An action-oriented research agenda for equitable and meaningful nature-based solutions in urban areas

Rachel Buxton[1*°], Chúk Odenigbo[2°], Emma J. Hudgins[3], Courtney Robichaud[1], Robin Mazumder[4], Steven J. Cooke[1], Kimberly Matheson[5,6,7], Paul J. Villeneuve[5], John M. Zelenski[8], Tanya Halsall[6], Catherine Bonier[9], Christopher Stoney[10†], Jaimie Vincent[1], Doug Anderson[11], Adrina C. Bardekjian[12], Kelley Bird-Naytowhow[13], Andrew Hatala[13], Simon Brascoupé[7], Natalie Brown[14], Verna Crossman[15], Jacqueline Hamilton[16], Nadha Hassen[17], Melissa Lem[18], J. Scott MacIvor[19], Megan Meaney[20], Lorien Nesbitt[21], Amanda O'Rourke[22], Camilo Ordóñez Barona[23], Stephanie A. Prince[24,25], Gary Pritchard[26,1], Jode Roberts[27], Jacqueline L. Scott[28], Carly D. Ziter[29], Meaghan Eastwood[30], Bev Windjack[31], Thomas Bowers[32], Joseph R. Bennett[1]

[°]Authors contributed equally

[1]Department of Biology and Institute of Environmental and Interdisciplinary Science, Carleton University, Ottawa, ON, K1S 5B6, Canada

*Corresponding author email Rachel.Buxton@carleton.ca

[2]Department of Geography, Environment and Geomatics, University of Ottawa, Ottawa, ON, K1N 6N5, Canada

[3]School of Agriculture, Food, and Ecosystem Sciences, University of Melbourne, Parkville, VIC 3010, Australia

[4]Department of Psychology and Ergonomics, Faculty V: Mechanical Engineering and Transport Systems, Technische Universität Berlin, Berlin, Germany

[5]Department of Neuroscience, Carleton University, Ottawa, ON, K1S 5B6, Canada

[6] University of Ottawa Institute of Mental Health Research, 1145 Carling Avenue, Ottawa, ON, K1Z 7K4, Canada

[7]CHAIM Centre, Carleton University, Ottawa, ON, K1S 5B6, Canada

[8]Department of Psychology, Carleton University, Ottawa, ON, K1S 5B6, Canada

[9]Azrieli School of Architecture & Urbanism, Carleton University, Ottawa, ON, K1S 5B6, Canada

[10]School of Public Policy & Administration, Carleton University, Ottawa, ON, K1S 5B6, Canada

[11]Invert Media, Toronto, ON, Canada M6H 3M8

[12]Tree Canada, Ottawa, ON K1R 6S3, Canada

[13]Department of Community Health Sciences, Max Rady College of Medicine, University of Manitoba, Winnipeg, MB, R3E 0W2, Canada

[14]Park People, Toronto, ON, M5V 3A8, Canada

[15]Canadian Forest Service, Natural Resources Canada, Ottawa, ON, K1A 0E4, Canada

[16]Department of Natural Resource Sciences, McGill University, Montreal, QC, H9X 3V9, Canada

[17]Faculty of Environmental and Urban Change, York University, Toronto, ON, M3J 1P0, Canada

[18]Park Prescriptions, BC Parks Foundation, Vancouver, BC, V7T 2X9, Canada

[19]Department of Biological Sciences, University of Toronto Scarborough, Toronto, ON, M1C 1A4, Canada

[20]ICLEI – Local Governments for Sustainability, Toronto, ON, M5V 3A8, Canada

[21]Department of Forest Resources Management, Faculty of Forestry, University of British Columbia, Vancouver, BC, V6T 1Z4, Canada

[22]8 80 Cities, Toronto, ON, M5V 3A8, Canada

[23]Department of Geography, Geomatics, and Environment, University of Toronto, Mississauga, ON, L5L 1C6, Canada

[24]Centre for Surveillance and Applied Research, Public Health Agency of Canada, Ottawa, ON, K1A 0K9, Canada

[25]School of Epidemiology and Public Health, Faculty of Medicine, University of Ottawa, Ottawa, ON, K1H 8M5, Canada

[26]4 Directions Conservation Consulting Services, Hiawatha, ON, K9J 0E6, Canada

[27]Nature in Cities Program, David Suzuki Foundation, Toronto, ON, M5T 1X4, Canada

[28]Department of Social Justice Education, University of Toronto, ON, M5S 1V6, Canada

[29]Department of Biology, Concordia University, Montreal, QC, H4B 1R6, Canada

[30]Climate Change Transition and Sustainability, Region of Waterloo, Kitchener, ON, N2G 4J3, Canada

[31]LADR Landscape Architects Inc., Victoria, BC, V8T 1M5, Canada

[32]Carbon Guild Corporation, Toronto, ON

[†]Deceased December 11, 2021

Abstract

Nature-based solutions provide opportunities to address the urgent, interconnected global challenges of environmental conservation, public health, and social justice in urban areas. Despite growing interest among policy-makers, the outcomes of nature-based solutions at the nexus of biodiversity, human health, and social justice are not well understood. We gathered a group of experts from different disciplines, organizations, lived experiences, and ways of knowing to identify key knowledge gaps to guide research for more effective urban nature-based solutions. Workshop discussions highlighted the need to diversify knowledge production around designing and implementing nature-based solutions through three guiding principles: 1) breaking down existing power imbalances and centring Indigenous knowledges; 2) learning by doing; and 3) co-developing research across disciplines, perspectives, ways of knowing, nations, communities, and institutions. Experts identified 33 key knowledge gaps emphasizing the importance of a more action-oriented research agenda, including better evaluation of the outcomes of urban nature-based solutions; diversifying methodologies and approaches; exploring links and trade-offs among goals for biodiversity conservation, health, and equity; and increasing support for nature-based solutions through education and communication. Given the urgency of the environmental crisis, the rapid rise in mental illnesses, increasing pressure on health care systems, and the undue burden borne by marginalized communities, a coordinated research agenda that uses a social justice lens, breaks institutional silos, and prioritizes real-world solutions is paramount. If urban nature-based solutions are to meet the goal of providing benefits for both human well-being and biodiversity, coordinated efforts must reflect the complexity of what it means for human and non-human organisms to live in urban environments.

23 **Keywords** Biodiversity conservation, health, Indigenous science, transformation, well-being,
24 urban, social justice

Reflexivity statement

This paper captures the coming together of multiple peoples, disciplines, and lived experiences. What started with a series of workshops on urban nature-based solutions, organised and led by four settlers in what is currently Canada, Drs. Buxton (settler, English/Franco-Albertan), Hudgins (settler, western European), Robichaud (settler, Acadian/English), and Bennett (settler, western European), became a rich conversation of the multiple linkages between all that it means to be human in relationship to the natural world. Important discussions with Indigenous peoples, scientists from other disciplines, environmental activists of multiple lived experiences and people who call urban spaces their home broadened the context of the link between nature and health in urban areas. This included the colonial history of cities, the patriarchal narrative of nature, and the capitalist commodification of the land. In the collective space that was eventually co-created with leadership from workshop participants during and after the workshop, points of change and challenge emerged. This required an increased breadth of expertise and positionalities to join in the writing of this paper to capture and summarise some of the knowledge shared, giving rise to the wide authorship from participants. To name a few examples: Doug Anderson (Bungee Red River Métis) challenged how natural spaces in urban environments could be stewarded by making reference to natural and spiritual laws; Robin Mazumder (settler, Indian/Bangladeshi-Canadian) spoke to experiential equity where urban spaces are experienced differently depending on one's intersecting identities; and, Chúk Odenigbo (settler, Black Franco-Albertan of African descent) reimagined nature-based solutions through a plurality of knowledges. Chúk led the crafting of the intersecting message that we cannot research biodiversity and health in institutional and disciplinary silos and must work in an ecosystem of collaboration, as nature does, to craft solutions that convey the same level of

harmony and balance. The data collection and writing process was a learning opportunity for all involved. As academics, we have a responsibility to support a change in how we do research in our disciplines, including co-learning and co-creating with communities, trainees, and partners. Thus, this paper engages in multidirectional interdisciplinary learning in hopes of reaching urban nature-oriented researchers who are shaping policy and environmental advocacy through their work to incorporate lenses of justice and collaboration.

Introduction

The loss of biodiversity is accelerating. We are concurrently experiencing rapid rises in stress-linked chronic inflammatory diseases and mental illnesses that are outpacing the capacity for primary care (WHO 2013; Furman et al. 2019). The impacts of these intertwined crises are unequally distributed, reflecting social hierarchies and asymmetries, where the most marginalized sectors of society bear undue burden (Díaz et al. 2006). Increasing urbanization exacerbates these issues (Gruebner et al. 2017) but also holds the potential to address them.

Urban areas are highly modified landscapes and complex social-ecological systems (Bai et al. 2017). Urban land cover was expected to triple between 2000 and 2030 (Seto et al. 2012), with over two-thirds of the world's population projected to live in cities by 2050 (UN 2018). High density infrastructure that characterizes urban spaces often leads to elevated levels of disturbance, pollution, heat, and reduced habitat and resource availability for wildlife (Ouyang et al. 2018). Thus, urbanization is a major contributor to global biodiversity loss (McDonald et al. 2008). At the same time cities represent important areas for conservation, often supporting many threatened species (Ives et al. 2016; Pogson et al. In review). In cities, wealthier, predominantly White neighbourhoods have greater vegetation cover and diversity of plants and animals, which results in better removal of air pollutants, buffers against noise pollution, reduced run-off, and other benefits (Leong et al. 2018; Nowak et al. 2022). In contrast, systemic racism and oppression not only result in unwelcoming municipal spaces for Black, racialized and otherwise marginalized peoples (Hoover and Lim 2021), but also contribute to the neglect of Indigenous-municipal relationships (Anderson and Flynn 2020). The historical imprint of racism and capitalist policies is evident in the design of many cities, from naming buildings after slave owners to redlining to land dispossession (Fu 2022). This enduring impact is intertwined with the

influence of European colonialism in settler states, shaping the trajectory of urban development (Schell et al. 2020). Inequitable access to urban nature perpetuates a cycle of direct and indirect harm and adverse health outcomes for the most marginalized communities that continues to be replicated over time (Gutschow et al. 2021).

Nature-based solutions are interventions that aim to protect, restore, and create ecosystems while addressing societal challenges, providing human well-being and biodiversity benefits (see Box 1 for the full definition and references). Nature-based solutions is an umbrella term that includes concepts such as green infrastructure, re-naturing, ecological engineering, nature-based health interventions, natural capital, ecosystem-based management, and ecosystem services (Sowińska-Świerkosz and García 2022). Nature-based solutions offer a potential framework for creating interventions that tackle the challenges of urbanization, for example: restoring habitat, reducing heat, increasing species diversity, decreasing flood risk, improving human psychological well-being, creating green jobs, increasing social cohesion, improving community resilience, and fostering a sense-of-place (Brink et al. 2016; Connop et al. 2016; Wamsler et al. 2016; van den Bosch and Ode Sang 2017; Redvers et al. 2021). Note that current research is limited in geographic scope and populations surveyed, with most studies exploring the benefits of greenspace (see Box 1) in high-income nations. There are also several Indigenous-led approaches in cities, such as land-based healing (Redvers 2020), land-making (Hatala et al. 2019), and environmental repossession (Ambtman-Smith and Richmond 2020), which are viewed less as a 'nature-based solution' more as a way to 'renew and strengthen relationships with and responsibilities for the land and water and all the layers of being surrounding it' (Yellowhead Institute 2019; Anderson and Flynn 2020).

Given the Eurocentric conception and design of nature-based solutions, there is much debate over their ability to deliver just outcomes and whether they are simply perpetuating the imposition of colonial, utilitarian frameworks of nature (Reed et al. 2024). Indigenous Peoples and Black, racialized, and other marginalized peoples often contend with racism and discrimination in public spaces, where violence can range from surveillance to outright physical harassment, negating any potential restorative effects of nature-based solutions (Mazumder 2021). While there are growing efforts to collaborate with Indigenous communities, there is a general unwillingness to recognize Indigenous jurisdiction and autonomy and to embrace Indigenous views of the land as systems of reciprocal relations (Townsend et al. 2020). Furthermore, while Indigenous Peoples and Black and racialized communities are increasingly present and visible in many urban landscapes, they are not appropriately consulted when creating nature-based solutions (Keucheyan 2018). Thus, nature-based solutions have been labelled by many as 'false solutions' that do little to alter the status quo (Cousins 2020; McGregor et al. 2020), perpetuating systemic injustices and oppression. Moreover, while urban greenspaces may provide habitat, wildlife are confronted with a variety of novel urban threats which can create ecological traps or sinks (where wildlife select greenspace which are rendered low quality because of threats), sometimes resulting in rapid population declines and local extirpation (Robertson et al. 2013).

Globally, there has been a surge in interest in nature-based solutions. Nature-based solutions are being used to repackage policy debates on biodiversity conservation, climate change, public health, and social justice (Sekulova and Anguelovski 2017). However, there is a limited understanding of outcomes across disciplines (Mahmoud et al. 2021) and limited understanding of how different approaches may lead to risks, trade-offs or co-benefits. A key

issue is the scarcity of research teams focused on nature-based solutions that span various disciplines, perspectives, and ways of understanding. This contributes to significant knowledge-actions gaps in both conservation and health sciences (Haines et al. 2004; Knight et al. 2008). This hinders the development of action-oriented research, defined as research that can support practice, programs, communities, and policy while contributing to an understanding of the outcomes of nature-based solutions (Small and Uttal 2005). Proactively identifying knowledge gaps with on-the-ground practitioners, policymakers, and researchers across disciplines and ways of knowing can facilitate more relevant, interdisciplinary, and action-oriented research to tackle interconnected urban issues.

We gathered a group of experts with a range of lived and professional experiences to assess key knowledge gaps for action-oriented nature-based solutions research that could maximize biodiversity conservation, human health benefits, and equitable outcomes in urban environments. We focused on the context in what is currently Canada, given the country's complex and interacting layers of governance (Indigenous, Federal, Provincial, Territorial, and Municipal) and growing political interest and financial resources for nature-based solutions. By focusing on broad social-ecological topics, our assessment is relevant to other countries, particularly those that must also navigate and address the complexity of settler colonial urban politics.

Methods

To identify knowledge gaps, we used a three-step modified Delphi approach (Mukherjee et al. 2015): 1) a survey (July to August 2021), 2) workshop (September 2 and 29, 2021), and 3) online discussion (December 2022 to May 2023). Ethics approval for this research was granted by Carleton University's Research Ethics Board (Clearance #115849). For both the survey and

workshop, we targeted participation from a variety of sectors (academia, government, non-profit, non-governmental organization [NGO], consulting), disciplines (biodiversity conservation, health, education, psychology, policy, equity), roles (practitioners, researchers, managers, policymakers), and lived experiences and ways of knowing (Indigenous, Black, racialized, and settler perspectives). We asked participants to focus on knowledge gaps that addressed the interconnected biodiversity conservation, human health, and equity outcomes of urban nature-based solutions, specifically those that could be filled by a research program or group. Because we were engaging experts across a range of perspectives, we kept our terminology broad, using several terms interchangeably (see Box 1).

Step 1: the survey

We distributed a survey through email to over 450 experts in urban nature-based solutions across Canada and shared the survey through Twitter and professional listservs (Supplementary material S1). We asked participants to identify up to five pieces of information needed for more effective nature-based solutions that drive equity, human health, nature stewardship, and/or biodiversity conservation in Canadian cities. Participants were then asked to rate the importance and feasibility of filling each knowledge gap they identified (Supplementary material S1). A total of 108 knowledge gaps were identified by 87 survey respondents (Supplementary material, Fig. S1). Those invited to the workshop were also invited to take the survey. A total of 12 people participated in both the workshop and survey. RTB, EJH, and CR worked together to group similar knowledge gaps and selected those from each group with the highest total importance score for inclusion in workshop materials intended to stimulate discussion (Supplementary material S2).

Step 2: the workshop

We held a two-day virtual workshop with 37 participants (September 2 and 29, 2021). Of the 37 workshop participants, 12 had a focus on biodiversity conservation, 17 on health and human dimensions, and 8 on policy and planning of nature-based solutions. Additionally, 21 workshop participants were affiliated with academic institutions, five worked for the federal government or municipalities, 13 worked for NGOs or consulting agencies, and two were landscape architects. Despite these categories, all work across disciplines, sectors, and at the interface between science, policy, planning, and management.

During each day, participants were split into a series of break-out rooms based on four key themes (Supplementary material S2). In recognition that the lead researcher's host institution is located on unceded territory of the Algonquin nation, Algonquin Elder Albert Dumont graciously accepted an invitation to open and close the meeting in a good way.

On the first day, participants identified a long list of knowledge gaps. Before the next session, RTB, EJH, and CR consolidated this list with those from the survey (removing redundancies). Additionally, recurring ideas or concepts that did not fit the definition of knowledge gaps (for definition see Box 1) were added to another list of 'guiding principles'. The second day, participants were asked to select the top 10-15 knowledge gaps within each of the four themes on a spreadsheet while engaging in discussion in breakout rooms. We used the last plenary discussion to group and summarize key guiding principles.

Step 3: the online discussion

Workshop participants indicated that most knowledge gaps identified cut across the initial themes used to organize the workshop (biodiversity; health and wellbeing; equity, diversity, and inclusion; and policy and planning). The core research team therefore discussed

potential new themes to categorize knowledge gaps (Fig. 1). To ensure that the breadth of comments and perspectives were understood and captured, workshop participants were provided with the final list of guiding principles and top knowledge gaps organized by theme for further online discussion. A one-month period was given to edit and comment on the final list.

Etuaptmumk

During the opening remarks of each workshop, we set a 'code of conduct', outlining Elder Albert Marshall's concept of *Etuaptmumk* (using resources from Reid et al. 2021) to stress that we were aiming for the coexistence of multiple perspectives and knowledges when identifying knowledge gaps, rather than one knowledge system subsuming another (Bartlett et al. 2012). We encouraged participants to give everyone the opportunity to contribute and show respect for all perspectives. In practice, this meant ensuring a rapporteur was present in each breakout room to facilitate contributions from the entire group. Moreover, when selecting priority knowledge gaps as a group, we made it clear that the objective was not consensus, but discussion of divergence and synergies.

Results

Guiding principles

Three key guiding principles arose from the workshop discussion. The first was the need for a general sociocultural shift and systems change away from the White-settler-colonial-patriarchal status quo that has and continues to shape the discourse and policy on nature-based solutions and urban greenspaces in Canada. Existing power imbalances continue to exacerbate issues of inequity when it comes to who makes decisions about, who benefits from, and who receives funding for research on nature-based solutions (Seddon et al. 2021). Moreover, issues of social and environmental justice remain peripheral in nature-based solutions research (Cousins

213 2020). Participants emphasized the need to view diverse perspectives as essential to the nature-
214 based solutions process, to acknowledge and unlearn discrimination (e.g., racism, classism,
215 patriarchy, ableism, queerphobia, settler colonialism), and to use lenses like social justice,
216 intersectional feminism, and anti-racism when undertaking urban environmental work (i.e., all
217 knowledge gaps are rooted in social justice and equity, Fig. 1).

218 Interweaving, bridging, or braiding Indigenous knowledges into nature-based solutions
219 was recognized as critical for transformative change (i.e., a fundamental, system-wide
220 reorganization across technological, economic, and social factors; IPBES 2019; Chaulk et al.
221 2025). Indigenous knowledge systems challenge contemporary Canadian conceptualizations of
222 nature-based solutions (Reed et al. 2022) and nature as a commodity that is separate from
223 humans (Eichler and Baumeister 2018; McGregor et al. 2020). Indigenous knowledge systems
224 are tightly bound to the land (McGregor 2004) and while different nations have unique and
225 diverse ways of knowing, a commonality is the view that the Earth is alive and infused with
226 spirit, where all beings are interconnected, interrelated and interdependent (Fox et al. 2017).
227 Colonization inverted this hierarchy of knowledge, where reductionist Eurocentric theories,
228 metrics, and statistics are seen as objective and superior to the natural and sacred laws that are
229 reflected through Indigenous cultures, ways of being, and ways of doing. Western science is now
230 the dominant (and often unquestioned) mode of knowledge generation, used and valued by
231 researchers, planners, and decision-makers. However, Western science is subject to bias and
232 subjectivity, and deferring to quantitative metrics without accompanying cultural shifts in what
233 we value as information perpetuates the status quo and limits the development of holistic
234 solutions.

Respecting sovereignly defined and applied Indigenous interests and strategies in urban areas will be key to meaningful nature-based solutions. This could mean returning dispossessed and unceded urban land to Indigenous nations or the application of what Indigenous knowledge keepers sometimes refer to as "Original Instructions" or "Indigenous laws" in the sovereign Indigenous management of urban lands (Redvers et al. 2020). Honouring Indigenous ways of knowing and sovereignty involves Indigenizing contemporary understandings of environment and health (Cloud and Redvers 2023), sharing stories, and building reciprocal relationships and partnerships that uphold Indigenous Inherent and Treaty Rights.

Participants identified the importance of pushing for structural transformation while addressing the second guiding principle – the immediate need to act now by testing and learning from nature-based solutions that centre and empower communities (e.g., Box 2). Given accelerating biodiversity loss and the increase in mental illness, it is important to act now. There is urgency to adopt solutions-oriented and learning by doing approaches (Bradshaw et al. 2021; WHO 2022). Although randomized controlled trials are important, assessing interventions on the ground using these methods is rarely possible or appropriate (i.e., interventions need to be deliberate, based on community needs, rather than applied randomly; Bauman et al. 2014). Incorporating experiments into practice; co-developing research with practitioners, decision-makers, and communities; and using decolonized methodologies offer opportunities for research foremost concerned with social justice that leads to knowledge translation and implementation of more effective nature-based solutions (Tuhiwai Smith 2012; Nel et al. 2016; Ockendon et al. 2021).

Thirdly, we identified the need for a range of approaches when researching and engaging in nature-based solutions. We discussed the importance of respecting multiple ways of

knowing and methodologies without letting one subsume another (e.g., *Etuaptmumk* and ethical space, where unique worldviews interact but remain distinct). Urban nature-based solutions are inherently transdisciplinary yet suffer from siloed disciplines, sectors, and data accessibility. Understanding outcomes and determining how to effectively mobilize nature-based solutions will involve co-developing research and sharing results across disciplines, perspectives, ways of knowing, and organizations. We identified the challenges of connecting researchers, policymakers, industry, and communities – from practical (e.g., difficulty and lack of incentives to develop networks) to systemic (e.g., different ways of relationship-building and communicating). For example, increasingly common communication tools with policymakers often involve metrics, such as ecosystem services or cost-benefit analyses (ICLEI 2018). However, for many communities, putting a dollar amount on nature is inappropriate and may obscure or contradict their needs. Within our workshop discussion, many participants emphasized knowledge gaps exploring ecosystem services and cost-benefit analysis, while others were firmly opposed to these concepts. Having conversations about diverging perspectives can be challenging and uncomfortable; however, as part of the cultural shift identified above, listening to and understanding different perspectives is necessary. A key knowledge gap identified in this workshop was how to move forward when different ways of knowing diverge.

Research agenda

Ultimately, we identified 33 priority knowledge gaps rooted in four themes (Table 1, Fig. 2). Each knowledge gap is meant to be considered within the context of the guiding principles, above.

Monitoring and evaluating outcomes

Evaluating the effectiveness of nature-based solutions in meeting biodiversity, health, and equity-related goals was identified as a major knowledge gap (Table 1). Notably, monitoring changes in biodiversity in response to nature-based interventions is necessary for determining the ability of projects to meet conservation goals. The outcomes of nature-based solutions for ecosystem health are infrequently monitored and reported, which may lead to interventions that are unable to sustain biodiversity benefits in the long term or even resulting in unintended consequences (Key et al. 2022). Embedding monitoring of conservation outcomes into nature-based solution programs can lead to adaptive approaches. To this end, we also identified the need to develop a method to compile standardized biodiversity data to compare outcomes across scales and time. Several platforms currently exist with compiled urban data (Table 1, e.g., vegetation data; https://www.canuedata.ca/), allowing evidence-based decision-making for nature-based solutions using similar metrics across cities. However, biodiversity information, including species inventories, threats to species and ecosystems, and potential conservation actions are unavailable at this scale. Understanding the distribution of species, their threats, and proposed actions could help prioritize areas in need of nature-based solutions (e.g., tree planting for species threatened by forest cover loss). While standardized measures can facilitate cross-jurisdictional information sharing and planning, in some situations they can be problematic, not accurately reflecting local needs. Thus, we identified the need for indicator species or ecosystems in urban systems, informed by holders of different types of knowledge and local social and cultural values. Developing measures that are informed by local governments and communities can support community-led outcome monitoring that can provide an opportunity for community-based decision-making (e.g., Indigenous-led biocultural indicators in the Great-

Bear Rainforest; DeRoy et al. 2019). It is well understood that environmental caretaking led by Indigenous Peoples results in better outcomes for well-being and biodiversity (Garnett et al. 2018; Dawson et al. 2021). Thus, we identified the need to understand and amplify the benefits of Indigenous-led initiatives in an urban context and understand the path towards supporting more Indigenous-led approaches (Table 1).

Similarly, a more nuanced understanding of how different aspects of nature-based solutions affect different aspects of health in different groups of people holding different identities is needed. This includes exploring connections between aspects of biodiversity (e.g., functional diversity, species richness etc.) and types of health outcomes (e.g., mental health, cardiovascular health) for different identities (e.g., newcomers to Canada). In nature-health research, less is understood about the benefits of the particular characteristics of greenspaces (Beute et al. 2021). Moreover, much of the research exploring the connection between nature and health is correlative (Frumkin et al. 2017), and little is known about how the health outcomes of nature-based solutions translate across scales, from an individual to the population at varying amounts of time spent in nature. Methods are needed to explore the mechanisms by which nature fosters health for people at different scales, while avoiding a 'one-size-fits-all' approach that prioritizes the majority.

Like all aspects of nature-based solutions research, exploring human-health outcomes must be driven by equity (Fig. 1 and Fig. 2). To support the redesign of nature-based solutions based on justice-led approaches, an improved understanding of the barriers to participating in nature-based interventions and accessing urban nature is needed (Table 1). This requires an intersectional approach informed by data and led by community experiences (Box 2, Scott and Tenneti 2024). Nature-based solutions have been labelled by many as a colonial tool, with

negative impacts ranging from displacement to community loss through nature commodification and compromised livelihoods (Anguelovski and Corbera 2022). Thus, in addition to spatial barriers (e.g., distributional green equity; Nesbitt et al. 2019, https://parkseek.ca/), there is also a need to understand how nature-based solutions exacerbate or break-down perceived, social, systemic, structural, and bureaucratic barriers rooted in colonialism and racism (Sax et al. 2022). Quantifying the well-being benefits of connecting to nature (e.g., multidimensional aspects of connection to nature; Tam 2013; spiritual and emotional connection through 'cultural ecosystem services'; Dickinson and Hobbs 2017) can be complex and in some cases, inappropriate or offensive (Chan et al. 2016). Relational aspects are often missing from nature assessments and policy because they fit poorly into the instrumental framing of ecosystem services (Chan et al. 2012; Himes and Muraca 2018). However, understanding and acting on the relational and spiritual outcomes of nature-based solutions that are difficult to quantify is no less important, and in some cases enshrined in law. For example, the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP), emphasizes the right of Indigenous Peoples to 'maintain and strengthen their distinctive spiritual relationship… and responsibilities' to the land (UNDRIP Article 25). Moreover, migrant-nature relationships, which are intersectional and deeply rooted in cultural histories (Ono et al. 2023), are largely underrepresented in urban nature-based solutions work. To complement quantitative approaches to measure well-being outcomes of nature-based solutions, co-production of a metric that captures relational aspects while respectfully considering socio-cultural diversity of cities is needed (Fig. 3, Table 1).

Diversifying methodologies and approaches to decision-making

Reviewing and evaluating policy instruments that support the adoption, and increase the effectiveness of nature-based solutions was identified as a knowledge gap (Table 1). Examples of

specific nature-based solution policy tools and their effectiveness in practice in cities are still scarce in the literature (Caillon et al. 2017). This includes understanding the effectiveness of incentives and regulations (Rode et al. 2015); policy tools that explicitly break down silos and consider the connection among biodiversity, health, equity, and Indigenous sovereignty (e.g., Environment in All Policies and Health in All Policies; Browne and Rutherfurd 2017); and connections among different levels of governance (e.g., international-level biodiversity conservation i.e., Convention on Biological Diversity and policy realities of land use planning in municipalities, governed in Canada by provinces, territories, and Indigenous governments).

Evaluating a variety of design and planning approaches using iterative, inclusive, and ongoing processes can lead to more equitable outcomes and increase social, perceptual, and physical access to nature-based solutions. We identified the need to explore Indigenous frameworks (e.g., Indigenous-municipal relationships centred on reconciliation; Anderson and Flynn 2020; colonial audits; Soutar 2022), ethical co-development methods (Ethical space; Ermine 2007; Urban Transition Labs; van der Jagt et al. 2019), and hybrid governance (Toxopeus et al. 2020) that give communities a central role in urban decision-making, rather than equity, diversity, and inclusion as an afterthought (Table 1). To ensure all voices are heard, both methods will involve relationship building and inclusive, sometimes non-quantifiable, notions of nature and health that capture lived experiences. This will require respecting local communities as extensive knowledge holders capable of making decisions, rather than expecting them to adopt Western practices to be legitimized. Moreover, avoiding the situation some community groups have faced where, because of disproportionate power dynamics, participation in bureaucratic channels result in a brief aside that there was ‘some opposition to the project’ and little meaningful change to the outcome (Rosan 2012). Exploring methods where nature-based

solution planning and policymaking is used as an avenue to advocate for social justice is needed, particularly those that explicitly acknowledge the potential risk these processes pose for racialized and marginalized communities. Finally, understanding approaches to amplify Indigenous-led urban land-based healing programs, including more holistic models of health, which are largely excluded from academic discourse (but for examples see: Redvers et al. 2021; Cloud and Redvers 2023) and how to give teeth to Indigenous law in urban areas (e.g., through recognizing UNDRIP; Table 1).

Lastly, we identified the need to understand what information drives decision-makers and planners at different levels (industry, policymakers, urban planners, politicians, communities) to increase support for nature-based solutions in cities. In many cases, evidence and local knowledge are not used to make decisions (Sutherland and Wordley 2017). Moreover, we identified the necessity to understand how to shift the priorities of decision-makers when justifying environmental policies, from economic drivers to social well-being. Additionally, there is a need to understand how actors at different levels of governance contribute to momentum for nature-based solutions. For example, pressure from industry can often undermine federal and provincial policy and implementation of nature-based solutions (Dembicki 2022).

Exploring links and trade-offs

Urban nature-based solutions can result in green gentrification, whereby projects attract investment and developer attention and subsequently more White and wealthy residents, or the greenwashing of existing gentrification processes (Sax et al. 2022). Thus, under-resourced and otherwise marginalized residents can be excluded from the benefits of environmental interventions, intensifying urban socio-spatial inequities (Wolch et al. 2014). At the same time, avoiding gentrification can be used as an excuse to justify a lack of investment in urban nature.

394 Understanding the link between biodiversity conservation and gentrification, and factors that
395 lead to co-benefits for biodiversity and social justice from nature-based solutions in different
396 contexts is important to create strategies that empower communities (Table 1; Pearsall and
397 Anguelovski 2016). In general, a better understanding of trade-offs, synergies, and co-benefits of
398 biodiversity, health, and social justice goals is needed. There is little understanding of how
399 nature-based solutions that maximize one factor (e.g., conservation) will affect others (e.g., road
400 closures in urban parks around sensitive habitat may reduce roadkill but limit accessibility;
401 Colléony and Shwartz 2019). This emphasizes the need for ethical methods for community
402 empowerment, as outlined above, and the need to increase connection among different
403 disciplines, sectors, organizations, departments, communities, and nations. This is particularly
404 the case for policy and planning, as housing and economic development policy-making typically
405 falls outside of departments responsible for nature-based solutions, and because green
406 gentrification is caused by a confluence of factors.

407 There may be conflicts or synergies among the needs of different people who are
408 vulnerable or marginalized (e.g., youth and elderly, marginalized gender identities and sexual
409 orientations, racialized people, people with disabilities, neurodiverse identities, individuals
410 experiencing poverty, cultural minorities). Different people experience urban nature in different
411 ways (i.e., experiential equity; Mazumder 2021), shaped by cultural and social identities and
412 systemic injustices of settler colonialism and racism. Consequently people may have preferences
413 for different landscapes or types of nature-based interventions, where personal identity can lead
414 to different nature-connectedness and mental and physical health outcomes (Capaldi et al. 2015;
415 Ordóñez-Barona 2017) and trade-offs with biodiversity conservation. We identified the need to
416 understand the relationship between nature and health among social identities using an

417 intersectional approach that leads to just and integrated strategies (Table 1). This will involve an
418 understanding of lived experiences, quality of life, and normative community expectations of
419 marginalized people in urban areas, which may be unrelated to biodiversity (Milfont and Schultz
420 2016). Land-use planning rarely incentivizes equity-based liveability nor biodiversity
421 conservation, further emphasizing the need for breaking down silos in policy-making. From
422 many culturally resurgent Indigenous perspectives, establishing more meaningful nature-based
423 approaches extends beyond humanly defined conceptions of equity, social justice, and
424 biodiversity, and well beyond better integrated human interests and strategies. It will involve
425 understanding the radical changes necessary to respect Indigenous law and treaties in municipal
426 policy, planning, and actions. Indigenous human laws are grounded in what are sometimes called
427 natural laws and sacred laws, which are distinct (Craft 2017). Finding ways to reflect these laws
428 into human laws and behaviours is seen by many Indigenous Peoples as essential to ensure that
429 healthy, balanced relationships among all layers of life and being are upheld through space and
430 time (Redvers et al. 2020).

431 Importantly, an evaluation of both positive and potential negative impacts of nature-based
432 solutions is needed, from an intersectional, coupled social-ecological perspective (Table 1).
433 Nature is not a neutral place for many people. For example, for people with disabilities,
434 inaccessible natural spaces can lead to feelings of exclusion (Corazon et al. 2019). For
435 Indigenous Peoples, Black communities, and women it can be a place of violence and stress
436 (Waldron 2022). Spending time in urban greenspace, where the impacts of environmental
437 degradation are apparent, can be a painful reminder of the ongoing effects of colonialism. In
438 general, landscape change can have a negative influence on human-nature connectedness
439 (Riechers et al. 2020), through mechanisms such as eco-anxiety (Panu 2020) or fear (e.g., of

crime, disease from insects; Vojvodíková et al. 2022). Understanding how to manage grief and curb hopelessness associated with witnessing large-scale environmental problems (e.g., wildfire smoke) is a key need, particularly with youth (Chawla 2020).

Understanding these risks and trade-offs is also important from a policy and governance perspective. Weighing the cost-benefit of nature-based solutions and economic valuation is currently an important policy tool (e.g., https://naturalcapitallab.com/), especially for prioritizing green over grey infrastructure and health care cost savings (Seddon et al. 2020). However, we discussed the need for caution in assigning economic value to nature-based solutions and to prioritize relational and non-monetary values. A key knowledge gap is understanding if and how these tools can be used without compromising relational values to nature (Table 1). Participants stressed the importance of changing mindsets and incentives to build policies focused on social and environmental well-being (see Guiding Principles).

Increasing support through knowledge-sharing and communication

Connection to nature is associated with pro-environmental behaviour (Whitburn et al. 2020). Yet our understanding of types and aspects of nature-based solutions that strengthen this association is limited, and most research has focused on Western cultures. Interventions that increase contact with and connection to nature are needed to encourage care for and respect of nature. Outdoor learning is a key mechanism, and we identified the need to understand how different pedagogical approaches encourage environmental stewardship, responsibility, and respect (Table 1; Suárez-Perales et al. 2021). In particular, testing alternative, holistic approaches that move beyond awareness of challenges to youth-led problem solving (Anderson et al. 2017; Ballard et al. 2017).

462 We need to understand how to communicate the importance of biodiversity and nature
463 for health to different audiences (e.g., doctors, schools, faith-based communities, cultural
464 communities), taking a contextual approach. This will involve understanding the health priorities
465 of different groups and how they perceive the medical system to make interventions more
466 accessible (e.g., park prescriptions, where physicians prescribe patients time spent in nature;
467 James et al. 2019). Moreover, developing appropriate communication will involve partnering
468 with grassroots organizations and community leaders to identify key messaging. Designing better
469 interventions will also involve understanding how identity and social-environmental factors
470 affect how people relate to nature, including care, stewardship, kinship, core values,
471 responsibility, and respect (Table 1; Chan et al. 2016). Understanding the range of practices and
472 experiences with urban nature, particularly those that challenge Western settler-colonial
473 approaches of separating humans from nature (Pascual et al. 2021).
474 Exploring and communicating success stories and bright spots of equitable urban nature-
475 based solutions is an opportunity to identify key features and contexts leading to success
476 (Apfelbeck et al. 2020). Research and storytelling around success stories can empower scientists,
477 communities, and decision-makers to continue to innovate new ways of working together
478 (Cvitanovic and Hobday 2018). Spreading positive messages about action for biodiversity
479 conservation and environmental justice is an essential component of inspiring social change
480 (Amel et al. 2017). Storytelling, including the use of digital and visual tools, is a particularly
481 powerful method of amplifying a range of voices (Cisneros et al. 2023). How to craft and spread
482 stories of success in an appropriate context that moves beyond individual change to mobilizing
483 collective action is a major knowledge gap (Table 1; Gladwin 2020).

Targeted communication around funding for nature-based solutions will also be key to ensure underfunded groups receive more support. Projects led by Indigenous Peoples and Black, racialized and other marginalized communities still suffer from systemic injustices of inequitable distribution of financial resources (Pereira et al. 2020). Moreover, granting agencies are often ill-equipped to appropriately assess the relevance of projects led by Indigenous and racialized scientists and projects partnering with communities (Ford 2022). Mechanisms to catalyse and direct funding (e.g., Box 2), provide awareness around evaluating the importance of applications, and, when necessary, bring in research capacity to support these programs (e.g., https://researchforthefrontlines.ca/) are critical (Table 1).

Discussion and conclusion

By working with a group of experts that spanned disciplines, organizations, and lived experiences, we were able to identify key knowledge gaps to facilitate action-oriented research around nature-based solutions. We identified guiding principles to frame these knowledge gaps and shift the culture to one of diverse, co-existing knowledge production: 1) breaking down existing power imbalances and centring Indigenous knowledges; 2) moving forward with equity-based action and learning by doing; and 3) co-developing research across disciplines, perspectives, ways of knowing, nations, communities, departments, and organizations.

Colonization and systemic racism, from land dispossession to hierarchies of knowledge, are fundamental lenses through which to understand how urbanization impacts biodiversity and health. Colonization has resulted in the dominance of Western science as the objective source of evidence to guide decision-making. Key to diversifying knowledge production in nature-based solutions research is acknowledging the values, biases, and assumptions embedded in Western sciences. Furthermore, bringing together the strengths of different ways of knowing and

disciplines is a way to provide a more comprehensive understanding of shared urban issues and improve problem solving (Johnson et al. 2016). In particular, it will be vital to centre Indigenous sciences, which are rooted in connectedness with creation and spirituality (Cajete 2000), rather than integrating them into Western knowledge. Countries as multicultural as Canada also have access to a wide array of knowledge production, for example Black knowledges and Afrofuturism (Holbert et al. 2020), Sikh philosophy (Mandair 2022), and queer literatures (Butler 2017). Using a diversity of knowledges can help build goals and define 'successful' outcomes of nature-based solutions in ways that are more equitable and inclusive (e.g., philosophical movements that seek to better value the common species found in urban spaces; Collard et al. 2015).

The interconnections among biodiversity, human health, and equity, calls for more research into innovative, holistic, and transparent monitoring, evaluation, and policy tools. Links with public health policy may be a key mechanism for protecting biodiversity and addressing environmental justice. In particular, explorations of how interventions address health needs of marginalized communities may be the most equitable metric of evaluating urban nature-based solutions. Fundamental to a holistic approach will be finding trade-offs and synergies, amongst goals and people's needs. Cities include people of wide-ranging identities, whether it be race, ethnicity, cultural origin, religion, gender, sexuality or ability-status, with unique needs around health and nature. Indigenous Peoples and Black, racialized, low-income, and otherwise marginalized communities often bear the brunt of the consequences of biodiversity loss, as well as the trade-offs of inequitable efforts to restore biodiversity (Meyerson 1997). For settler colonial societies, these inextricable links emphasize the need for bottom-up mechanisms to ensure solutions are community and grassroots designed and led, rooted in tools of social justice,

antiracism, anti-ableism, Indigenization and decolonization. In reimagining cities to support engagement with nature that is mutually beneficial for human and non-human species, nature-based solutions rooted in Indigenous ways of knowing and community needs offer the possibility of decolonization.

Our initial aim for this exercise was to identify research at the health-nature-equity nexus of nature-based solutions. The survey and workshops were designed and hosted by White settler scientists and academics who call what is currently Canada home. However, in engaging with the workshop participants, conversations shifted, led and hosted by the participants, stemming from their various academic, professional, lived, and cultural experiences. With input and leadership from participants during and after the workshop, this study developed into an even more meaningful critical discussion seeking to move away from patriarchal, Eurocentric, colonial approaches, and building collective forms of healing and resistance. While we consider ourselves people who love and care for the environment, each participant had unique family histories, religious affiliations, home cities, lived experiences, educations, and pedagogies. This allowed for diverse experiences and perspectives to enter what are often sterile conversations on biodiversity and nature-loss in urban settings. Therefore, what was created is a broad set of knowledge gaps that recognize the importance of coordinated efforts that break institutional silos and reflect the complexity of what it means to live in urban environments. We acknowledge that our group, like any subset of people, does not represent all lived-experiences; thus, we wish to stimulate ongoing conversations to broaden researcher perspectives around nature-based solutions. We cannot improve urban biodiversity without improving the societal norms and institutional systems that are fuelling its demise. Although nature-based solutions are not going to solve the deep-seated social and environmental challenges we are currently grappling with, if

553 rooted in equity and respect for Indigenous ways of knowing, they offer positive pathways
554 forward.

555 Conflict of interest statement

556 We have no conflict of interest.

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92 Box 1. Definitions of terms used in the text. Only definitions of nature-based solutions and knowledge gaps were provided to survey and workshop participants.

Biodiversity and nature: Defining biodiversity or nature that fits across disciplines and ways of knowing is challenging, if not impossible. Throughout this exercise, we used these terms interchangeably and broadly rather than attempting coalescence. 'Nature' describes various biotic and abiotic features of nonhuman origin that compose urban landscapes (Hartig et al. 2014). Given the urban context, nature is contrasted with the built environment. Workshop participants identified urban nature ranging from medicinal plants, street trees, canals, green roofs, parks, yards, to urban protected areas. Nature includes 'biodiversity', defined as the variety of life on Earth, from genes to ecosystems (Marselle et al. 2021), which is associated with ecosystem functioning, resilience, and health (Tilman et al. 2014). 'Nature, especially in the health literature, also includes 'greenspace' or an area of vegetation set apart for recreational or aesthetic purposes in an otherwise urban environment. The term 'land' includes 'nature', but for many Indigenous Peoples it goes deeper to be integral to cultural identity, where all beings are interconnected, related and imbued with spirit (McGregor et al. 2020; Redvers et al. 2020). The more-than-human world exist on their own terms and 'nature' and 'land' are intertwined with cultural protocols of respect, reciprocity, and responsibility (Pierotti and Wildcat 2000). We note that defining 'nature' is difficult even in English and is even more challenging to define in ways that correspond meaningfully with Indigenous conceptions.

Health: We use the World Health Organization definition "a state of complete physical, mental, and social well-being not merely the absence of disease or infirmity" and the definition of planetary health, where a healthy environment is needed to support healthy communities (Redvers 2021).

Justice and equity: we use interchangeably, defined as multidimensional concepts based on the *"distribution* of costs, responsibilities, rights, and benefits; the *procedure* by which decisions are made and who has a voice; and *recognition*—acknowledgement of and respect for the equal status of distinct identities, histories, values, and interests" (Friedman et al. 2018). These terms can be difficult to translate to correspond reliably in relation to Indigenous ideas.

Land-based program: We use Redvers (2020) definition "A culturally defined program or service … which involves cultural teachings and intergenerational knowledge transfer, combined with any number of other activities or goals. Programs are informed by an Indigenous pedagogy wherein the land is the main source of knowledge and teaching."

Nature-based solutions: In the survey and workshop we used this term interchangeably with 'nature-based intervention' and 'nature-based project', defined as programs, activities, or strategies to promote health and well-being with nature exposure (e.g., tree planting, park prescription programs, urban protected areas, medicine wheel gardens, habitat restoration, community gardens, for full list see Supplementary material S1; Shanahan et al. 2019). 'Nature-based solution', the broader concept used here, is defined by the International Union for Conservation of Nature as "actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (Cohen-Shacham et al. 2016).

Knowledge gaps: All information and knowledge needed to support progress towards more effective nature-based solutions, adopting an inclusive and pluralistic view of what counts and is respected as both knowledge and science (Buxton et al. 2021). Knowledge gaps are achievable by a research program or group.

924

Box 2. An example of ethical collaboration, trust building, and centring diverse communities for nature-based solutions planning and policy making in Toronto, Canada. This program also represents an adaptive, learning-by-doing approach.

Toronto is Canada's largest city, built on the traditional territories of the Mississaugas of the Credit, the Anishnabeg, the Chippewa, the Haudenosaunee and the Wendat peoples and is covered by Treaty 13 and the Williams Treaties. A system of ravines covers 17% of the city's area, representing critical habitat for a variety of important species and an opportunity for human-nature connection (City of Toronto 2016). Urban development and climate change pose increasing threats to ravine ecosystems. Moreover, inadequate and inaccessible infrastructure are barriers to access for equity-deserving communities (Scott and Tenneti 2021).

To increase equitable access to natural ravine spaces while cultivating relationships of reciprocity and respect for the land, Park People in partnership with the City of Toronto have developed the InTO the Ravines program (https://parkpeople.ca/opportunity/into-the-ravines/). The program design has evolved over time, incorporating learnings from a partnership toolkit (Nature Canada 2021) derived from focus groups on outdoor programming for youth of colour (Scott and Tenneti 2021) and Toronto's municipal Ravine Strategy (City of Toronto 2016). Feedback from program participants and local Indigenous leaders is currently guiding a program update to centre land-based, Indigenous-led learning sessions. The program provides support for community leaders from equity-deserving communities, including training workshops, peer mentorship, and grants to support community events (e.g., nature walks) and stewardship projects. All participants take part in city-wide learning opportunities, featuring experts in Black history of the ravines (Scott 2021) and the role of the ravines in Indigenous storytelling (Carriere 2020).

As an alternative to centrally developed programming, inTO the Ravines is responsive to evolving participant needs, providing flexible, unrestricted resources for community leaders to engage neighbours in ravine activities. Participants from past years mentor current participants, allowing the program partners to decentre themselves and transfer aspects of program delivery and decision-making to community leaders. Program evaluations show that participating in events had a profound impact on attendees: nearly 25% had never visited a ravine before, 91% intended to encourage friends and family to visit the ravines, 100% reported feeling more connected to their community, and 83% reported feeling more connected to nature and other living things (Park People 2022,).

Participants in Ravine Days, Rowntree Mills Park, Toronto, 2023. "I am thankful for the nice trees" and "I am thankful for my family" say the gratitude cards made by kids in the picture on the right (*credit: Jennifer Lee, Markbrook Residents Group & Steps Public Art*)

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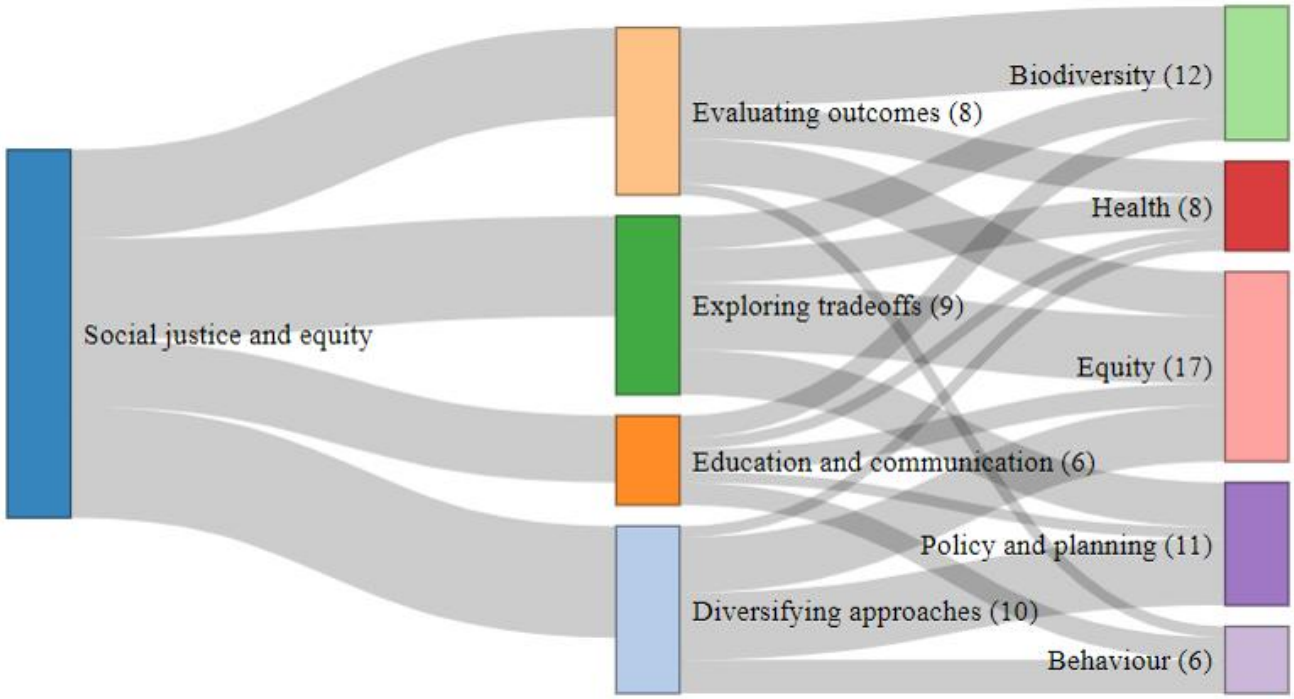

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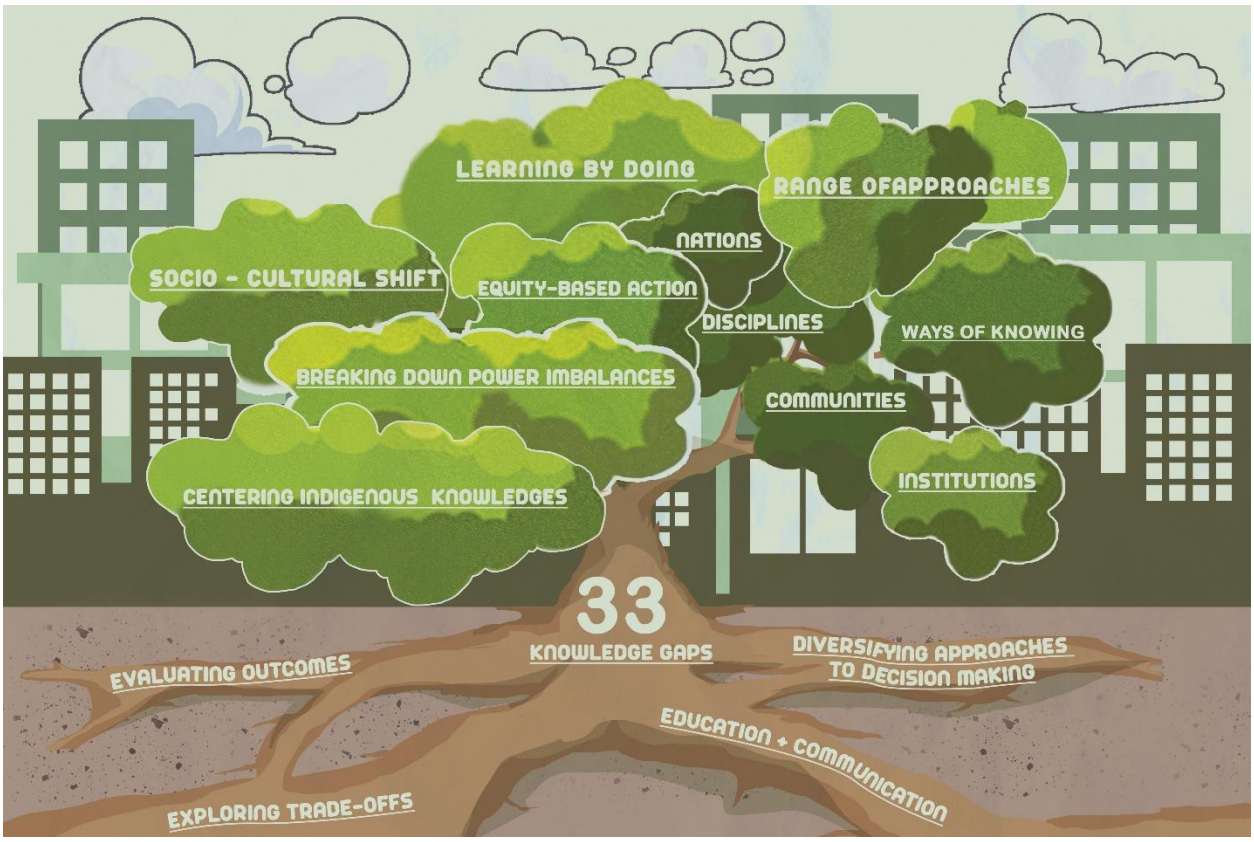
927 **Figure 1.** Sankey diagram showing the number of knowledge gaps in each key theme of a research agenda for nature-based solutions.

928 All knowledge gaps stem from social justice and equity.



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930 **Figure 2.** Visual representation the resulting 33 knowledge gaps forming our research agenda.
931 These knowledge gaps are rooted in 4 themes (monitoring and evaluating outcomes, diversifying
932 methodologies and approaches to decision-making, exploring links and trade-offs, and increasing
933 support through education and communication). All knowledge gaps are meant to be considered
934 under the canopy of (within the context of) the guiding principles. Image by Brian Akin.

935

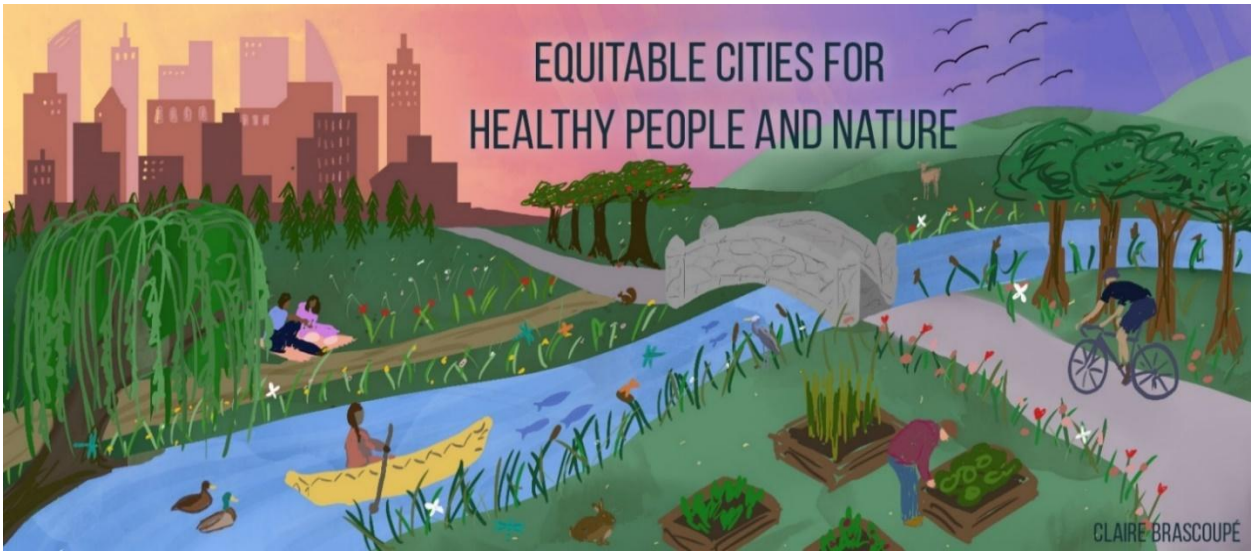

Figure 3. The variety of ways of relating to nature in cities reflects socio-cultural diversity of urban areas. People with different ways of knowing, lived experiences, inhabiting different bodies and identities lead to different ways of connecting with nature, from sport, gardening, canoeing, picnicking, playing, napping, ceremony, feasting, teaching. These and other descriptors imply different overlapping aspects of relations within nature which far exceed the definition of greenspace or ecosystem services. Image by Claire Brascoupé.

944 **Table 1.** 33 knowledge gaps for an action-oriented research agenda that maximizes the biodiversity, human health, and equity benefits

945 of nature-based solutions identified through a workshop and survey of experts in what is currently Canada.

Theme	Knowledge gap
Monitoring and evaluating outcomes	• Monitor biodiversity before and after nature-based solutions to explore the ability of projects to meet goals • Develop a method to compile standardized biodiversity monitoring across scale and time to explore threats and prioritize interventions • Develop key biodiversity indicator species or ecosystems in urban areas informed by local holders of different types of knowledge, to support outcome monitoring and decision-making • Identify and amplify the outcomes and benefits of Indigenous practices for care-taking of urban nature to facilitate more opportunities for Indigenous sovereignty in cities • Understand what natural environments, aspects of biodiversity, and nature-based solutions support different aspects of human health • Understand the mechanisms by which nature provides health benefits to people at different scales while avoiding a 'one-size-fits-all' approach • Understand the root causes of barriers to participating in nature-based solutions and accessing urban nature to support redesign according to justice-led approaches • Develop appropriate methods to characterize aspects of nature connection that are more difficult to quantify, including more mindful inclusion of community and spiritual wellbeing
Diversifying methodologies and approaches	• Evaluate the effectiveness of incentives versus regulatory policy tools in supporting uptake of nature-based solutions and their ability to effectively meet goals • Identify policy tools that explicitly consider biodiversity, Indigenization, social justice & health in cities as connected • Explore the interaction between international and national policy on nature-based solutions and land-use planning at a municipal level • Understand how to centre the history of the land and Indigenous frameworks in nature-based solutions • Identify and evaluate design processes that lead to more equitable outcomes to nature-based solutions and increase access to nature • Explore and summarize methods for ethically collaborating, building trust, and centering diverse communities for nature-based solutions planning and policy-making • Understand how to co-produce nature-based solution projects with communities, involving rights-holders and diverse stakeholders from the beginning

	• Identify and amplify Indigenous-led land-based healing programs and how Indigenous land-based knowledge is applied to health in an urban context • Evaluate the effectiveness of approaches that drive decision-makers and planners in different institutions to increase support and implementation of nature-based solutions • Understand how to shift priorities of decision-makers from economic drivers to social wellbeing when justifying nature-based policies
Exploring links and tradeoffs	• Understand the link between nature-based solutions and gentrification/the housing crisis • Understand trade-offs between biodiversity conservation, health, and social justice goals and outcomes and develop guidance on how to prioritize needs • Identify ways to increase connection among different disciplines, sectors, and organizations, communities and nations to ensure co-benefits make their way into policy and planning • Identify conflicts and intersections, and their root causes, between different people's needs to generate holistic equitable nature-based solutions • Understand the relationship between the experiences of people who are vulnerable or marginalized in nature and both physical and mental health outcomes to account for intersectionalities • Explore methods to incorporate liveability, quality of life, environmental justice, and biodiversity conservation into policy • Understand how to evolve our systems to better centre Indigenous law and treaties into nature-based municipal policy and planning and ensure relationships are upheld • Understand negative association and experiences with natural spaces and nature-based solutions • Explore the economic costs and benefits of nature-based solutions for biodiversity and health without compromising the importance of relational values
Increasing support through knowledge-sharing and communication	• Understand what types of nature-based solutions encourage stewardship, responsibility, pro-social, and pro-environmental behaviours • Understand mechanisms to build support for urban biodiversity conservation through education and outdoor learning • Understand how to communicate the importance of nature for health to different audiences • Understand how different people engage with biodiversity (perceptions, relationships, responsibility, morals, and ethics) in urban environments for better intervention design • Identify mechanisms to better document nature-based solution success stories and share them in a compelling way to support social change and inform policy and practice • Identify who is receiving funding and support for nature-based projects and to guide which groups require increased support and targeted communication about funding opportunities

946

Supplementary material S1: Extended survey methods

We disseminated a survey to 450 expert participants. Experts were researchers, scholars, policy specialists, or Indigenous Elders within what is currently Canada who were identified by reviewing the literature on nature-based solutions, urban ecology, health equity, land-based healing, nature-connectedness, and the link between health and nature. We then used snowball sampling, where participants and potential workshop candidates identified further participants within their broader networks. We also disseminated the survey over Twitter and professional listservs. We used an online survey to collect responses to questions during a five-week timeframe and anonymized the resulting data on knowledge gaps.

We asked survey participants to describe their role in nature-based solutions (practitioner, researcher and/or scientist, manager or other); to identify their area of expertise (biodiversity; human health and wellbeing; equity, diversity, and inclusion; policy; human behaviour, nature connectedness; nature-based education; or other); and what best describes the organization they work for (NGO, non-profit, federal government, provincial government, municipal government, academic institution, consulting firm, self-employed, or other). We used the term "nature-based intervention", "nature-based project", and "nature-based solution" interchangeably, defined as initiatives to promote health with nature exposure. Participants were then asked to identify up to five knowledge gaps that would maximize benefits to biodiversity, human health, and equity. In order to rank and rate knowledge gaps, we used a structured decision-making approach (Gregory et al. 2012). We asked participants to rate each knowledge gap on a scale of 1-5 (low to high) by its importance for each of the following: applicability (how applicable addressing the knowledge gap is to nature-based solution policy or practice), certainty (with what level of certainty the information will yield answers that inform or support nature-based solutions), scope (the

geographic and/or temporal extent at which the results of the knowledge gap can be applied), and feasibility (how many years will it take to address the knowledge gap and how logistically complicated and costly it is to address the information need).

Knowledge gaps were identified by 87 survey respondents with diverse areas of expertise (Supplementary Fig. S1). We refined and collapsed knowledge gaps to avoid redundancies (e.g., similar concept with different wording), in which case their ratings were averaged. We categorized knowledge gaps identified in the survey into thematic areas that served as the starting point for the workshop discussions (Supplementary material S2). In each thematic area, we selected the knowledge gaps with the highest total importance scores and included them in materials given to workshop participants before and during the first day of online discussion (Supplementary material S2).

We used the following examples of nature-based solutions or projects in the survey and workshop opening remarks: protected urban parks and natural environments, restoration, tree planting, greening projects (e.g., school ground greening), land-based healing, ceremonial practices, medicine wheel/teaching gardens, 'park prescriptions' (where health practitioners prescribe nature–based experiences), green exercise/fitness programs, community gardens, community science programs, land-based education, river cleanups, and green infrastructure (e.g., bioswales, green roofs, rain gardens).

Workshop participants were recruited by phone and email. To capture conversation, rapporteurs took notes and workshops were recorded for review. We used a combination of notes, review of recordings, and spreadsheets shared on the second workshop day to write the text and create the final list of knowledge gaps.

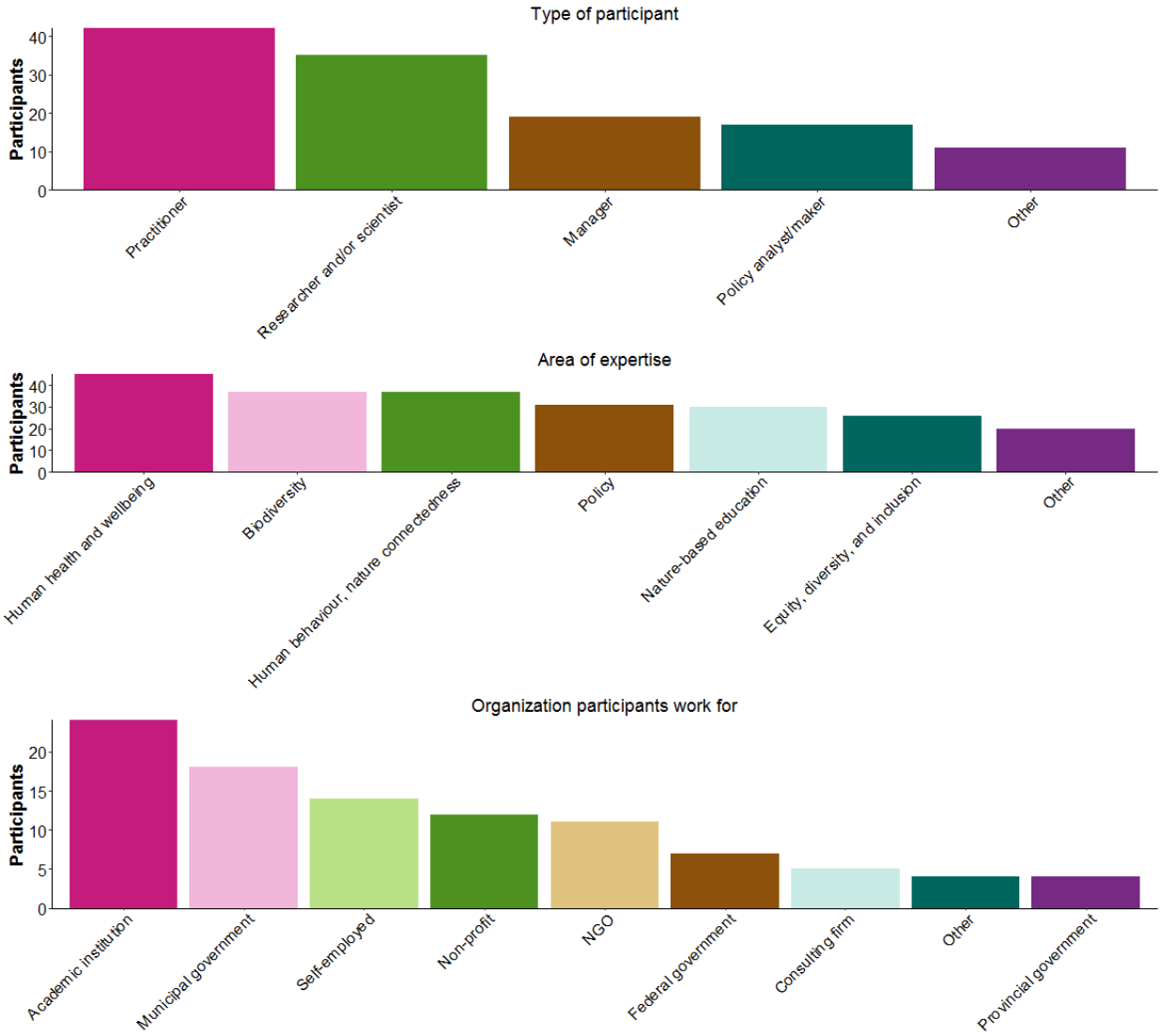

Figure S1. Area of expertise of 87 survey respondents categorized by: i) role of the participant in the field of nature-based solutions, ii) their focal discipline, and iii) institution they work for.

Supplementary material S2: Workshop materials to guide discussions based on broad aims of nature-based solutions and key results from the online survey.

Theme Profile: **BIODIVERSITY**

Context:

Urbanization is a major contributor to biodiversity loss

Urban land cover is expected to triple from 2000 to 2030, altering large areas of natural habitat

Many cities are biodiversity hotspots, with high concentrations of species at risk of extinction

For 70% of Canadians, urban biodiversity represents their primary exposure to nature

Urban parks and greenspace are important refuges for native and threatened species and can provide important ecosystem services

What we heard: **Information needs highlighted from the survey results**

- Understanding the outcomes of different types of nature-based projects and the influence of the built landscape
- Quantifying ecosystem service outcomes of nature-based projects (climate adaptation, reduced air pollution etc.)
- Understanding key indicators and metrics of biodiversity outcomes
- How to manage pest species and support pollinators
- Need for long term monitoring and inventory, open source data, and baseline studies (e.g., urban protected areas, threatened species, tree canopy)
- Identifying replacements for turf grass that support biodiversity
- How biodiversity fosters nature connectedness and linking with social justice

Guiding questions:

1. What information is required to ensure nature-based projects encourage nature connectedness, stewardship, and pro-environmental behaviours?
   - Education and outreach
   - Appreciation of value
   - Involvement in conservation
   - Individual/political motivation
   - Behaviour
2. Are there data gaps or data accessibility gaps?
   - Inventory
   - Monitoring
   - Research
3. How can we better understand the outcomes of nature-based projects for biodiversity?
   - Outcomes of restoration
   - Mitigating threats
4. If information is not the limiting factor, what mechanisms are needed to transform information into action?
   - Pathways to resources
5. How can we respect multiple ways of knowing, co-create solutions for better nature-based projects, and amplify Indigenous-led initiatives?

Theme Profile: HEALTH AND WELLBEING

Context:

Natural environments provide a variety of psychological wellbeing and health benefits, from improving mental health to reducing cancer mortality.

The presence, accessibility, "greenness", and duration and type of time spent in natural spaces are known to affect health outcomes, but the role of biodiversity is underexplored

Nature-based health interventions are increasingly used to prevent illness, promote wellbeing, and treat specific conditions

Interventions include the protection and restoration of greenspace and specific programs

What we heard: Information needs highlighted from the survey results

- Understanding specific relationships between aspects of nature (e.g., species diversity, habitat types) and human health outcomes
- How nature-based interventions influence mental health to be able to provide prescriptive recommendations
- Understanding relationships between nature and health outcomes for people who are racialized in Canada
- What are the costs, benefits, and potential economic savings on health interventions provided by access to nature?
- Reducing barriers, ensuring access to nature, and incorporating community engagement to maximize potential health benefits for everyone

Guiding questions:

1. What information is required to ensure nature-based health interventions encourage nature connectedness, stewardship, and pro-environmental behaviours?
   - Education and outreach
   - Appreciation of value
   - Individual/political motivation
   - Behaviour
2. Are there data gaps or data accessibility gaps?
   - Inventory
   - Monitoring
   - Research
3. How can we better understand the outcomes of nature-based projects for human health?
   - Outcomes of interventions
   - Which projects are most effective?
   - Inequities in access/experience as a health intervention
4. If information is not the limiting factor, what mechanisms are needed to transform information into action?
   - Pathways to resources
5. How can we respect multiple ways of knowing, co-create solutions for better nature-based projects, and amplify Indigenous-led initiatives?

Theme Profile: EQUITY, DIVERSITY, AND INCLUSION

Context:

In many cities, lower socioeconomic groups and ethnic minorities face multiple barriers to accessing nature, including lower quantity, quality, and safety of parks

Both participants in and beneficiaries of nature-based projects are often upper-middle-class white communities

Nature-based projects can catalyze gentrification processes (green gentrification) and enforce settler colonial land management practices

Intersectional, anti-racist approaches are a key factor in planning for nature-based projects

What we heard: Information needs highlighted from the survey results

- Understanding who has access to nature in Canadian cities and where nature-based intervention are most needed to increase diversity of access
- What are barriers to access and how can they be overcome (e.g., transportation)
- How to implement nature-based interventions while avoiding gentrification
- Understanding the outcomes of nature-based interventions and motivations for stewarding nature for different racialized groups and cultures, including new Canadians
- Mechanisms to mobilize knowledge to support Indigenous-led projects
- How to center social justice as a key component of nature-based interventions

Guiding questions:

1. What information is required to ensure nature-based projects encourage nature connectedness, stewardship, and pro-environmental behaviours for all?
   - Education and outreach
   - Appreciation of value from different perspectives
   - Diversity of involvement in conservation
   - Individual/political motivation
   - Behaviour
2. Are there data gaps or data accessibility gaps?
   - Inventory
   - Monitoring
   - Research
3. How can we better understand the outcomes of nature-based projects for EDI?
   - Social justice
   - Equity of access
4. If information is not the limiting factor, what mechanisms are needed to transform information into action?
   - Pathways to resources
5. How can we respect multiple ways of knowing, co-create solutions for better nature-based projects, and amplify Indigenous-led initiatives?

Theme Profile: POLICY AND PLANNING

Context:

Approaches, policies, regulations, and legislation that consider nature and health in the design and planning of cities vary considerably across Canada

Top-down policies and plans can have perverse local EDI and wellbeing outcomes

Although there are many urban nature-based projects across Canada, outcomes are rarely evaluated or made accessible, making evidence-based planning challenging

A lack of community engagement, public support, and political support are major barriers to mobilizing urban nature-based projects

What we heard: Information needs highlighted from the survey results

- More baseline studies and accessible evidence needed, including user-friendly tools, to guide best practices
- Understanding trade-offs and win-wins for nature-based projects that benefit biodiversity, ecosystem services, health, and social justice
- Need for information at the community scale, centered on relationship building, while accounting for different ways of knowing, especially in poor, racialized, and Indigenous communities
- Developing metrics, taking into account trade-offs, cost, and community support
- Understanding the motivations and attitudes underlying decision-making that does not prioritize biodiversity or wellbeing

Guiding questions:

1. What information is required to ensure policies supporting nature-based projects that encourage nature connectedness, stewardship, and pro-environmental behaviours?
   - Education and outreach
   - Appreciation of value
   - Involvement in conservation
   - Individual/political motivation
   - Behaviour
2. Are there data gaps or data accessibility gaps to inform effective policies and plans?
   - Cost-benefit analysis
   - Publicly available tools
3. How can we better understand the outcomes of nature-based projects to inform policies and planning?
   - Synergies
   - Trade-offs
4. If information is not the main barrier for win-win policies and plans, what mechanisms (including pathways to resources) are needed to transform information into action?
   - Pathways to resources
5. How can we respect multiple ways of knowing, co-create policy and planning solutions for better nature-based projects, and amplify Indigenous-led initiatives?

Supplementary material S3: Online survey circulated to 450 experts in urban nature-based solutions.

Nature-based solutions to bolster health and biodiversity in Canadian cities

Purpose of the research: To identify key science and information needs to help maximize the benefit of nature-based interventions for biodiversity conservation, human health, and equity. Context: Over 70% of Canadians live in urban areas, a proportion that is expected to continue increasing. Urban growth is a key contributor to the ongoing biodiversity crisis and public health problems, leading to health risks, inequitable access to resources, and environmental degradation. Ultimately, urban living reduces people's contact with the natural environment, which is problematic because exposure to nature is associated with better health and promoting environmentally sustainable behavior. Meanwhile, efforts to conserve biodiversity mainly focus on large, relatively untouched areas with high biodiversity. *Restoring and protecting biodiversity in urban areas through nature-based solutions offers an opportunity to foster nature connectivity and health for an enormous number of people, while simultaneously improving conservation outcomes.* What we're asking you to do: Explore the key obstacles to achieving nature-based interventions that address biodiversity conservation, human health, and equity. To outline the nature-based interventions you work on in Canada. And identify key pieces of evidence needed for more effective nature-based interventions that drive equity, health, nature stewardship, and biodiversity conservation in Canadian cities. The importance of this information: The nature-based interventions identified by experts like yourself will help to inform priorities for future research efforts within Canada to support more equitable cities for healthy people and nature.

Section 1

Carleton UNIVERSITY

Consent

Voluntary participation: Your participation in this study is completely voluntary and you may chose to withdraw your participation at any time. Time commitment: We estimate that the survey will take approximately 15-30 minutes to complete. However, the survey can take as long as the participant chooses, and we welcome all levels of involvement. Questions about the research? If you have questions about the research in general, please feel free to contact Dr. Rachel Buxton either by telephone (343-777-4325) or e-mail (Rachel.buxton@carleton.ca) If you have any ethical concerns

with the study, please contact the REB chair, Carleton University Research Ethics Board-B by telephone (613-520-2600 ext. 4085) or e-mail (ethics@carleton.ca) This research has been cleared by Carleton University Research Ethics Board-B (Clearance #) Note that there is no compensation for filling out this survey, however, your responses are integral to inform priorities for future research efforts within Canada to support more equitable cities for healthy people and nature. The information needs will be summarized in a report, serving as the starting point for a workshop discussion, and will be published in the supplementary material of resulting publications.

1

I consent to participate in this study conducted by Dr. Rachel Buxton. I have understood the nature of this project and wish to participate. My written name below indicates my consent.

2

Would you prefer to remain anonymous?

- Yes
- No

Section 2

About your research or work

3

Would you describe yourself as a

- Practitioner
- Researcher and/or scientist
- Manager
- Other

4

What does your work focus on? (You can select more than one answer)

- Biodiversity (broadly - from genes to ecosystems)
- Human health and wellbeing
- Equity, diversity, and inclusion
- Policy
- Human behaviour, nature connectedness
- Nature-based education
- Other

5

What best describes the organization you work for?

- NGO (non-governmental organization)
- Non-profit
- Federal government
- Provincial government
- Municipal government
- Academic institution
- Consulting firm
- Self-employed
- Other

Section 3

Nature-based interventions

Nature-based health interventions, also known as nature-based solutions, are becoming increasingly common. Initiatives to promote health with nature exposure are proliferating globally. This can include protected urban areas, 'park prescriptions' where health practitioners prescribe nature–based experiences for patients with specific health conditions, planting vegetation in community gardens, greening school grounds, community science, land-based education, river cleanups, targeted urban restoration projects, land-based healing, and ceremonial practices. There is room below for 1-3 interventions. If you are involved in >3 interventions, please reach out to Rachel.buxton@carleton.ca

6

Are you involved in any nature-based intervention projects in Canadian cities?

- Yes
- No

7

Can we feature these nature-based interventions in our publicly-available online database and map?

- Yes, feature all of them
- No, feature none of them
- Only feature the first intervention
- Only feature the second intervention
- Only feature the third intervention
- Other

8

Are you managing and/or participating in any urban nature-based interventions aimed at health, wellness, or biodiversity conservation in Canada? Please describe the first intervention.

9

How would you categorize the first intervention?

- Healing and/or community garden
- Indoor intervention
- New urban public park/garden
- Restored urban public park/garden
- Outdoor education
- Other

10

Does the first intervention have a URL? If so, please provide below.

11

Where is the location of the first intervention? Please be as specific as possible (e.g., GPS points, address, cross streets)

12

What were the outcomes of the first intervention for peoples' health and/or wellbeing?

13

What were the outcomes of the first intervention for biodiversity conservation (e.g., increased bird species richness, more insects, increased pro-conservation behaviour/awareness of participants)

14

Were there any equity considerations for this intervention? (e.g., avoiding gentrification, cultural appropriateness)

15

Are you managing and/or participating in more than one urban nature-based intervention?

- Yes
- No

16

Please describe the second intervention.

17

How would you categorize the second intervention?

- Healing and/or community garden
- Indoor intervention
- New urban public park/garden
- Restored urban public park/garden
- Outdoor education
- Other

18

Does the second intervention have a URL?

19

Where is the location of the second intervention? Please be as specific as possible (e.g., GPS points, address, cross streets)

20

What were the outcomes of the second intervention for peoples' health and/or wellbeing?

21

What were the outcomes of the second intervention for biodiversity conservation (e.g., increased bird species richness, more insects, increased pro-conservation behaviour/awareness of participants)

22

Were there any equity considerations for this intervention? (e.g., avoiding gentrification, cultural appropriateness)

23

Are you managing and/or participating in more than two urban nature-based interventions?

- Yes
- No

24

Please describe the third intervention.

25

How would you categorize the third intervention?

- Healing and/or community garden
- Indoor intervention
- New urban public park/garden
- Restored urban public park/garden
- Outdoor education
- Other

26

Does the third intervention have a URL?

27

Where is the location of the third intervention? Please be as specific as possible (e.g., GPS points, address, cross streets)

28

What were the outcomes of the third intervention for peoples' health and/or wellbeing?

29

What were the outcomes of the third intervention for biodiversity conservation (e.g., increased bird species richness, more insects, increased pro-conservation behaviour/awareness of participants)

30

Were there any equity considerations for this intervention? (e.g., avoiding gentrification, cultural appropriateness)

Section 4

Identifying knowledge gaps for nature-based interventions

Nature-based interventions offer an opportunity to ensure equitable access to health-benefiting urban green space while contributing to efforts that curb biodiversity loss. Yet many unknowns remain: the relationship between biodiversity and health is not fully understood, few interventions report the effects on biodiversity, program components that encourage pro-environmental behaviours are unknown, and determining which type of interventions serve a variety of people and cultures is a challenge. In this section, please identify evidence that would help overcome obstacles to maximizing the benefit of nature-based interventions for biodiversity conservation, human health, and equity. There is room for up to five. We define an information need as the monitoring, data, science, research, and/or knowledge needed to support progress towards more effective nature-based intervention policy and practice.

31

Please describe a piece of evidence needed to help overcome obstacles to maximizing the benefit of nature-based interventions for biodiversity conservation, human health, and equity. (Please try to be as detailed as possible)

32

Please rate the applicability of this evidence need. How applicable are the results from addressing the information gap to policy or management action? (1 - less applicable 5 - more applicable)

1
2
3
4
5

33

Please rate the certainty of this evidence need. Will the information yield answers with a high level of certainty to act or with a high level of certainty of contributing to successful conservation/health intervention? (1 - uncertain 5 - more certain)

1
2
3
4
5

34

At what geographic extent can the results from addressing the evidence need be applied?

- Local
- Regional
- National
- International

35

How long will it take to address the evidence need?

- < 1 year
- 1-2 years
- 2-5 years
- 5-10 year
- 10+ years

36

How logistically complicated and costly is it to address the evidence need? (1 - complex/costly 5 - simple/cheap)

1
2
3
4
5

37

Would you like to contribute a second evidence need?

- Yes
- No

38

Please describe a second piece of evidence needed to help overcome obstacles to maximizing the benefit of nature-based interventions for biodiversity conservation, human health, and equity. (Please try to be as detailed as possible)

39

Please rate the applicability of this evidence need. How applicable are the results from addressing the information gap to policy or management action? (1 - less applicable 5 - more applicable)

1
2
3
4
5

40

Please rate the certainty of this evidence need. Will the information yield answers with a high level of certainty to act or with a high level of certainty of contributing to successful conservation/health intervention? (1 - uncertain 5 - more certain)

1
2
3
4
5

41

At what geographic extent can the results from addressing the evidence need be applied?

- Local
- Regional
- National
- International

42

How long will it take to address the evidence need?

- < 1 year
- 1-2 years
- 2-5 years
- 5-10 year
- 10+ years

43

How logistically complicated and costly is it to address the evidence need? (1 - complex/costly 5 - simple/cheap)

1
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3
4
5

44

Would you like to contribute a third evidence need?

- Yes
- No

45

Please describe a third piece of evidence needed to help overcome obstacles to maximizing the benefit of nature-based interventions for biodiversity conservation, human health, and equity. (Please try to be as detailed as possible)

46

Please rate the applicability of this evidence need. How applicable are the results from addressing the information gap to policy or management action? (1 - less applicable 5 - more applicable)

1
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3
4
5

47

Please rate the certainty of this evidence need. Will the information yield answers with a high level of certainty to act or with a high level of certainty of contributing to successful conservation/health intervention? (1 - uncertain 5 - more certain)

1
2
3
4
5

48

At what geographic extent can the results from addressing the evidence need be applied?

- Local
- Regional
- National
- International

49

How long will it take to address the evidence need?

- < 1 year
- 1-2 years
- 2-5 years
- 5-10 year
- 10+ years

50

How logistically complicated and costly is it to address the evidence need? (1 - complex/costly 5 - simple/cheap)

1
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51

Would you like to contribute a fourth evidence need?

- Yes
- No

52

Please describe a fourth piece of evidence needed to help overcome obstacles to maximizing the benefit of nature-based interventions for biodiversity conservation, human health, and equity. (Please try to be as detailed as possible)

53

Please rate the applicability of this evidence need. How applicable are the results from addressing the information gap to policy or management action? (1 - less applicable 5 - more applicable)

- 1
- 2
- 3
- 4
- 5

54

Please rate the certainty of this evidence need. Will the information yield answers with a high level of certainty to act or with a high level of certainty of contributing to successful conservation/health intervention? (1 - uncertain 5 - more certain)

- 1
- 2
- 3
- 4
- 5

55

At what geographic extent can the results from addressing the evidence need be applied?

- Local
- Regional
- National
- International

56

How long will it take to address the evidence need?

- < 1 year
- 1-2 years
- 2-5 years
- 5-10 year
- 10+ years

57

How logistically complicated and costly is it to address the evidence need? (1 - complex/costly 5 - simple/cheap)

1
2
3
4
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58

Would you like to contribute a fifth evidence need?

- Yes
- No

59

Please describe a fifth piece of evidence needed to help overcome obstacles to maximizing the benefit of nature-based interventions for biodiversity conservation, human health, and equity. (Please try to be as detailed as possible)

60

Please rate the applicability of this evidence need. How applicable are the results from addressing the information gap to policy or management action? (1 - less applicable 5 - more applicable)

1
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61

Please rate the certainty of this evidence need. Will the information yield answers with a high level of certainty to act or with a high level of certainty of contributing to successful conservation/health intervention? (1 - uncertain 5 - more certain)

1
2
3
4
5

62

At what geographic extent can the results from addressing the evidence need be applied?

- Local
- Regional
- National
- International

63

How long will it take to address the evidence need?

- < 1 year
- 1-2 years
- 2-5 years
- 5-10 year
- 10+ years

64

How logistically complicated and costly is it to address the evidence need? (1 - complex/costly 5 - simple/cheap)

1
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Section 5

Thank you for taking time to fill out this survey.

We contacted you because of your expertise in urban interventions. In drawing on the country's leading experts, we recognize that we are seeking time from busy people. We thank you for making this survey a priority - we're confident that this project and resulting publications will have a strong impact on Canada's science and policy to make cities better for people and nature.