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REGISTERED REPORT STAGE 1: STUDY DESIGN

Weaving Indigenous knowledge systems and Western sciences in terrestrial research, monitoring and management in Canada: A protocol for a systematic map

Dominique A. Henri[1] | **Jennifer F. Provencher**[2] | **Ella Bowles**[3] | **Jessica J. Taylor**[4] | **Jade Steel**[3] | **Carmen Chelick**[3,5] | **Jesse N. Popp**[6] | **Steven J. Cooke**[4] | **Trina Rytwinski**[4] | **Deborah McGregor**[7] | **Adam T. Ford**[3] | **Steven M. Alexander**[8,9]

[1] Wildlife Research Division, Science and Technology Branch, Environment and Climate Change Canada, Montreal, Quebec, Canada

[2] Ecotoxicology and Wildlife Health Division, Science and Technology Branch, Environment and Climate Change Canada, Ottawa, Ontario, Canada

[3] Department of Biology, University of British Columbia Okanagan, Kelowna, British Columbia, Canada

[4] Canadian Centre for Evidence-Based Conservation, Institute of Environmental and Interdisciplinary Sciences, Carleton University, Ottawa, Ontario, Canada

[5] Biodigenous Consulting Ltd., Kelowna, British Columbia, Canada

[6] School of Environmental Sciences, University of Guelph, Guelph, Ontario, Canada

[7] Osgoode Hall Law School and Faculty of Environmental and Urban Change, York University, Toronto, Ontario, Canada

[8] Environment and Biodiversity Sciences, Fisheries and Oceans Canada, Ottawa, Ontario, Canada

[9] Environmental Change and Governance Group, University of Waterloo, Waterloo, Ontario, Canada

Correspondence
Dominique A. Henri, Wildlife Research Division, Science and Technology Branch, Environment and Climate Change Canada, 105 McGill Street, 7th Floor, Montreal, Quebec, ON H2Y 2E7, Canada.
Email: dominique.henri@canada.ca

Dominique A. Henri and Jennifer F. Provencher are co-first authors.

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Abstract

1. Human activities and development have contributed to declines in biodiversity across the globe. Understanding and addressing biodiversity loss will require the mobilization of diverse knowledge systems.
2. While calls for interdisciplinary practices in environmental research date back decades, there has been a more recent push for weaving multiple knowledge systems in environmental research and management, specifically Indigenous knowledge systems (IKS) and Western sciences.
3. The use of multiple knowledge systems in environmental research can improve understanding of socio-ecological connections, build trust in research findings and help implement evidence-based action towards biodiversity conservation. Mobilizing multiple types of knowledge in environmental research and management can be beneficial; however, challenges remain.
4. There is a need to understand how and where studies have woven IKS and Western sciences together in order to learn about frameworks and processes used, and identify best practices.

5. Here, we present a protocol for a systematic map that will examine the extent, range and nature of the published literature that weaves IKS and Western sciences in terrestrial ecosystems research, monitoring and management in Canada.
6. The systematic map will aim to capture all available and relevant studies found in the published academic and grey literature. The search will use standardized search terms across four publication databases, four specialized websites and one web-based search engine. Bibliographies of relevant review articles captured by our search strategy will be cross-checked to identify additional studies. Calls for evidence among professional networks will also complement the search strategy. All searches will be conducted in English. Search results will be reviewed in two stages: (1) title and abstract and (2) full text. All screening decisions at the full-text stage will be included into the map database.
7. The systematic map will use a narrative synthesis approach employing descriptive tables, statistics and figures (including a map with geospatially referenced studies) to summarize findings.
8. Results from this mapping exercise can serve to support environmental research and management efforts working across IKS and Western sciences by highlighting best practices, as well as evidence gaps.

KEYWORDS
Canada, ecological research, environmental management, Indigenous knowledge systems, literature review, terrestrial ecosystems, traditional and local ecological knowledge, Western science

1 | INTRODUCTION

Human activities, development and resource extraction are dominant forces on Earth (Vitousek et al., 1997), responsible for creating numerous threats that contribute to declines in biodiversity across the globe (Cardinale et al., 2012; SCBD, 2020). Many of these threats, such as climate change, deforestation and plastic pollution, are incredibly complex issues that require the mobilization of diverse knowledge in order to be understood and addressed (IPBES, 2019). While calls for interdisciplinary science practices in environmental research date back decades (Hicks et al., 2010; IPCC, 2007), there has been a more recent push for these practices to include the weaving of different knowledge systems, specifically Indigenous knowledge systems (IKS) and Western sciences (Henri et al., 2018, 2020; Johnson et al., 2016; McGregor, 2004; Popp et al., 2019; Tengö et al., 2014, 2017; see Table 1 for definitions). For example the International Panel on Climate Change and the International Platform on Biodiversity Services have specifically called for greater inclusion of IKS in their assessments (Ford et al., 2016; Tengö et al., 2017).

'Weaving knowledge systems' refers to a process through which multiple types of knowledge are equitably brought together to enable the reciprocal exchange of understanding for mutual learning and application (Alexander, Provencher, Henri, Taylor, Lloren, et al., 2019; Johnson et al., 2016; Tengö et al., 2017). This notion implies a dynamic and co-evolving process of knowledge co-production (Castleden et al., 2017) through which the integrity of each knowledge system is respected and maintained (Rathwell et al., 2015; Reid et al., 2021). As such, it is a process similar to what other authors have termed 'braiding' or 'bridging' knowledge systems (Alexander, Provencher, Henri, Taylor, Lloren, et al., 2019; Johnson et al., 2016; Kimmerer, 2013; McGregor, 2008; Rathwell et al., 2015; Reid et al., 2021). The expression 'weaving' moves beyond the narrative of 'integrating', 'combining' or 'incorporating' knowledge systems which has been critiqued for connoting or suggesting the assimilation of IKS into a dominant and overarching Western scientific paradigm (Johnson et al., 2016; Reid et al., 2021). The process of weaving knowledge systems places IKS on equal par with Western sciences (Johnson et al., 2016), recognizes the inherent value of IKS and may be understood as coming from a place of respect for Indigenous peoples and their intellectual traditions (Kimmerer, 2002).

Bridging multiple knowledge systems in environmental research and management improves our understanding of socio-ecological connections and mechanisms (Kimmerer, 1998; Kutz & Tomaselli, 2019; Pierotti & Wildcat, 2000), and builds trust in decision-making and research findings (Patterson et al., 2020). The weaving of knowledge systems can also facilitate uptake of findings by different decision-making bodies that can help implement actions towards conservation of ecosystems (Ban et al., 2018; Eckert et al., 2020). Ultimately, it can serve to address ongoing issues related to the power and agency of

TABLE 1 Definitions of key concepts

Knowledge systems
Knowledge systems are 'made up of agents, practices, routines and institutions that organize the production, validation, transfer, and use of knowledge' (Cornell et al., 2013).
Indigenous knowledge systems
We define 'Indigenous knowledge systems' (IKS) according to Berkes as 'a cumulative body of knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment' (Berkes, 2012, p. 7), and also McGregor as 'more than a body of knowledge […] [encompassing] such aspects as spiritual experience and relationships with the land' (McGregor, 2004, p. 79; McGregor, 2018). Indigenous knowledge systems are a 'way of life, rather than being just the knowledge of *how* to live, it is the actual *living* of that life' (Ibid, p. 79). We understand the expression 'Indigenous knowledge systems' to be broader in scope and more holistic than the term 'Indigenous knowledge' conveys. We find it important to further highlight that 'Indigenous sciences' are embedded in Indigenous knowledge systems (Cajete, 2000; Johnson et al., 2016; Turnbull, 2000a, 2000b). Johnson et al. define Indigenous science as 'a "multi-contextual" system of thought, action and orientation applied by an Indigenous people through which they interpret how Nature works in "their place" […] Indigenous science knowledge is derived using the same methods as modern Western science including: classifying, inferring, questioning, observing, interpreting, predicting, monitoring, problem solving, and adapting' (Johnson et al., 2016, p. 5).
Western sciences
'Western sciences' refer to sciences from the academy, honed according to Western ideologies and belief systems (Alexander, Provencher, Henri, Taylor, Lloren, et al., 2019; Mazzocchi, 2006). Our application of the term Western sciences aligns with how Aikenhead and Ogawa define 'Eurocentric sciences': 'Eurocentric sciences possess a powerful way of knowing about nature, and this includes knowledge appropriated over the ages from many other cultures (e.g., Islam, India and China). Such knowledge was modified sufficiently to fit Eurocentric worldviews, metaphysics, epistemologies, and value systems. Eurocentric science is also known as the culture of Western science in some fields of cultural anthropology […] to emphasize the group's shared norms, values, beliefs, expectations, technologies, and conventional actions' (Aikenhead & Ogawa, 2007, p. 543).

Indigenous knowledge holders to inform decision-making (Wheeler et al., 2020) by shaping decision spaces and mechanisms where Indigenous and Western knowledge systems are viewed as equally important (IPBES, 2019; Tengö et al., 2014). Understanding and addressing power asymmetries between knowledge systems is an important part of developing equitable approaches to environmental research and management (McGregor et al., 2010; Polfus et al., 2016; Wong et al., 2020). Weaving knowledge systems therefore holds transformative potential by offering opportunities to conduct research and decision-making in ways that promote social justice and Indigenous self-determination (Held, 2019; Ludwig, 2016; McGregor, 2018; Reid et al., 2021).

In the North American context, 'Indigenous peoples' is a broad term used to describe the original inhabitants of these lands and their descendants. In Canada, this includes First Nations, Métis and Inuit that each has their own unique histories, cultures and languages (RCGS, 2018). Within present day Canada, Indigenous peoples have occupied their territories since time immemorial and have deeply rooted and long-standing relationships and extensive knowledge of the ecosystems and landscapes they have actively managed for millennia (Ban, Davies, et al., 2017; Ban, Eckert, et al., 2017; Ban et al., 2018). Their cumulative body of knowledge, practice and belief gives rise to multifaceted IKS that vary within and between communities (Reo, 2011; Houde, 2007; Table 1). These knowledge systems are increasingly mobilized in research practices and discussions (e.g. Inuit Qaujimajatuqangit [IQ], Anishinaabe Giikenasewin, Heiltsuk Haíłzaqvḷa, Cowichan Nations' Hul'qumi'num). However, in Canada and elsewhere, colonization has negatively impacted Indigenous ways of knowing through forced relocation, changes in livelihood practices, loss of traditional rights, ecosystems degradation, as well as loss of language and cultural institutions (Smith, 2012; Tang & Gavin, 2016; TRCC, 2015). Accordingly, applying multiple ways of knowing to prioritize, conserve and restore relationships between Indigenous peoples and the environment they live in – and are a part of – is critical and can help advance reconciliation with Indigenous peoples (Wong et al., 2020).

In recent decades, the importance of IKS has been increasingly reflected in policy and legislation. At the international level, there has been greater recognition of the value of IKS for biodiversity conservation and sustainable use in international policy (Berkes, 2012; UN, 1987, 1992) and through the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP; UN, 2007). However, there is still limited information indicating that IKS have been widely respected and/or reflected in national legislation globally (SCBD, 2020). In Canada, there is a mandate within many federal government departments to consider and respectively include IKS in decision-making (e.g. Canadian Environmental Protection Act, 1999, c. 33; Impact Assessment Act, 2019, c. 28, s. 1; Migratory Birds Convention Act, 1994, c. 22; Oceans Act, 1996, c.31; Species at Risk Act, 2002, c. 29). British Columbia is the only province or territory to have passed legislation to implement UNDRIP to date (GBC, 2020) and is doing high-level planning with First Nations for wildlife management (BCFNWF, 2020). Additionally, several funding agencies are calling on researchers to braid IKS and Western sciences equitably through the full cycle of research and monitoring programs, from inception to reporting of results (e.g. Natural Sciences and Engineering Research Council, Social Sciences and Humanities Research Council, Nunavut Wildlife Management Board, Nunavut General Monitoring Plan).

Therefore, there is a current need in Canada to understand 'how' and 'where' studies have woven IKS and Western sciences together, in order to learn about frameworks and processes used. While a

TABLE 2 Description of eligibility criteria guiding article screening

Population
Articles that concern all terrestrial ecosystems (e.g. grasslands, prairies, forests, woods, mountains, taiga, tundra, terrestrial components of watersheds, marshlands), habitat or species (including birds, mammals, herpetofauna, insects, plants and fungi). Articles involving resource management (i.e. silviculture, soil, agriculture) will only be included if outcomes are directly related to biodiversity or ecosystem health. Studies reporting process optimization (e.g. timber production, harvest techniques) will be excluded.
Study design
Articles that report empirical results (either qualitatively or quantitatively) where knowledge combining or weaving practices and/or methods are discussed or inferred. Empirical studies included will fall into one of three broad categories: (1) studies focused on environmental/ecological research and monitoring (i.e. those reporting on direct or indirect observation or experience from IKS and Western sciences); (2) studies focused on the processes and practices of bridging knowledge systems in the context of environmental decision-making; and (3) studies concerned with perceptions of ecological or environmental phenomenon that weave IKS and Western sciences (e.g. perceptions of ecosystem services).
Geographical scope
Articles including case studies conducted within Canada's jurisdictional boundaries, as well as cases where traditional Indigenous territories transcend contemporary nation-state boundaries (i.e. the Canada–United States border).
Language
English and French.

critical examination of these frameworks will help describe best practices and approaches, there has been little work to date compiling and collating such studies in order to apply a critical and meaningful appraisal. This includes exploring the 'how': how knowledge weaving is done in practice to ensure that it proceeds in a way that respects and considers Indigenous cultural values and research methodologies.

Systematic mapping specifically aims to collate, describe and catalogue available evidence relating to a topic or question of interest that may be used later in addressing specific questions (e.g. related to efficacy, methodology or best practices) as systematic reviews do, but with a geographic component as well (James et al., 2016). To date, a previously published protocol (i.e. Alexander, Provencher, Henri, Taylor, & Cooke, 2019) has been used to complete two systematic maps that examined studies in Canada that weave IKS and Western sciences together to address research and management questions relating to coastal (Alexander, Provencher, Henri, Taylor, Lloren, et al., 2019) and freshwater ecosystems in Canada (S. M. Alexander et al., unpubl. ms.). These reviews have covered studies that bridge IKS and Western sciences in aquatic ecosystems and regions across Canada (e.g. lakes, rivers, wetlands, marine and coastal regions). However, with the exception of a review that has examined the use of traditional ecological knowledge in forest management (Cheveau et al., 2008), we are unaware of any systematic review and/or map conducted to date covering terrestrial landscapes such as grasslands, forests, taiga and tundra that span the territories of Indigenous peoples in the land now known as Canada.

2 | OBJECTIVES

The primary question that this work seeks to address is, 'What methods, models and approaches have been used in studies that seek to weave IKS and Western sciences in terrestrial ecosystems research, monitoring or management in Canada'? The purpose of this protocol is to set out a methodology for the conduct of a systematic map that will collate and catalogue relevant articles relating to the above research question in order to address a series of questions in future phases of the project.

Articles identified and explored through this protocol and its associated systematic map will have the following characteristics (see Table 2 for more details):

- *Population*: Articles that report findings on research, monitoring or management related to terrestrial ecosystems, habitat or species.
- *Study design*: Articles that report empirical results, either qualitatively or quantitatively, and where knowledge combining or bridging practices and/or methods are discussed or inferred that seek to weave IKS and Western sciences.
- *Geographical scope*: Articles including case studies conducted within Canada's jurisdictional boundaries, as well as cases where Indigenous territories overlap contemporary nation–state boundaries (i.e. the Canada–United States border; e.g. Ktunaxa territory in western North America and Haudenosaunee territory in eastern North America).

3 | MATERIALS AND METHODS

The original protocol was published in March 2019 (Alexander, Provencher, Henri, Taylor, & Cooke, 2019) and first applied in a systematic map that examined studies that wove together IKS and Western sciences in Canadian coastal marine ecosystems (Alexander, Provencher, Henri, Taylor, Lloren, et al., 2019). As with the previous coastal marine version, the proposed systematic map will follow the guidelines provided by the Collaboration for Environmental Evidence (2018), and comply with *Reporting standards for Systematic Evidence Syntheses* in environmental research (ROSES; i.e. detailed forms for ensuring evidence syntheses report their methods to the highest possible standards; see Haddaway et al., 2018) (Supporting Information 1).

3.1 | Searching for articles

This systematic map protocol will use standardized search terms across four publication databases, specialized websites and one web-based search engine, as described in more detail below. This protocol will consider the bibliographies of relevant reviews to identify any articles that may not be found using the search strategy noted above. Calls for evidence among professional networks will also complement the search strategy.

3.1.1 | Search string

The initial English search terms were adapted from Alexander, Provencher, Henri, Taylor, Lloren, et al. (2019) and tailored to terrestrial environments to reflect the scope of our proposed map (Supporting Information 2). Search terms included terrestrial-specific terms (e.g. forest, plain, bison), as well other themes such as climate change and weather, which are within the scope of the map. Health was also added as a qualifier in order to capture studies examining wildlife and ecosystem health (see Supporting Information 2). Furthermore, specific feedback was sought from community partners and Indigenous co-authors to ensure the inclusion of species and ecosystems that were particularly important to Indigenous communities. Knowledge-gathering workshops facilitated by, among others, co-authors JNP and EB with 12 Anishinaabe communities in Ontario collectively conveyed a strong sense that no single species was more important than another and that species were all connected (Gallant et al., 2020; Patterson et al., 2020). Accordingly, we included ecosystem terms to capture more holistic studies (e.g. boreal, wetland, grassland). In addition, Indigenous colleagues (see ACKNOWLEDGEMENTS) and co-authors (JNP, CC) were asked to list any particular species that they were familiar with and felt were regionally important to include (see Supporting Information 2); the list provided was by no means exhaustive nor meant to represent all regions, species or Indigenous nations across Canada.

We then developed a set of search strings that were modified and refined iteratively through a scoping exercise using Web of Science Core Collections and Scopus which evaluated the sensitivity of the search terms and associated wildcards. Database-specific search strategies (including Boolean operators), date ranges and number of returns for each database were tested (Supporting Information 3). Based on the information from a previous systematic map (Alexander, Provencher, Henri, Taylor, Lloren, et al., 2019) completed using our original coastal marine protocol (Alexander, Provencher, Henri, Taylor, & Cooke, 2019) and species of interest to Indigenous communities, a collection of benchmark papers ($n = 26$; Supporting Information 4) was used to ensure relevance and comprehensiveness of the search strings. Benchmark papers were selected by four of the co-authors (SMA, EB, DAH and JFP) based on results excluded from the previous two coastal marine and freshwater maps (but within the scope of this systematic map), and on professional experience in the field of study in Canada.

3.1.2 | Searches

All searches will be conducted in English. Four bibliographic databases (i.e. ISI Web of Science Core Collections, Scopus, ProQuest Dissertations & Theses Global, Federal Science Library [Canada]) will be searched using Carleton University's institutional subscriptions. As a supplement to the bibliographic database searching, a search using Google Scholar will also be performed using two simplified search strings to search for additional published academic and grey literature. The top 250 search results for each search string (sorted by relevance) will be exported for screening in Excel. In a deviation from the previously published protocol (Alexander, Provencher, Henri, Taylor, & Cooke, 2019), Google will not be used as a search engine for this review due to its lack of consistency and limited ability to return relevant results in past reviews (Alexander, Provencher, Henri, Taylor, Lloren, et al., 2019). In order to ensure inclusion of a wide range of sources and materials, four specialist websites (i.e. Library and Archives Canada, Canadian Public Policy Collection, Government of Canada Publications, Environment and Climate Change Canada) relevant to the topic will be manually searched using their built-in search facilities using simplified English search term combinations. The top 30 search results from each website (up to 180 results per website), sorted by relevance, will be screened for inclusion. The bibliographies of any relevant review article (i.e. not containing empirical data) identified during screening stages will also be hand-searched for any additional relevant articles that were not captured during the above searches. Although searches will be conducted using English search terms only, French articles identified in this manner (i.e. those which include English translations of the title and abstract) will be included for screening and subsequent coding if relevant.

In addition, calls for evidence will be used to complement the search strategy described above. This will be done via an email circulated among the authors' professional networks and on social media platforms (i.e. Twitter, Facebook) asking groups and people to identify studies, papers, theses and reports that fit the scope of the systematic map. Calls for evidence will be distributed via personalized emails to co-management boards ($n = 28$) and Aboriginal Aquatic Resource and Oceans Management (AAROM) organizations ($n = 25$) in Canada with a mandate related to terrestrial ecosystems (Supporting Information 5).

3.2 | Screening articles and eligibility criteria

3.2.1 | Screening process

The results from the four bibliographic databases will be exported into EPPI Reviewer Web (Thomas et al., 2020), where duplicates will be removed prior to screening. Results from Google Scholar screened at both the title and abstract stage and full-text stage will be exported directly into Excel.

All articles identified through the search process outlined above will be screened for inclusion in the map at two distinct stages: (1) title and

abstract and (2) full-text using the criteria outlined in the original protocol (Alexander, Provencher, Henri, Taylor, & Cooke, 2019), with some modifications as described below (see Section 3.2.2). Prior to screening articles at title and abstract, a consistency check will be performed by all reviewers on an initial subset of approximately 5% of articles. Inter-reviewer Kappa statistics will be calculated (requiring a 'moderate' level of agreement between reviewers [Landis & Koch, 1977] before moving forward), and discrepancies between reviewers will be discussed and the inclusion criteria clarified before reviewers proceed independently. If reviewer agreement is lower than moderate, a second round of inter-reviewer comparisons will be done to reconcile any differences before screening is allowed to proceed.

Attempts will be made to find the full-text of any article included at title and abstract using Carleton University subscriptions or Environment and Climate Change inter-library loan services when needed. Prior to full-text screening, a consistency check will again be performed between the reviewers with a random subset of approximately 5% of articles included at title and abstract. Kappa statistics will be used to examine variation in agreement between the reviewers. Again, discrepancies will be discussed and inclusion criteria will be further clarified with the help of review team members. If agreement between reviewers is lower than moderate, another subset of articles will be screened by reviewers and Kappa statistics will be examined until at least a 'moderate' to 'substantial' agreement is achieved before full-text screening is allowed to proceed. Any discrepancies will be reconciled prior to screening and the inclusion criteria will be reviewed and clarified for final use. During screening, reviewers will have the ability to request a second opinion from another member of the review team for any articles with unclear eligibility.

At no point during title and abstract or full-text screening will a reviewer be allowed to influence the inclusion decision for any article that they were an author of. A list of articles excluded at the full text assessment will be provided as a Supporting Information file in the systematic map with details regarding reasons for exclusion.

3.2.2 | Eligibility criteria

A pre-established set of eligibility criteria (Table 2) will guide article screening. All four inclusion criteria will need to be met in order for an article to be included in the final dataset of articles and case studies.

3.3 | Study validity assessment

Given the broad objective and scope of this systematic map, the validity of individual articles or case studies will not be appraised.

3.4 | Data coding strategy

Coding and data extraction will be conducted at the case study level rather than at the article level since, in some instances, a single article could contribute two or more case studies when the purpose of the article is comparing and contrasting multiple cases – assuming here that empirical-based research is always a case study. A standardized coding questionnaire (Supporting Information 5) will be deployed through an Excel spreadsheet to collate responses and ensure consistency across coders. The questionnaire was modelled on Alexander, Provencher, Henri, Taylor, and Cooke (2019) with some changes to a few variables (e.g. changes in categorical variables) and additional questions that are specific to the topic of this map. Additional questions pertaining to Indigenous participation in research, equity and power sharing were inspired by analytical themes and categories developed by Thompson et al. (2020) as part of a review of Indigenous knowledge and participation in environmental monitoring, as well as by the analytical framework proposed by David-Chavez and Gavin (2018) in an assessment of Indigenous community engagement in climate research. Included studies will be coded by team members. Prior to meta-data extraction, a consistency check will be conducted with the questionnaire among the reviewers. The review team's extracted data from a random subset of articles (approximately 5%–10% of articles included at full-text) will be included in a consistency check before full meta-data extraction proceeds. All coding decisions will be reviewed by the review team and any discrepancies will be reconciled and clarified before allowing data extraction to continue. In addition, the lead author will review all coding decisions for consistency upon the conclusion of meta-data coding. Resulting data will be exported from Excel and recorded in a comma separated file. Formatting of the data will be standardized in R and analyzed using a customized script. The R code and data files used for formatting and analysis will be made available with the results of these methods.

3.5 | Study mapping and presentation

The systematic map will include two main outputs: (1) a written narrative synthesis and a coded database and (2) composite maps. Case studies will be examined to describe the overall amount of available evidence, and to provide readers with an overview understanding of cases that contribute to the body of literature that weaves IKS and Western sciences together in terrestrial research, monitoring and management in Canada.

Specifically, we will employ a narrative synthesis approach (Popay et al., 2006) that will include the use of descriptive statistics, figures and tables to summarize findings and insights. Case study variables that will be examined and described will include the following: year of publication; publication type (i.e. published academic and grey literature, theses); Indigenous authorship; Elder participation; age group of knowledge holders; focal terrestrial ecosystem (i.e. forest, woodland, prairie, taiga, tundra); focal species; and focal region within Canada. Descriptive statistics, figures and tables will be combined with a framework-based synthesis to help identify trends and gaps in the evidence. Framework-based synthesis (e.g. Dixon-Woods, 2011) will be used to guide the development of three structured matrices (similar to Alexander, Provencher, Henri, Taylor, Lloren, et al., 2019). Bar

graphs will be made using base R, and structured matrices will be developed using ggplot2 (Wickham, 2016). Sankey data visualizations to understand how themes are connected across studies (e.g. see Alexander, Provencher, Henri, Taylor, Lloren, et al., 2019) will be produced in R using the publicly available package networkD3 (Allaire et al., 2017).

Composite maps covering the study region of the systematic map (i.e. Canada) will be developed depicting where all of the included cases took place across geographic regions (similar to Alexander, Provencher, Henri, Taylor, Lloren, et al., 2019). These maps will report the locations of case studies, thus articles that present information from more than one region will be referenced in each of those regions on the maps. Maps depicting the approximate geospatial locations of case studies will be constructed in ArcMap 10.6.1 (ESRI, 2019).

3.6 | Data sharing policy

Once the study (i.e. systematic map and protocol) will be complete, all data will be archived at Environment and Climate Change Canada and Fisheries and Oceans Canada. A publicly accessible online version of the systematic map and a queryable database will also be developed.

4 | DISCUSSION

This study aims to produce a protocol and systematic map that will examine the extent, range and nature of the published literature that weaves IKS and Western sciences in terrestrial research, monitoring and management in Canada. Results from the proposed systematic map can serve to support new and ongoing environmental research, management and policy efforts working across IKS and Western sciences. This work will contribute to the growing literature that discusses 'where' and 'how' knowledge systems have been woven together by highlighting methods, processes and frameworks used for weaving knowledge systems, as well as by identifying best practices and evidence gaps. In doing so, we hope this study can ultimately inform discussions on how multiple knowledge systems can support policy development and implementation of evidence-based action towards biodiversity conservation.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

DAH, JFP, SMA, JJT, EB and SJC conceived the ideas and designed methodologies. DAH and JFP led the writing of the manuscript. EB, JJT, CC, JS, JNP, SJC, TR, DM, SMA and ATF provided comments and revisions. All authors contributed critically to the drafts and gave final approval for publication.

DATA AVAILABILITY STATEMENT

This article does not contain data.

PEER REVIEW

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ORCID

Dominique A. Henri https://orcid.org/0000-0002-1280-1919

REFERENCES

Aikenhead, G. S., & Ogawa, M. (2007). Indigenous knowledge and science revisited. *Cultural Studies of Science Education*, *2*, 539–620. https://doi.org/10.1007/s11422-007-9067-8

Alexander, S. M., Provencher, J. F., Henri, D. A., Taylor, J. J., & Cooke, S. J. (2019). Bridging Indigenous and science-based knowledge in coastal-marine research, monitoring, and management in Canada: A systematic map protocol. *Environmental Evidence*, *8*, 15. https://doi.org/10.1186/s13750-019-0159-1

Alexander, S. M., Provencher, J. F., Henri, D. A., Taylor, J. J., Lloren, J. I., Nanayakkara, L., Johnson, J. T., & Cooke, S. J. (2019). Bridging Indigenous and science-based knowledge in coastal and marine research, monitoring, and management in Canada. *Environmental Evidence*, *8*, 36. https://doi.org/10.1186/s13750-019-0181-3

Allaire, J., Ellis, P., Gandrud, C., Kuo, K., Lewis, B., Owen, J., Russell, K., Rogers, J., Sese, C., & Yetman, C. (2017). *D3 Javascript network graphs from R*.

Ban, N., Frid, A., Reid, M., Edgar, B., Shaw, D., & Siwallace, P. (2018). Incorporate Indigenous perspectives for impactful research and effective management. *Nature Ecology & Evolution*, *2*, 1680–1683.

Ban, N. C., Davies, T. E., Aguilera, S. E., Brooks, C., Cox, M., Epstein, G., Evans, L. S., Maxwell, S. M., & Nenadovic, M. (2017). Social and ecological effectiveness of large marine protected areas. *Global Environmental Change*, *43*, 82–91. https://doi.org/10.1016/j.gloenvcha.2017.01.003

Ban, N. C., Eckert, L. E., McGreer, M., & Frid, A. (2017). Indigenous knowledge as data for modern fishery management: A case study of Dungeness crab in Pacific Canada. *Ecosystem Health and Sustainability*, *3*, 1379887. https://doi.org/10.1080/20964129.2017.1379887

Berkes, F. (2012). *Sacred ecology* (3rd ed.). Routledge.

BC-First Nations Wildlife Forum. (2020). *Cultivating abundance*. First Nations perspectives from the BC-First Nations Wildlife and Habitat Conservation Forum.

Cajete, G. A. (2000). *Native science: Natural laws of interdependence*. Clear Light Publishers.

Cardinale, B. J., Duffy, J. E., Gonzalez, A., Hooper, D. U., Perrings, C., Venail, P., Narwani, A., Mace, G. M., Tilman, D., Wardle, D. A., Kinzig, A. P., Daily, G. C., Loreau, M., Grace, J. B., Larigauderie, A., Srivastava, D. S., & Naeem, S. (2012). Biodiversity loss and its impact on humanity. *Nature*, *486*, 59–67. https://doi.org/10.1038/nature11148

Castleden, H. E., Hart, C., Harper, S., Martin, D., Cunsolo, A., Stefanelli, R., Day, L., & Lauridsen, K. (2017). Implementing Indigenous and Western knowledge systems in water research and management (Part 1): a systematic realist review to inform water policy and governance in Canada. *International Indigenous Policy Journal*, *8*(4), 7.

Collaboration for Environmental Evidence (CEE). (2018). *Guidelines* and standards for evidence synthesis in environmental management. Collaboration for Environmental Evidence.

Cheveau, M., Imbeau, L., Drapeau, P., & Bélanger, L. (2008). Current status and future directions of traditional ecological knowledge in forest management: A review. *The Forestry Chronicle*, *84*(2), 231–243. https://doi.org/10.5558/tfc84231-2

Cornell, S., Berkhout, F., Tuinstra, W., Tàbara, J. D., Jäger, J., Chabay, I., de Wit, B., Langlais, R., Mills, D., Moll, P., & Otto, I. M. (2013). Opening up knowledge systems for better responses to global environmental change. *Environmental Science & Policy*, *1*(28), 60–70.

David-Chavez, D. M., & Gavin, M. C. (2018). A global assessment of Indigenous community engagement in climate research. *Environmental Research Letters*, *13*, 123005. https://doi.org/10.1088/1748-9326/aaf300

Dixon-Woods, M. (2011). Using framework-based synthesis for conducting reviews of qualitative studies. *BMC Medicine*, *9*, 39. https://doi.org/10.1186/1741-7015-9-39]

Eckert, L. E., Claxton, N. X., Owens, C., Johnston, A., Ban, N. C., Moola, F., & Darimont, C. T. (2020). Indigenous knowledge and federal environmental assessments in Canada: Applying past lessons to the 2019 impact assessment act. *FACETS*, *5*, 1–23.

Environmental Systems Research Institute (ESRI). (2019). *ArcGIS* desktop. Environmental Systems Research Institute.

Ford, J. D., Cameron, L., Rubis, J., Maillet, M., Nakashima, D., Cunsolo Willox, A., & Pearce, T. (2016). Including indigenous knowledge and experience in IPCC assessment reports. *Nature Climate Change*, *6*, 349–353. https://doi.org/10.1038/nclimate2954

Gallant, M., Bowles, E., Patterson, H., & Popp, J. N. (2020). *Anishinaabe knowledge, concerns and priorities related to climate change*. A report from the "Connecting Guardians in a Changing World" workshop. Wildlife, Indigenous Science, Ecology Lab, Department of Geography and Environment, Mount Allison University.

Government of British Columbia. (2020). *Declaration on the Rights of Indigenous Peoples Act: 2019/2020 annual report*. Government of British Columbia.

Haddaway, N. R., Macura, B., Whaley, P., & Pullin, A. S. (2018). ROSES reporting standards for Systematic Evidence Syntheses: Pro forma, flow-diagram and descriptive summary of the plan and conduct of environmental systematic reviews and systematic maps. *Environmental Evidence*, *7*, 7. https://doi.org/10.1186/s13750-018-0121-7

Held, M. B. E. (2019). Decolonizing research paradigms in the context of settler colonialism: An unsettling, mutual, and collaborative effort. *International Journal of Qualitative Methods*, *18*, 1–16. https://doi.org/10.1177/1609406918821574

Henri, D. A., Martinez-Levasseur, L. M., Weetaltuk, S., Mallory, M. L., & Gilchrist, H. G. (2020). Inuit knowledge of Arctic Terns (*Sterna paradisaea*) and perspectives on declining abundance in southeastern Hudson Bay, Canada. *PLoS One*, *15*(11), e0242193. https://doi.org/10.1371/journal.pone.0242193

Henri, D., Jean-Gagnon, F., & Gilchrist, H. (2018). Using Inuit traditional ecological knowledge for detecting and monitoring avian cholera among Common Eiders in the eastern Canadian Arctic. *Ecology and Society*, *23*(1), 22. https://doi.org/10.5751/ES-09289-230122

Hicks, C. C., Fitzsimmons, C., & Polunin, N. V. C. (2010). Interdisciplinarity in the environmental sciences: Barriers and frontiers. *Environmental Conservation*, *37*, 464–477. https://doi.org/10.1017/S0376892910000822

Houde, N. (2007). The six faces of traditional ecological knowledge: Challenges and opportunities for Canadian co-management arrangements. *Ecology and Society*, *12*(2), 34. https://doi.org/10.5751/ES-02270-120234

IPBES. (2019). *Summary for policymakers of the global assessment report on biodiversity and ecosystem services*. Zenodo. https://doi.org/10.5281/zenodo.3553579

IPCC. (2007). *Climate* change *2007*: *Synthesis* report. Contribution of Working Groups I, II, and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. International Panel on Climate Change (IPCC).

James, K. L., Randall, N. P., & Haddaway, N. R. (2016). A methodology for systematic mapping in environmental sciences. *Environmental Evidence*, *5*, 7. https://doi.org/10.1186/s13750-016-0059-6

Johnson, J. T., Howitt, R., Cajete, G., Berkes, F., Louis, R. P., & Kliskey, A. (2016). Weaving Indigenous and sustainability sciences to diversify our methods. *Sustainability Science*, *11*, 1–11. https://doi.org/10.1007/s11625-015-0349-x

Kimmerer, R. (2002). Weaving traditional ecological knowledge into biological education: A call to action. *Bioscience*, *52*(5), 432–438.

Kimmerer, R. (1998). Intellectual diversity: Bringing the Native perspective into natural resources education. *Winds of Change*, *13*, 14–18.

Kimmerer, R. W. (2013). *Braiding Sweetgrass*. Milkweed Editions. Minneapolis, Minnesota.

Kutz, S., & Tomaselli, M. (2019). Two-eyed seeing" supports wildlife health. *Science*, *364*, 1135–1137. https://doi.org/10.1126/science.aau6170

Landis, J. R., & Koch, G. G. (1977). The measurement of observer agreement for categorical data. *Biometrics*, *33*, 159–174. https://doi.org/10.2307/2529310

Ludwig, D. (2016). Overlapping ontologies and Indigenous knowledge. From integration to ontological self-determination. *Studies in History and Philosophy of Science Part A*, *59*, 36–45. https://doi.org/10.1016/j.shpsa.2016.06.002

Mazzocchi, F. (2006). Western science and traditional knowledge: Despite their variations, different forms of knowledge can learn from each other. *EMBO Reports*, *7*, 463–466. https://doi.org/10.1038/sj.embor.7400693

McGregor, D. (2008). Linking traditional ecological knowledge and western science: Aboriginal perspectives from the 2000 State of the Lakes Ecosystem Conference. *The Canadian Journal of Native Studies*, *28*(1), 139–158.

McGregor, D., Bayha, W., & Simmons, D. (2010). Our responsibility to keep the land alive: Voices of northern Indigenous researchers. *Pimatisiwin: A Journal of Aboriginal and Indigenous Community Health*, *8*, 101–123.

McGregor, D. (2018). Mino-Mnaamodzawin: Achieving Indigenous environmental justice in Canada. *Environment and Society: Advances in Research*, *9*, 7–24 https://doi.org/10.3167/ares.2018.090102

McGregor, D. (2004). Traditional ecological knowledge and sustainable development: Towards coexistence. In M. Blaser, H. A. Feit, & G. McRae (Eds.), *In the way of development: Indigenous peoples, life projects and globalization* (pp. 72–91). Zed Books.

Patterson, H., Bowles, E., & Popp, J. N. (2020). *Environmental and sociocultural impacts of glyphosate-based herbicides used in forestry: Perspectives from Indigenous knowledge and Western Science*. A report from the "Connecting Guardians in a Changing World" Workshop. Wildlife, Indigenous Science, Ecology Lab, Department of Geography and Environment, Mount Allison University.

Pierotti, R., & Wildcat, D. (2000). Traditional ecological knowledge: The third alternative. *Ecological Applications*, *10*, 1333–1340.

Polfus, J. L., Manseau, M., Simmons, D., Neyelle, M., Bayha, W., Andrew, F., Andrew, L., Klütsch, C. F. C., Rice, K., & Wilson, P. (2016). Łeghágots'enetę

(learning together): The importance of Indigenous perspectives in the identification of biological variation. *Ecology and Society*, *21*(2), 18. https://doi.org/10.5751/ES-08284-210218

Popay, J., Roberts, H., Sowden, A., Petticrew, M., Arai, L., Rodgers, M., & Britten, N. (2006). *Guidance on the conduct of narrative synthesis in systematic reviews*. ESRC Methods Program.

Popp, J. N., Priadka, P., & Kozmik, C. (2019). The rise of moose co-management and integration of Indigenous knowledge. *Human Dimension of Wildlife*, *24*, 159–167. https://doi.org/10.1080/10871209.2019.1545953

Rathwell, K., Armitage, D., & Berkes, F. (2015). Bridging knowledge systems to enhance governance of environmental commons: a typology of settings. *International Journal of the Commons*, *9*(2), 851–880.

Royal Canadian Geographic Society. (2018). *Indigenous Peoples Atlas of Canada*. The Royal Canadian Geographical Society (RCGS) in conjunction with the National Centre for Truth and Reconciliation, the Assembly of First Nations, Inuit Tapiriit Kanatami, Métis National Council and Indspire.

Reid, A. J., Eckert, L. E., Lane, J. F., Young, N., Hinch, S. G., Darimont, C. T., Cooke, S. J., & Ban, N. C. (2021). Two-eyed seeing": An Indigenous framework to transform fisheries research and management. *Fish and Fisheries*, *22*(2), 243–261. https://doi.org/10.1111/faf.12516

Reo, N. (2011). The importance of belief systems in traditional ecological knowledge initiatives. *International Indigenous Policy Journal*, *2*, 1–4. https://doi.org/10.18584/iipj.2011.2.4.8

Secretariat of the Convention on Biological Diversity. (2020). *Global Biodiversity Outlook 5*. Secretariat of the Convention on Biological Diversity.

Smith, L. T. (2012). *Decolonizing methodologies: Research and Indigenous peoples* (2nd ed.). Zed Books.

Tang, R., & Gavin, M. C. (2016). A classification of threats to traditional ecological knowledge and conservation responses. *Conservation and Society*, *14*(1), 57–70. https://doi.org/10.4103/0972-4923.182799

Tengö, M., Brondizio, E. S., Elmqvist, T., Malmer, P., & Spierenburg, M. (2014). Connecting diverse knowledge systems for enhanced ecosystem governance: The multiple evidence base approach. *Ambio*, *43*, 579–591. https://doi.org/10.1007/s13280-014-0501-3

Tengö, M., Hill, R., Malmer, P., Raymond, C. M., Spierenburg, M., Danielsen, F., Elmqvist, T., & Folke, C. (2017). Weaving knowledge systems in IPBES, CBD and beyond—Lessons learned for sustainability. *Current Opinion in Environmental Sustainability*, *26–27*, 17–25. https://doi.org/10.1016/j.cosust.2016.12.005

Thomas, J., Graziosi, S., Brunton, J., Ghouze, Z., O'Driscoll, P., & Bond, M. (2020). *EPPI-Reviewer*: A*dvanced software for systematic reviews, maps and evidence synthesis*. EPPI-Centre Software. UCL Social Research Institute.

Thompson, K. L., Lantz, T., & Ban, N. C. . (2020)) A review of Indigenous knowledge and participation in environmental monitoring. *Ecology and Society*, *25*(2), 10. https://doi.org/10.5751/ES-11503-250210

Truth and Reconciliation Commission of Canada. (2015). *Honouring the truth, reconciling for the future: Summary of the final report of the Truth and Reconciliation Commission of Canada*. www.trc.ca/assets/pdf/Executive_Summary_English_Web.pdf

Turnbull, D. (2000a). *Masons, tricksters, and cartographers: Comparative studies in the sociology of scientific and indigenous knowledge*. Routledge.

Turnbull, P. (2000b). Introduction: Learning to understand Western and Indigenous science. *Humanities Research*, *1*, 7–20.

United Nations. (2007). *United Nations declaration on the rights of indigenous peoples*. United Nations (UN).

United Nations. (1992). *Convention on biological diversity*. United Nations.

United Nations (1987). *Our common future*. United Nations.

Vitousek, P., Aber, J., Howarth, R., Likens, G., Matson, P., Schindler, D., Schlesinger, W. H., & Tilam, D. (1997). Human alteration of the global nitrogen cycle: Sources and consequences. *Ecological Applications*, *7*, 737–750.

Wheeler, H. C., Danielsen, F., Fidel, M., et al. (2020). The need for transformative changes in the use of Indigenous knowledge along with science for environmental decision-making in the Arctic. *People Nat.*, *2*, 544–556. https://doi.org/10.1002/pan3.10131

Wickham, H. (2016). *ggplot2: Elegant graphics for data analysis*. Springer-Verlag.

Wong, C., Ballegooyen, K., Ignace, L., Johnson, M. J. G., & Swanson, H. (2020). Towards reconciliation: 10 calls to action to natural scientists working in Canada. *FACETS*, *5*, 769–783. https://doi.org/10.1139/facets2020-0005

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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