (or) modification at multiple scales across jurisdictions and over time, and ensure such data are available for public access.

Connectivity analysis built upon accurate and complete data is greatly facilitated by a wide range of analytical tools that can examine broad structural connectivity based on the spatial configuration of the landscape and human footprint, model how species may functionally respond to the landscape and move across it, and identify critical pinch-points for mitigation or restoration (Keeley et al. 2021) (**Fig. 5**). Such analyses are needed at a range of spatial scales (e.g., between existing protected areas and continentally) and temporal scales (e.g., daily or seasonal movements, migrations, and genetic flows) and examining both the current distribution of biodiversity as well as climate connectivity. Such analyses are intensive and require capacity and expertise beyond the capabilities of most sub-national protected areas organizations.

Fig. 5. Elk calf entangled in a barbed wire fence, Wyoming (Photo by Mary McKinney). Multi-scale connectivity analyses to examine not only the current distribution of conservation features and barriers but also climate connectivity mapping will be required to promote effective implementation of connectivity conservation initiatives.

While knowledge and information related to the above would be empowering, it must be resourced and current evidence suggests that various challenges plague conservation organizations in Canada, some of which have been detailed above, and conspire to limit and use various forms of knowledge that can be used to support decision-making (Lemieux et al. 2021a).

> **Key Action 12**: Support multi-scale connectivity analyses to examine not only the current distribution of conservation features and barriers but also climate connectivity mapping. A national connectivity partnership (detailed in Key Action 9) would help facilitate connectivity analyses through the provision of financial and human resources and identification of connectivity conservation goals at various temporal and spatial scales.
>
> **Key Action 13:** Develop new ways of co-developing and co-considering knowledge systems that respect multiple forms of knowledge and decision-making. Invest in natural and social science (including community science) and Indigenous Knowledge systems and insights in research and knowledge mobilization activities to support effective planning and implementation of connectivity conservation including design, monitoring, and reporting. Incorporate social–ecological and biocultural indicators and adapt governance and management systems to accommodate them.
>
> **Key Action 14:** Apply knowledge for key evidence-based management purposes. Develop and monitor connectivity conservation metrics, inclusive of natural and social science and Indigenous knowledge dimensions of connectivity conservation (including socio-economic and biocultural outcomes). Train staff to support natural and social science and Indigenous dimensions of connectivity conservation efforts.

Conservation and other organizations involved in connectivity conservation require the capacity to assess outcomes at socially, ecologically, and economically meaningful multi-temporal and multiscale levels of decision-making. Whether and how evidence is deployed in conservation management will be key to achieving the "effective" dimensions of the Post-2020 GBF. In fact, Target 20 specifically calls for Parties to ensure that quality information, including traditional knowledge, is developed and applied effectively. Crucially, Target 21 extends this by stressing they also be "equitable", calling on Parties to the CBD to "Ensure equitable and effective participation in decision-making related to biodiversity by Indigenous peoples and local communities, and respect their rights over lands, territories and resources, as well as by women and girls, and youth" (Open-Ended Working Group on the Post-2020 GBF 2021).

> **Key Action 15:** Collaborate with the broader conservation community, including research organizations (e.g., universities), nongovernmental organizations (NGOs), Indigenous Peoples and organizations, and others to help inform the evidence-based management of ecosystems and connectivity conservation areas that support biodiversity outcomes. This could be facilitated through the establishment of RTCCs noted in Key Action 10, perhaps something akin to the Networks of Centres of Excellence in Canada or LCCs in the U.S. (Jacobson and Haubold 2014).

Closing perspectives

Protected and conserved areas will not solve the global biodiversity crisis on their own even if the global target of 30% coverage of terrestrial, freshwater, and marine areas is achieved or surpassed. Existing protected and conserved areas are usually not sufficiently large nor optimally located to stem the decline of biodiversity (Baldwin et al. 2018). While they are crucial and may carry much of the burden associated with stemming ongoing biodiversity loss, a functional, durable ecological network largely depends on the capacity and management of ecological corridors and surrounding landscapes (including freshwater areas) to support ecological connectivity and other transboundary processes (Hilty et al. 2020).

As Maxwell et al. (2020) emphasized, governments must "future-proof" area-based conservation by mainstreaming biodiversity across environmental and socio-economic policies. Effective integration of connectivity conservation, as detailed above, will entail transformational efforts to mainstream biodiversity considerations into forestry, agriculture, energy/mining, urban and rural planning, transportation, recreational and infrastructural developments, and EIA, as well as aligning legislative and policy tools. Major changes within these sectors will be essential to ensuring not only the conservation and sustainable use of biodiversity, but in many instances the continued legitimacy of the sectors and governing agencies themselves. Effective implementation of connectivity conservation will also require unprecedented collaborative with Indigenous Nations.

Fortunately, there are many examples of recent successes in connectivity conservation from which to draw inspiration (Keeley et al. 2019; Hilty et al. 2020; Lemieux et al. 2021b). There are a growing number of examples of Indigenous-led land-use and protected and conserved area planning that weave western science and Indigenous Knowledge to identify protected areas and important areas for connectivity. For example, the goal of the Cree Regional Conservation Strategy in central Québec, Canada, is to create an interconnected network of conservation areas of cultural and ecological importance for the safeguarding of biodiversity that maintains corridors for wildlife migration and to facilitate range shifts (Cree Nation 2015). There are also notable local infrastructure projects, such as the Right Honorable Herb Gray Parkway in Windsor, Ontario, Canada, that installed 11 wildlife eco-passages and restored habitat for species at risk as an integral part of the $1.4B project (**Fig. 3**) (Ministry of Transportation (MTO) 2016). Internationally, there are projects such as Florida Forever in the United States that showcase how diversifying messages on the benefits of conservation

can foster broader support for creating a protected areas network (Lindenmayer et al. 2018). Such messaging supported the eventual passing of the *Florida Wildlife Corridors Act* (2021), which focuses on maintaining and restoring wildlife access to the habitats needed to allow for migration (among other things). The key will be to rapidly replicate and expand such successes to maintain and improve connectivity by 2030, in alignment with the new Post-2020 GBF.

This article has focussed on changes and actions required in many countries around the world, while illustrating them within the Canadian context. The transformative recommendations and associated key actions recommended in this article, while ambitious, will need to be put in place with unprecedented urgency if Parties to the CBD truly aspire to achieve the goals and targets of the forthcoming Post-2020 GBF. The COVID-19 pandemic and global responses to it demonstrate the importance of landscape-scale nature conservation for human health and well-being as well as the tremendous capacity for rapid and pivotal social and institutional transformations (Editorial 2021; Plowright et al. 2021). A new report by the Economist Intelligence Unit, commissioned by the World Wildlife Fund, shows a growing number of people around the world are concerned about nature loss, and biodiversity issues are gaining more traction online than ever before, including in emerging markets (The Economist Intelligence Unit and WWF 2021). Indeed, the momentum and public support required to implement the transformative changes recommended in this Perspective may never have been higher than they are now. The amalgamation of past failures in halting biodiversity loss, and new ambitious targets outlined in the Post-2020 GBF, necessitate urgent and concerted action by all Parties to the CBD, including greater consideration of retaining and restoring ecological connectivity over the next decade and beyond.

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Author contributions

CJL, KFB, DM, RP, LC, and JH conceived and designed the study. CJL, KFB, DM, RP, LC, and JH performed the experiments/collected the data. CJL, KFB, DM, RP, LC, and JH analyzed and interpreted the data. CJL and KFB contributed resources. CJL, KFB, PW, DK, and RP drafted or revised the manuscript.

Competing interests

The authors declare no competing interests. The views expressed in this paper are those of the authors and don't necessarily represent the views of their respective affiliations.

Data availability statement

This manuscript does not report data.

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