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Key information needs to move from knowledge to action for biodiversity conservation in Canada

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ABSTRACT

To address the ongoing global biodiversity crisis, conservation approaches must be underpinned by robust information. Canada is uniquely positioned to contribute to meeting global biodiversity targets, with some of the world's largest remaining intact ecosystems, and a commitment to co-application of Indigenous ways of knowing alongside scientific, socioeconomic, and other approaches. We elicited input from experts across a range of disciplines to identify the key information needed to advance policy and management actions to conserve biodiversity in Canada. Experts concluded that, in many cases, a lack of information is not the major barrier to biodiversity conservation; instead, mechanisms to translate information into action are most urgently needed. Recognizing multiple ways of knowing, especially Indigenous knowledge systems, will be critical to support the transformative change needed to conserve biodiversity at a national scale. Collaboration among natural, social and data scientists can facilitate social change and biodiversity information management. Experts identified 50 priority information needs which emphasize the importance of (i) reviewing policies and actions and disseminating lessons learned from successes and failures; (ii) better understanding mechanisms to build public support; (iii) improving, in specific instances, understanding of the status and trends of habitats, species, ecosystems, and threats for planning and management; and (iv) mobilizing biodiversity information. Through the Convention on Biological Diversity, the global community has resolved to "live in harmony with nature"; through our Canadian case-study, we conclude that the most pressing need to address this resolution is an improved understanding of how to move from conservation knowledge to conservation action.

1. Introduction

As the United Nations' (UN) Decade on Biodiversity draws to a close and the international community grapples with an ongoing crisis of biodiversity loss (Ceballos et al., 2015), it is increasingly apparent that transformative changes are required (IPBES, 2019). For this transformative change to be effective, the fundamental reorganization across technological, economic, and social factors must be guided by robust evidence (Díaz et al., 2019). To facilitate action for biodiversity conservation, the Parties to the UN Convention on Biological Diversity (CBD) adopted a strategic plan, including the 'Aichi Biodiversity Targets' (2011–2020; UNEP/CBD, 2010). Despite some successful policy and management responses, efforts have neither halted nor reversed biodiversity loss (Tittensor et al., 2014); rather, biodiversity across many taxa continues to decline worldwide (Mace et al., 2018).

Given its disproportionately large contributions to global ecosystem services, Canada is uniquely positioned to make significant contributions towards global biodiversity targets (Coristine et al., 2019). With 26% of the world's relatively unfragmented ecosystems (Watson James et al., 2016), Canada is rich in natural capital, natural assets from which humans derive a range of benefits. Moreover, collaborative structures linking levels of government and a desire to work towards the co-application of Western science and Indigenous knowledge systems have resulted in a strong biodiversity conservation network across the country (Indigenous Circle of Experts, 2018; National Advisory Panel, 2018). Yet, Canada's diversity of biomes and ecoregions, as well as its economic reliance on natural resource sectors, result in complex socio-ecological systems within which to address conservation issues. As well, 72% of Canada's population lives in urban areas that represent $<0.2\%$ of Canada's land area (Statistics Canada, 2018), separating many Canadians from natural areas.

Canada was the first industrialized country to sign and ratify the Convention on Biological Diversity 1992, which has since shaped national biodiversity policy. In 2015, the 2020 Biodiversity Goals and Targets for Canada were adopted as a national approach contributing to the global Aichi Targets (FPT Governments of Canada, 2015). For all targets, it is recognized that supporting successful conservation policies and effective interventions, while minimizing adverse consequences, hinges on the availability of robust information (Sutherland et al., 2004). Canada has a strong institutional capacity for evidence-based decision-making to inform biodiversity conservation (Cooke et al., 2016). Moreover, given the critical role that Indigenous peoples play in biodiversity stewardship (Berkes, 2012), and the international obligations to recognize this contribution (i.e., UN Declaration on the Rights of Indigenous Peoples), Indigenous knowledges should play a central role in guiding biodiversity conservation in Canada (Artelle et al., 2019).

Proactively identifying key gaps in biodiversity conservation information can encourage more timely and relevant research, and help to develop evidence-based policy and management actions (Sutherland et al., 2011). Assessing gaps is particularly important since the CBD is in the process of developing a global biodiversity framework for the next decade (UNEP/CBD, 2020). Thus, as a diverse group of experts, we assessed key information needs for biodiversity conservation in Canada. We ensured that these information needs were directly linked to potential policy and management actions by relating these needs to Canada 's, 2020 biodiversity goals and targets. However, we focused on broad biophysical and socioeconomic topics covered in the targets to ensure our assessment will remain relevant post-2020, not only in Canada, but for other countries aiming to meet the CBD targets. We prioritized these information needs with the goal of identifying those most crucial to support transformative change, or fundamental social change, to conserve biodiversity at a national scale. Finally, we discuss how addressing key information gaps can help to facilitate these changes in Canada and contribute to meeting conservation targets at global levels.

2. Materials and methods

A core team of seven organizers (first six and last authors) designed and implemented the project. Ethics approval for this research was granted by Carlton University's Research Ethics Board (Clearance #111108). We defined biodiversity conservation as halting and reversing the decline of life on Earth, from genes to ecosystems (after the CBD), and maintaining or re-establishing the relationships and uses that have conserved the lands and waters for thousands of years (Indigenous Circle of Experts, 2018).

We defined Indigenous knowledges (pluralized to reflect the heterogeneity of knowledge held across diverse Indigenous cultures) as diverse ideas, beliefs, concepts, and perceptions of Indigenous peoples shaped by cultural heritage, traditions, values, and history, influencing a community's relationship with the surrounding environment (McGregor, 2004). Indigenous knowledges are situated within entire systems or ways of knowing (i.e., Indigenous knowledge systems). We defined

information needs as all research, knowledge, and data required to achieve biodiversity conservation, adopting an inclusive view of what counts and is respected as 'knowledge' and 'science'. To identify information needs, we used a three-step process: online survey (July–September 2019), in-person workshop (January 29–30, 2020), and email discussion (February–September 2020, Fig. 1, Supplementary material S1). First, we disseminated a survey to 400 Canadian biodiversity experts in a variety of topics (Supplementary material S1), inviting contributions from academia, government, environmental non-governmental organizations, Indigenous organizations, and industry representatives. We asked participants to identify up to five information needs that would help overcome obstacles to achieving biodiversity conservation in their area of expertise and to rate each need by its importance and feasibility (see Supplementary material S1 for details). A total of 276 information needs were identified by 76 survey respondents (Fig. S1). We used the survey results and the general themes contained in the 2020 biodiversity goals and targets for Canada as the starting point for the workshop discussions (Fig. 1, Supplementary materials S2 and S3). Of the 51 workshop participants, 38 conduct research or management in natural sciences, seven focus on social sciences, six are policy analysts or program managers, and one is an Elder, yet most work across disciplines and at the interface between science, policy, and management. Five workshop participants identified as Indigenous, 16 were affiliated with academic institutions, 10 worked for NGOs, 22 for the federal government, and 3 for provincial or territorial governments. During the two-day workshop, participants were split into a series of break-out groups. After identifying a long list of information needs, each break-out group was then asked to prioritize the list to the top 3–5, considering importance and feasibility. After this, L. McDermott led the group through ceremony, encouraging the creation of "ethical space". To create ethical space is to provide a venue for ceremony and collaboration, and to allow all knowledge systems to interact in the spirit of equitable engagement (Indigenous Circle of Experts, 2018). We used the lens of ethical space to refine the information needs and reflect on their prioritization.

We created the final comprehensive list of 273 information needs by combining the transcribed notes and lists from the workshop with the survey results, merging any candidate information needs that were similar, and removing those that were either too vague, poorly linked to potential conservation policy and actions, or broadly thematic, using Sutherland et al. (2011) as a guide (Supplementary material S4). To create a preliminary list of priority needs, we selected the information needs identified as priorities in the workshop and those rated as the most important and feasible in the survey. Finally, through an iterative process of refining by online discussion (Fig. 1), we identified the top 50 information needs. This process ensured that only information needs agreed to be the most important, relevant, and feasible were included in the final prioritized list.

3. Results

3.1. Central concepts framing the information needs

Five key concepts emerged from the survey and workshop about the nature of the information needed to combat biodiversity loss in Canada. The first was that Indigenous knowledge systems must play a central role

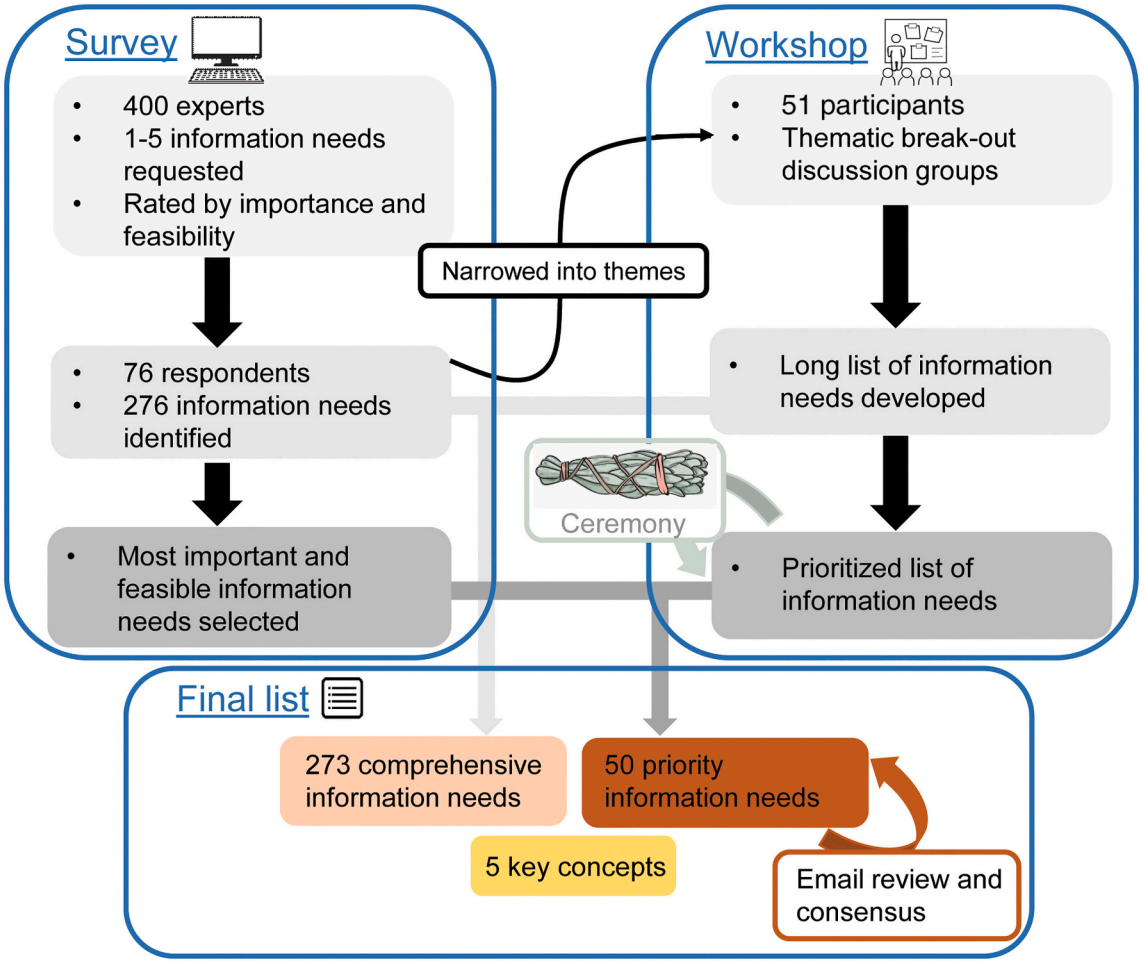

Fig. 1. Our process for generating the final comprehensive and prioritized lists of information needs for biodiversity conservation policy and practice in Canada.

in the success of Canada's conservation efforts. The pursuit of effective conservation will require Indigenous leadership to be respected, and the co-creation of solutions with Indigenous peoples to be prioritized (Chapman and Schott, 2020). Two key pathways to co-creation were emphasized: ethical space (partnership model of cooperative spirit between Indigenous peoples and Western institutions, where space is created for these unique world views to interact; Ermine, 2006) and "Two-Eyed Seeing" (a guiding principle for equitably embracing multiple perspectives, to reconcile the use of Western methodology and theory with Indigenous knowledge systems for the benefit of all; Bartlett et al., 2012). However, there is a lack of clear guidance to operationalize these approaches in conservation, and in its absence a default Western approach is often used. Conservation practitioners and decision-makers need guidance on methods to allow for multiple ways of knowing to work in parallel, to achieve collective conservation solutions. This includes respecting Indigenous knowledge holders as experts and equal partners, as well as using relationship-based approaches at every level of biodiversity work.

Second, many participants emphasized the importance of approaches to better translate existing information into conservation action. This includes understanding ways to facilitate the mainstreaming of biodiversity conservation, identifying political barriers and how to overcome them, and ultimately, better prioritizing the collection of new information so that it relates directly to conservation action. Although communication between scientists and decision-makers has improved, the use of science in policy and practice remains limited (Sutherland and Wordley, 2017). Further, a perceived need for more research or monitoring can lead to delays in addressing the difficult social or political decisions needed for conservation (Meek et al., 2015). Thus, when asked about the major obstacles to achieving biodiversity conservation, some contributors identified a lack of information as the most important, but most survey participants (83%) identified factors other than information gaps (i.e., planning and management, sustainable use, and engagement).

A third central concept was the importance of engaging with data scientists to address critical information management needs and to synthesize considerable amounts of existing biodiversity-related information across institutions, disciplines, and sectors. Although enormous amounts of environment-related data are collected across much of Canada (e.g., as part of environmental assessment processes), this information is often unavailable and unverifiable to outside parties (Jacob et al., 2018). Thus, it is sometimes impossible to distinguish whether ecological information exists but is inaccessible, or is non-existent (Poisot et al., 2019). Recently developed search engines (e.g., Google Dataset Search) and centralized open access repositories for information (e.g., Canada's Open Government Portal) were deemed by participants as essential building blocks to normalize sharing standards and to find biodiversity data. Workshop participants also emphasized the importance of training in data management and supporting initiatives to improve information sharing, including synthesizing data from multiple sources. Because Indigenous and local knowledge can reveal patterns and processes needed to inform decision-making and research, partnering with Indigenous and local knowledge-holders can decrease the need for collecting new data (Berkes, 2012).

Similarly, the importance of social science perspectives to understand both the social and political challenges and possibilities of conservation in order to create change was emphasized. Human dimensions were identified as a major theme of information needs despite the fact that most survey (57%) and workshop (80%) participants had a background in natural sciences. Indeed, the need for social science perspectives has become widely recognized, because many aspects of biodiversity loss are not technical problems that more information will solve, but rather human problems requiring changes in thought, politics, education, and human behaviour (Bennett and Roth, 2019). Changing human attitudes and behaviours in ways that benefit the environment is inherently complex and multifaceted, and social scientists have grappled with these issues for decades (Heimlich and Ardoin, 2008). Renewed efforts to understand and implement theories of change from multiple ways of knowing could catalyze the transformative change needed for biodiversity conservation.

Finally, the scalability of information needs was identified as another central concept. Managing biodiversity across jurisdictions (Indigenous, municipal, provincial or territorial, and federal) is particularly complex in a large, diverse, ecosystem-service rich country like Canada. Most conservation work is carried out at regional or local scales, yet these strategies may not work at a national scale and vice versa (e.g., Ostrom, 2009), resulting in trade-offs between top-down and bottom-up policy. This points to the need for landscape-level coordination. Moreover, Canada's many ecoregions are expected to respond differently to land-use and climate changes (Rehfeldt et al., 2012). Thus, meeting national conservation goals requires planning and action across scales, sectors, and regions, each with potentially distinct information needs.

3.2. Information needs

The central concepts discussed above underscore the complexity of identifying information needs for biodiversity conservation. Ultimately, we prioritized 50 specific information needs in six categories (Table 1).

3.2.1. Review and evaluate existing conservation policies and actions

A comprehensive review of policies, programs, incentives, disincentives, beneficial management practices, tools, and their ability to support or impede biodiversity conservation efforts was identified as a key information need. Notably, identifying policies that successfully address key sources of biodiversity loss (i.e., habitat loss, pollution, and over-exploitation; WWF-Canada, 2020). Accounting for successes and failures can help identify institutional barriers, and determine which processes lead to more positive conservation outcomes (Bennett et al., 2016). Reviews are especially needed for vulnerable habitats that provide key ecosystem services in Canada, such as wetlands (Zedler and Kercher, 2005). Reviews exploring the uptake of beneficial management practices in working landscapes including forestry, urban, or agricultural areas can play a critical role in advancing biodiversity conservation while considering the economic well-being of communities (Bennett and Balvanera, 2007). We also identified the need to make information about effective practices, including consumer choices, available to the public. Developing practices that build trust with resource users like harvesters and fishers (e.g., co-management; Armitage et al., 2009) was also identified as a key information need. Finally, research is needed to better inform the coordination of multiple land managers to achieve goals at larger spatial scales, for example by harmonizing municipal biodiversity strategies across jurisdictions (Aronson et al., 2017).

Priority information needs included a review of successful Indigenous-led land stewardship programs (e.g., Indigenous Guardian Programs, Indigenous Protected and Conserved Areas), and an understanding of unrealized opportunities for conservation that come through treaties (such as clear Indigenous jurisdiction over what happens in Indigenous managed lands and waters). This understanding is necessary to guide the co-development of biodiversity conservation practices and policies, while supporting self-determination and upholding treaty obligations.

Another major need is information about the effectiveness of conservation actions (e.g., https://www.conservationevidence.com/). Workshop participants concluded that there is a need to ensure effectiveness monitoring is a component of any new policies and practices. This includes considering the cost of actions in relation to benefits, to ensure the effective allocation of limited financial resources, especially for species at risk of extinction (Martin et al., 2018). Further, there is a need to compare the effectiveness of single species, multi-species, and integrative ecosystem management approaches for species at risk (e.g., IUCN Ecosystem Red List approach, Keith et al., 2015).

Table 1
Key information needs prioritized from a workshop and survey of biodiversity conservation experts in Canada.

Information needs
Theme: Review and evaluate existing conservation policy and actions
• Evaluate existing policies, programs, incentives, and tools that impact conservation outcomes to identify successes, challenges, and opportunities for improvement
• Identify institutional or other barriers to implementing and enforcing effective conservation policies
• Identify and evaluate beneficial management practices for biodiversity in agriculture, forestry, fisheries and other sectors, considering approaches and barriers to enhance uptake
• Synthesize information on beneficial practices and choices for community members or non-governmental actors who want to support biodiversity conservation, and the extent to which these are enabled or impeded by societal structures
• Evaluate the influence of management structures, practices, and interactions with conservation managers and enforcement agents on behaviour, trust, compliance, and stewardship by fishers, hunters and trappers
• Review and assess biodiversity benefits from municipal conservation planning and initiatives, and how these initiatives interact and may be generalized across jurisdictions
• Review examples of land conservation practices and stewardship by Indigenous peoples to co-develop sustainable harvest practices, climate adaptation, governance, and reconciliation, supporting self determination
• Co-evaluate the obligations that come through treaties that may offer additional opportunities for achieving conservation objectives
• Evaluate the cost-effectiveness of specific conservation actions by assessing the benefits to species and ecosystems per unit cost
• Identify the appropriate balance of single species, multi-species and ecosystem-based management approaches to conserve biodiversity.
Theme: Understand mechanisms to build and mobilize public support and facilitate transformative change
• Evaluate what language and approaches for communicating the importance of biodiversity and severity of biodiversity loss will most effectively increase biodiversity stewardship and biodiversity policies
• Determine how to appropriately portray and communicate the intrinsic, instrumental, and relational values associated with species and ecosystems
• Identify approaches to communicate ecosystem services that may enhance uptake of co-beneficial management practices and actions that promote biodiversity, particularly in an agricultural context
• Understand how and why different stakeholders value biodiversity and ecosystem services relative to other goods and interests
• Develop approaches to translate public interest in climate change and biodiversity into behavioural change, sustainable actions, social norm change, and effective regulations and policies to protect biodiversity and climate
• Identify and summarize lessons learned from programs in biodiversity and biodiversity-related education that have a demonstrable impact on educators, learners, and people, land, and water
• Understand how to increase effective communication among urban and municipal planners, ecologists, and engineers to ensure the integration of ecological needs in the built environment
Theme: Conduct targeted research for planning and management
• Evaluate potential synergies and/or trade-offs between planning for ecosystem services and biodiversity conservation, including the cost of inaction
• Project short- and long-term species and ecosystem responses to climate and land-use change under a range of future scenarios to identify potential climate refugia and corridors
• Understand the implications of future climate and land-use uncertainty and environmental variability on biodiversity conservation modelling and decisions
• Identify how to most effectively take advantage of the carbon storage potential of natural ecosystems and carbon offsets to benefit biodiversity conservation while mitigating climate change
• Develop general guidance, in a format suitable for managers, to describe how habitat area, configuration and connectivity influences biodiversity and ecosystem services to support species migrations and habitat shifts in landscapes most affected by fragmentation and climate change
• Co-develop, with Indigenous communities, approaches to place non-monetary value on areas and species based on their sustenance, recreational, spiritual and cultural significance, in ways that they can be taken into account in conservation planning and management
• Co-develop appropriate mechanisms for translating information contained in oral histories and Indigenous ways of knowing into a format that is conducive to uptake into both mainstream and Indigenous planning, policy- and decision-making
• Identify and protect priority places for biodiversity in Canada using systematic inventories (e.g., KBA approach) while capturing biocultural knowledge
• Develop recommendations to guide urban planning to conserve and restore connected networks of ecosystems for key urban biodiversity
Theme: Monitor the status and trends of biodiversity
• Develop effective approaches to optimize allocation of resources between research and monitoring versus conservation action
• Develop a national, harmonized approach to wetland inventory and monitoring and make data available involving meaningful rights-based Indigenous engagement with multiple stakeholders
• Develop standardized national approaches for classifying, mapping and monitoring of terrestrial ecosystems at multiple scales, including vegetation, landform, soils, and other wildlife habitat components
• Develop efficient and effective approaches for evaluating and monitoring the status of under-represented species groups
• Develop innovative and efficient approaches to expand the monitoring of non-commercial aquatic species or commercial species outside of their harvested range
• Identify areas, including on private lands, where a lack of biodiversity information hampers implementation of conservation actions
• Co-develop resources and tools to support and build biodiversity monitoring capacity in Indigenous communities so they may exercise Indigenous rights, laws, and responsibilities to steward the land
• Inventory historical loss of biodiversity and natural habitat to help guide restoration activities and develop mechanism for public awareness and input
• Understand long-term ecological baselines and ranges of natural variability based on Indigenous knowledges[a]
• Identify where indicator approaches are effective in inventorying species composition, ecosystem services and health, and Indigenous biodiversity values
• Develop an indicator of sustainable forest management that considers impacts on aquatic biodiversity
• Develop a robust indicator to support national, multi-scale, biodiversity monitoring system that builds on existing federal and provincial efforts
Theme: Understand major threats to biodiversity and how they might be addressed via transformative change
• Develop a spatially explicit database of pesticide application to develop application guidelines that minimize negative biodiversity impacts
• Understand how agricultural intensification versus extensification, crop type, agricultural land use, and rotation affect biodiversity
• Develop standardized and coordinated information on the lethal and sub-lethal effects of pollutants on wildlife and potential for better guidelines and management options
• Understand thresholds within which management interventions to key threats to aquatic and terrestrial systems will be successful
• Improve understanding of approaches to monitor and mitigate the cumulative and interactive effects of multiple stressors that alter the ability of habitats to support biodiversity
• Determine key future pathways of biological invasions under climate change and land use scenarios, and identify approaches to minimize risk to native species and ecosystems
• Determine key threats from other jurisdictions to Canadian wildlife, especially for migratory species
Theme: Improve mobilization and accessibility of information
• Develop better mechanisms to synthesize, coordinate, and share biodiversity information and data among jurisdictions
• Develop methods to integrate data across regions, taxa, and spatial-temporal scales
• Develop approaches to improve access for practitioners, managers, and the public to remote sensing and GIS biodiversity data of consistent quality across sources and disseminate resulting evidence
• Develop appropriate ways to address and communicate uncertainty and trade-offs in systems-level models of cause-effect relationships between species and habitat variables
• Co-develop policies with Indigenous people that achieve respect for culturally sensitive information, while maintaining openness and transparency where possible

[a] Pluralized to reflect the heterogeneity of knowledge held across diverse Indigenous cultures.

3.2.2. *Understand mechanisms to build and mobilize public support*

Awareness of biodiversity concepts is relatively high in Canada, and many Canadians support the idea of ambitious conservation goals (Wright et al., 2019). However, there remains a need to determine how to translate public interest in biodiversity into meaningful changes in behaviour, action, and stewardship. Priority information needs emphasized better communicating the importance of biodiversity conservation, including understanding effective language (e.g., using catch phrases; Begon, 2017), utilizing other forms of expression (e.g., art, storytelling), portraying the intrinsic and relational values associated with nature (including cultural and spiritual values; Chan et al., 2016),

focusing on ecosystem services as a communication tool (Thompson et al., 2016), and using lessons learned from successful efforts to communicate climate change issues (Nerlich et al., 2010; Legagneux et al., 2018). Effective communication can be facilitated by understanding how and why different people and stakeholders value biodiversity relative to other interests. Public engagement is fundamental to shift human attitudes about nature, mainstream biodiversity issues, and leverage transformative change (Díaz et al., 2019). Thus, a key information need is understanding how programs in biodiversity and biodiversity-related education could successfully motivate educators and learners to cultivate relational values of responsibility and advance biodiversity conservation. Finally, understanding how to integrate ecological needs into engineering standards and municipal planning, and increasing communication and knowledge co-production with planners, ecologists, and engineers will be key to ensure the integration of biodiversity needs into the built environment.

3.2.3. Targeted research for planning and management

Targeted research to improve conservation decisions is increasingly important for conservation biology (Mair et al., 2018) especially in light of rapidly changing climate conditions. We identified several information needs related to decision support, including how to combine conserving both wildlife and ecosystem services (including the limitations of an ecosystem service approach; Xiao et al., 2018), understanding adaptive capacity and projected response of species and ecosystems to climate change (Stralberg et al., 2020), carbon storage, connectivity to support resilience of fragmented populations (Keeley et al., 2019), and future uncertainty and variability (McBride et al., 2007). The latter is particularly important given anticipated consequences of climate change on Canada's coastlines, wetlands, boreal, and Arctic ecosystems (Bush and Lemmen, 2019).

Planning that couples social and ecological scenarios is essential to understand future consequences of alternative management choices (Ban et al., 2013). We identified the need to understand how to incorporate non-monetary values of species and ecosystems into conservation planning. This is especially relevant for co-management, where taking into account cultural sites, spirit of place, Indigenous food security, and sovereignty interests are crucial. This will require mechanisms that respectfully engage and reflect Indigenous knowledges, as well as the perspectives of key stakeholders, within co-produced formats for use in planning, policy, and decision-making. To guide the identification and protection of priority places for biodiversity in Canada while capturing biocultural values, there is a need for systematic inventories of biodiversity (e.g., Key Biodiversity Area [KBA] initiative currently underway, http://www.kbacanada.org/) to include multiple values and knowledge systems.

We identified the need to develop spatial guidance for decision-makers describing how habitat area, configuration, and connectivity influence biodiversity and ecosystem services. We also identified the need to develop guidance on conserving, restoring, and connecting urban and peri-urban ecosystems for urban planning. This will require understanding the conservation benefits of different types of green spaces and the efficacy of engineered solutions (i.e., Urban Ecological Infrastructure, Childers et al., 2019). It will also require understanding the effects of development patterns – from urban intensification to suburban sprawl – on biodiversity, and ways of minimizing negative effects within and around urban areas in a policy context.

3.2.4. Monitor the status and trends of biodiversity

Financial resources for biodiversity conservation are finite and should be managed in ways that allow for their optimal use. We identified the need to understand the optimal allocation of resources, between monitoring, inventory, and research, versus conservation action. Additional effort is necessary to complete and harmonize inventories for key habitats – notably wetlands – across multiple spatial scales and jurisdictions. In light of advances in remote sensing, there is also a need to revisit inventory strategies with multiple stakeholders and Indigenous peoples (Sieber, 2006), to create products that can benefit more people and achieve a variety of objectives. Given the need for national assessments and mapping, methods that incorporate important biodiversity components from scales ranging from continental (e.g., migratory flyways) to local (e.g., agricultural hedgerows, municipal green spaces, small wetlands) will need to be developed. Such approaches should also facilitate monitoring changes in these components.

For some species groups, there are knowledge gaps in basic status and trends that hamper biodiversity conservation, e.g., invertebrates, non-commercial aquatic species and commercial species outside of their harvested range, as well as species on privately-owned land and in remote areas. Exploring the potential of innovative and efficient tools such as eDNA (Leduc et al., 2019) or community-based monitoring (Conrad and Hilchey, 2011), assembling ad-hoc datasets (Cumming et al., 2010), and mobilizing existing, inaccessible information may help to fill these gaps. Local gaps could also be filled through co-development of resources and tools that improve the capacity of Indigenous and other communities to monitor and map biodiversity.

An understanding of variability in the abundance and diversity of species, over short and long time scales, can bring new awareness to conservation issues. Co-developed methods that consider Indigenous knowledge could help establish baselines that are more meaningful over historical time scales. We identified the need to better incorporate baselines into monitoring and restoration actions, as well as concepts that make use of the history of change, such as ecological equivalency, novel ecosystems, and rapid change (Zedler et al., 2012). As comprehensive long-term data are scarce and often impractical to gather, we need improved proxies to measure changes in biodiversity. Specifically, we need effective proxies to reflect species composition, ecosystem services and health, and Indigenous values across various ecosystem and land uses. We also identified the need to consider impacts on aquatic biodiversity, alongside the pre-existing terrestrial indicators, in sustainable forest management. Efforts to develop indicators could support the consolidation and simplification of high-level reporting on the "state of biodiversity" (Loh et al., 2005; Halpern et al., 2012).

3.2.5. Understand major threats to biodiversity

We identified priority information needs related to addressing major threats to biodiversity. In some cases, major gaps remain before we can develop approaches to tackle threats through management actions.

Specific gaps that were highlighted include understanding the relative impacts of pollutants and agricultural expansion (especially to support decisions for species at risk, McCune et al., 2019). Standardized and coordinated information on pollutants should be widely available (e.g., diffuse sources of new and emerging pesticides, therapeutants, road salt, microplastics). Similarly, a spatial inventory of pesticide application, an understanding of disease transmission from aquaculture and agricultural operations into natural systems, and an understanding of how agricultural intensification, extensification, and configuration affect biodiversity (Tscharntke et al., 2012) would help implement better management practices and guidelines. More in depth understanding of lethal and sub-lethal direct and indirect effects of pollutants, and the thresholds within which management interventions will be successful, is necessary to develop better policies and practices, particularly for aquatic systems (Srain et al., 2020).

Information is also required to monitor and mitigate the cumulative effects of multiple threats affecting biodiversity in rapidly changing, real-world conservation settings. Information about stressor-response relationships and how multiple stressors, especially from industrial development, interact with natural processes and accumulate across space and time can support decisions to manage cumulative environmental effects (Jones, 2016). Threats may be cumulative at international scales and management should account for the contributions of threats in other countries to the declines of Canadian wildlife, particularly for migratory species (Meretsky et al., 2011). Another need highlighted in

the workshop was to identify invasion pathways and their implications for native species, how these may be facilitated or exacerbated by climate change, and how this knowledge can be used to better manage invasive species (Hulme, 2015).

3.2.6. Improve mobilization and accessibility of information

Standards for data management and dissemination are urgently needed to cope with the rapidly increasing flow of environmental data generated by new monitoring technologies. In Canada, as with many countries, inconsistent data collection, monitoring, and management practices make it difficult to share data among government departments, jurisdictions, researchers, and with the public (Privy Council Office Government of Canada, 2018). To effectively address information needs, the regulations, capacity, and tools to mandate and adequately manage, share, and mobilize information of relevance to conservation will be key (Expert Panel on Biodiversity Science, 2010). Ideas to better share data are emerging both in academia and government, such as the FAIR data principles, a set of standards to promote the Findability, Accessibility, Interoperability, and Reusability of open data (Wilkinson et al., 2016).

Methods to unify national data must involve mechanisms to synthesize and share remote sensing and GIS biodiversity data of consistent quality between jurisdictions (e.g., municipalities, provinces and territories) and actors (practitioners, managers, industry, and the public). The integration of data within the national statistical system will support the interpretability and coherence of biodiversity with socio-economic data. Co-development of context-specific policies and approaches to handle, store, and respect Indigenous sourced information will be crucial to balancing openness and transparency while respecting Indigenous data sovereignty needs (i.e., https://fnigc.ca/ocap). We also recognized the need to reach consensus around appropriate ways to communicate and reduce uncertainty in modelled cause-effect relationships at a systems-level (e.g., between habitat and species populations or communities).

4. Discussion

Given the ongoing failure of the global community to meet biodiversity targets, new approaches and greater commitment are needed (Mace et al., 2018). The strategies, pathways, and practices to support this transformative change must be based on robust information. Using an expert elicitation approach, we identified 50 priority information needs for biodiversity conservation policy and practice in Canada. In addition, experts identified five key concepts that frame these information needs: 1) multiple ways of knowing are critical for transformative change; 2) a lack of information is often not the critical barrier to biodiversity conservation; 3) new collaborations with data scientists will facilitate necessary improvements in information management; 4) social scientists have a crucial role to play in guiding social change for the benefit of biodiversity, and 5) an improved ability to coordinate conservation management across spatial scales, jurisdictions and sectors is key for meeting national conservation goals.

Some of the information needs we identified are similar to those identified in a previous exercise (Rudd et al., 2011). However, our results reveal new priorities for the coming decade, including an urgent need for frameworks and research agendas that promote co-existence of scientific and Indigenous knowledge systems, and facilitate Indigenous leadership in conservation action. Previous biodiversity conservation "horizon scanning" exercises identified the need to consider Indigenous knowledge and that "in some instances 'sufficiently sound scientific information' for decision-making can be derived from traditional knowledge" (Rudd et al., 2011, citing Government of Canada, 2001). We go beyond this to emphasize the need to change narratives and approaches centered on 'incorporation' of Indigenous knowledge into western scientific approaches (Reid et al., 2020). Specifically, we reiterate the imperative that Indigenous knowledges should be considered equally as evidence and information, and importantly, we advocate for embracing multiple ways of knowing as an instrument for transformative change as envisioned through Indigenous worldviews, philosophies and environmental ethics such as Two-Eyed Seeing and Ethical Space. While substantial progress has been made towards this goal, for example through the work of the Pathways to Target 1 initiative and Indigenous Circle of Experts (2018), much remains to be done.

We also acknowledge a crucial need to bridge the knowledge-action gap. Indeed, some of the information identified as a priority here likely already exists, but is not accessible, synthesized at an appropriate scale, or in a form that is useful for biodiversity planning and management. Given that current resources are insufficient to address the ongoing global biodiversity crisis, we suggest that collecting new information be paired with a clear plan for how it relates to conservation action. Moreover, we identified interdisciplinary gaps in knowledge, including sociocultural, economic, and institutional information barriers across Canada's economic sectors that are the root causes of biodiversity loss. Overall, our results emphasized a focus on human dimensions and information management to inform biodiversity conservation policy and management in Canada.

With the drafting of a post-2020 biodiversity framework underway, the coming years could mark a turning point for global biodiversity conservation – and Canada has a significant role to play (Coristine et al., 2019). The new goals and targets will frame actions of governments and other decision-makers over the next decades. The themes and priorities that arose from our Canadian case-study are global in their application. Others have similarly highlighted the importance of implementation and urgency of action to address the causes of biodiversity loss (Díaz et al., 2020) and the importance of Indigenous perspectives in biodiversity conservation (Garnett et al., 2018; Artelle et al., 2019; Schuster et al., 2019). Learning from conservation successes and failures and strengthening collaboration and communication among scientists, Indigenous peoples, stakeholders, and decision-makers will be required to transform information into action to conserve nature, both in Canada and internationally.

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CRediT authorship contribution statement

Rachel T. Buxton: conceptualization, methodology, validation, formal analysis, investigation, data curation, writing – original draft, visualization, supervision, project administration, co-production, securing permissions and permits, team building, project sunset.

Andrea J. Reid: conceptualization, investigation, writing – review & editing, project administration, co-production, partnership development and consultation, project sunset, training, bridging & brokering.

Joseph R. Bennett, Steven J. Cooke, Charles M. Francis, Paul A. Smith, Charles Shulman: conceptualization, investigation, supervision, funding acquisition, project administration, writing – review & editing, co-production.

Elizabeth A. Nyboer, Allison D. Binley: investigation, data curation, writing – original draft, writing – review & editing, co-production.

Gary Pritchard, Danika Littlechild, Larry McDermott, Rod Whitlow: investigation, writing – review & editing, co-production, bridging & brokering.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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