

SYSTEMATIC MAP

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Bridging Indigenous and science-based knowledge in coastal and marine research, monitoring, and management in Canada

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Abstract

Background: Drawing upon multiple types of knowledge (e.g., Indigenous knowledge, local knowledge, science-based knowledge) strengthens the evidence-base for policy advice, decision making, and environmental management. While the benefits of incorporating multiple types of knowledge in environmental research and management are many, doing so has remained a challenge. This systematic map examined the extent, range, and nature of the published literature (i.e., commercially published and grey) that seeks to respectively bridge Indigenous and science-based knowledge in coastal and marine research and management in Canada.

Methods: This systematic map applied standardized search terms across four databases focused on commercially published literature, carefully selected specialist websites, and two web-based search engines. In addition, reference sections of relevant review articles were cross-checked to identify articles that may not have been found using the search strategy. Search results were screened in two sequential stages; (1) at title and abstract; and (2) at full text following a published protocol. All case studies included were coded using a standard questionnaire. A narrative synthesis approach was used to identify trends in the evidence, knowledge gaps, and knowledge clusters.

Results: A total of 62 articles that spanned 71 Canadian case studies were included in the systematic map. Studies across the coastal and marine regions of Inuit Nunangat accounted for the majority of the studies. Whether the focus is on management and decision making or research and monitoring, the predominant ecological scale was at the species level, accounting for over two-thirds of the included studies. There were 24 distinct coastal and marine species of central focus across the studies. Nunavut had the greatest taxonomic coverage as studies conducted to date cover 13 different genera. The predominant methodology employed for combining and/or including Indigenous knowledge was case study design, which accounted for over half of the studies. Other methodologies employed for combining and/or including different ways of knowing included: (i) community-based participatory research; (ii) mixed methods; (iii) ethnography; and (iv) simulation modelling. There are a suite of methods utilized for documenting and translating Indigenous knowledge and an equally diverse tool box of methods used in the collection of scientific data. Over half of the case studies involved Indigenous knowledge systems of the Inuit, while another significant proportion involved Indigenous knowledge systems of First Nations, reflecting 21 unique nations. We found that demographics of knowledge holders were generally not reported in the articles reviewed.

Conclusions: The results of this systematic map provide key insights to inform and improve future research. First, a variety of methodologies and methods are used in these types of studies. Therefore, there is a need to consider in more detail how Indigenous and science-based knowledge systems can be respectively bridged across subjects

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while also recognizing specific place-based needs of Indigenous communities. Second, the work highlights the need to better report the demographics of knowledge holders. Further inquiry focused on the extent of knowledge co-production and assessing Indigenous participation across different stages of the research process would serve the research community well to improve future research and monitoring in support of, and to strengthen, evidence-based environmental management.

Keywords: Coastal management, Indigenous knowledge systems, Integrative research, Marine management, Monitoring, Systematic map, Canada, Ecological research, Traditional ecological knowledge

Background

The benefits of incorporating multiple types of knowledge (e.g., Indigenous knowledge, local knowledge, science-based knowledge; see Table 1 for definitions) in environmental research and management are many. Drawing upon diverse knowledge systems improves our understanding of social-ecological interdependencies, can lead to innovation, and contribute to the identification of desirable pathways for the future [1]. Furthermore, it expands the evidence-base, increases legitimacy, and builds trust in decision making and environmental management (e.g., [1–4]). Importantly, these aspects are critical to implementation of conservation actions and realizing tangible benefits for ecosystems and the communities that depend upon them.

Local knowledge, such as that held by recreational anglers, coastal residents, and commercial fishers (e.g., [5, 6]) plays an important role in evidence-based decision making, natural resource management, and ecological research. For example, it can be used where other data are sparse and when combined with archival records can contribute to the historical reconstruction of fisheries [6]. However, here we focus specifically on the intersection of Indigenous knowledge systems and science-based knowledge systems (*sensu* [7, 8]). We recognize that there is a risk in such simplifications and the reification of knowledge systems as Indigenous and science-based knowledge systems are diverse, complex, and increasingly

intertwined [9]. However, when seeking to understand and examine instances where different knowledge systems have been brought together, delineations play a role in facilitating explorations at such intersections. For further, in-depth discussions laying out the differences between knowledge systems see for example [10–12].

Canada is the second largest country in the world with a total landmass of 9,984,670 km², and has the longest coastline (202,080 km) globally. Its sheer size and geographical location contribute to the presence of a significant range of climates (i.e., temperate, sub-Arctic, Arctic), and a diversity of coastal and marine habitats and ecosystems (e.g., seagrass, kelp, cold-water corals, glass sponge reefs) [13]. Jurisdictionally, Canada is comprised of ten provinces, three territories, and 24 Comprehensive Land Claim Agreements covering approximately 50% of the country's land mass.

The governance and regulatory landscape for Canada's coastal and marine environment is decentralized [13]. While the majority of the constitutional powers remain at the federal level, they span multiple departments including, but not limited to: Fisheries and Oceans Canada (e.g., *Fisheries Act*, 1985; *Oceans Act*, 1996), Environment and Climate Change Canada (e.g., *Species at Risk Act*, 2002; *Canadian Environmental Protection Act*, 1999), Natural Resources Canada (e.g., *Canada Petroleum Resources Act*, 1985; *Canada Oil and Gas Operations Act*, 1985), and Transport Canada (e.g., *Canada Shipping Act*, 2001).

Table 1 Glossary of key concepts

Term	Definition
Knowledge system	Made up of agents, practices, routines, and institutions that organize the production, validation, transfer, and use of knowledge [67, 68]
Indigenous knowledge systems	A "cumulative body of knowledge, practices, and beliefs, evolving and governed by adaptive processes and handed down and across (through) generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment" [69] ^a
Science-based knowledge systems	With roots in Greek philosophy and the Renaissance, are a fluid and evolving body of knowledge that tends to favor objectivity and reductionism [70]
Bridging knowledge systems	A process that maintains the integrity of each respective knowledge system while enabling the reciprocal exchange of understanding for mutual learning [7, 8]. It is similar to [42] who refer to "integrative approaches" in order to capture the dynamic and co-evolving process of knowledge co-production associated with the intersection of Indigenous and science-based knowledge systems

^a Ref. [71] draws attention to the danger of describing Indigenous Knowledge systems as 'cumulative' as it suggests that it improves only through *addition* rather than also through the process of *revision*

Despite the significant constitutional powers, there are a number of co-management arrangements found across Canada's three coasts (e.g., Nunavut Wildlife Management Board), with other similar arrangements with Indigenous peoples expected to be established as a result of recent federal commitments.

'Indigenous peoples' is a collective name for the original peoples of North America (known also as Turtle Island) and their descendants. Indigenous peoples of Canada includes three distinct groups—First Nations, Métis, and Inuit—with unique histories, cultures, and languages. According to the 2016 census 1,673,785 people self identify as First Nation, Métis, or Inuit [14]. Disaggregated, the First Nation population (977,230) accounts for the majority of Indigenous peoples, followed by the Métis (587,545), and Inuit populations (65,025) [14]. Despite making up only 4.9% of the total population of the country, Indigenous peoples of Canada have a deep and extensive knowledge of Canada's coastal and marine environments [15].

In the Canadian context, an increased focus on environmental research, monitoring, and management practices that are inclusive of Indigenous knowledge systems is driven by a number of interrelated factors, including: federal legal requirements and international commitments to include Indigenous knowledge in environmental conservation, ethical considerations, and increased research capacity and self-determination among Indigenous communities. At the national level, a number of acts administered by federal departments responsible for environmental protection require the consideration of Indigenous knowledge in activities related to environmental conservation in Canada ([13]; i.e., *Impact Assessment Act*, 2019; *Species at Risk Act*, 2002; *Canadian Environmental Protection Act*, 1999; *Oceans Act*, 1996; *Migratory Bird Convention Act*, 1994). For example, the *Canadian Environmental Protection Act* (CEPA) (1999) recognizes "the integral role of science, as well as the role of traditional aboriginal knowledge, in the process of making decisions relating to the protection of the environment and human health." Relatedly, the Minister of Fisheries and Oceans may "conduct studies to obtain traditional ecological knowledge for the purpose of understanding oceans and their living resources and ecosystems" (*Oceans Act*, 1996, s.42(j)). At the international level, Canada is party to a number of international conventions, agreements, and declarations that highlight the importance of Indigenous knowledge (or related concepts) in biodiversity conservation and sustainable resource use; these include the United Nations Declaration on the Rights of Indigenous Peoples (2007), the Convention on Biological Diversity (1992), the Convention for the Protection of Migratory Birds the United States

and Canada (1916), and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES, 1973). Canada is also a member of the Arctic Council, an inter-governmental body that has committed to supporting and utilizing Indigenous knowledge across a number of themes in Arctic governance.

In addition, environmental researchers in Canada increasingly recognize their ethical responsibility to involve relevant Indigenous communities and/or organizations in any research or monitoring activities taking place within their traditional territory [16]. Environmental research conducted across the country can affect Indigenous communities, whether through the research process itself, or through the implications of the research for policy and management. The importance of such an ethical commitment towards Indigenous engagement can be further explained by the history of research involving Indigenous peoples in Canada:

Research involving Aboriginal peoples in Canada has been defined and carried out primarily by non-Aboriginal researchers. The approaches used have not generally reflected Aboriginal world views, and the research has not necessarily benefited Aboriginal peoples or communities. As a result, Aboriginal peoples continue to regard research, particularly research originating outside their communities, with a certain apprehension or mistrust [17].

Lastly, environmental research in Canada is increasingly characterised by Indigenous priorities and involvement in research governance [18, 19]. Greater research capacity and self-determination of Indigenous communities and organizations across the country has led Indigenous groups to shape research priorities, ethics, and approaches to better reflect their values and traditions [16, 18, 19], thus leading to a stronger emphasis on environmental research that bridges Indigenous and science-based knowledge.

Successfully incorporating multiple types of knowledge in environmental research and management remains a challenge [20, 21]. Indeed, previous work has illustrated that natural resource management and environmental decision-making in Canada remains largely based on a scientific and bureaucratic framework of resource management that poses significant barriers to the meaningful inclusion of Indigenous views and knowledge [22–26]. For example, efforts to integrate Indigenous and science-based knowledge systems for co-management of wildlife in northern Canada has, in some cases, led to the decontextualization and compartmentalization of Indigenous knowledge through its translation (and distortion) into forms that can be incorporated into existing management bureaucracies and acted upon by scientists and resource

managers [27–31]. Schemes for involving Indigenous peoples in environmental research and decision-making have notably also been criticized for reducing Indigenous knowledge systems to a collection of mere factual data about the environment, thus failing to acknowledge the value system and cosmological context within which this knowledge was generated and within which it makes sense [32–34].

There has been a proliferation of place-based case studies focused on ecological research and monitoring which bring together different knowledge systems, shedding light on diverse species, habitats, and ecosystems globally (e.g., [35, 36]). Similarly, there has been an increasing number of place-based case studies focused on natural resource management and decision-making contexts where different knowledge systems have been brought together, providing important insights on key contextual factors and the associated processes, pathways, and mechanisms that contribute to successes and failures (e.g., [37, 38]). Despite the continued growth of case studies and empirical research on the subject in coastal and marine contexts (see for example [39, 40]), there has been no comprehensive and systematic mapping of this growing literature. Such a collection of case studies will provide an opportunity to critically examine what methods, models, and approaches for integrative work have been most successful and thus offer promising pathways and guidance. Furthermore, such an examination could improve our understanding of the what and how, when it comes to integrative approaches. Moreover, it could provide critical insights for *engaging* with diverse knowledge systems (*sensu* [41]). However, prior to any in-depth analysis and critical appraisal of the literature to identify best practices and approaches (e.g., [42]), it is necessary to first document the extent, range, and nature of the published literature (see Objective of the Map).

Stakeholder engagement

An increased focus on environmental research, monitoring, and management practices in Canada that are inclusive of Indigenous knowledge systems is driven by a number of interrelated factors, including federal legal requirements, international commitments, ethical considerations, and increased research capacity and self-determination among Indigenous communities. In addition, the Government of Canada has committed to achieving reconciliation with Indigenous Peoples of Canada and supporting evidence-based decision making [43, 44]. Accordingly, there is a need to understand when, where, and how diverse knowledge systems are drawn upon in environmental research, monitoring, and decision-making. In response, a review of the published literature where Indigenous and science-based knowledge

are drawn upon was proposed by Canadian stakeholders (i.e., Fisheries and Oceans Canada (DFO)). Additional input and feedback from other science-based departments (e.g., Environment and Climate Change Canada, Natural Resources Canada) and local/regional organizations (e.g., co-management boards in Canada with a coastal or marine mandate, Aboriginal Aquatic Resource and Ocean Management (AAROM) recipient groups/organizations) was sought throughout the review process via informal conversations, electronic communications, and presentations. Due to the breadth of the review and primary question (see below) we conducted a systematic map to provide an overview of the literature and available case studies.

Objective of the review

We sought to examine the extent, range, and nature of published case studies (i.e., commercially published and grey) that seek to respectively bridge Indigenous and science-based knowledge in ecological research, monitoring, or natural resource management across Canada with a focus on coastal marine ecosystems.

Specifically, we asked: What methods, models, and approaches have been used in studies that seek to bridge Indigenous and science-based knowledge in coastal and marine research, monitoring, or management in Canada?

Definition of the question components

The primary question can be broken down into the following three components:

Population: Cases of coastal or marine research, monitoring, or management.

Study design: Articles that report empirical results, either qualitatively or quantitatively, and where integrative knowledge or knowledge integration practices and/or methods are discussed or inferred that seek to bridge Indigenous and science-based knowledge.

Geographical scope: Case studies conducted from across Canada's three coastal and marine regions (i.e., Atlantic, Pacific, Arctic).

Methods

This systematic map followed the methods outlined in our protocol published in the Environmental Evidence Journal [45]. In doing so, this systematic map followed the Collaboration for Environmental Evidence Guidelines [46] and complied with ROSES reporting standards [47] (see Additional file 1). Our methods deviated from the protocol only in that slightly fewer results from both Google and Google Scholar search engines were exported and screened than anticipated. Throughout all stages of this map, reviewers were not responsible for making decisions about articles they have authored.

Searching for articles

This systematic map applied standardized search terms across four databases focused on peer reviewed publications, carefully selected specialist websites, and two web-based search engines. In addition, reference sections of relevant review articles were cross-checked to identify articles that may not have been found using the search strategy. The searches were conducted between July 2018 and November 2018.

Search terms and languages

The search terms and associated strings were developed and optimized using a scoping exercise to evaluate the sensitivity associated with alternate terms and wildcards. The terms were broken into three components and were combined using Boolean operators “AND” and/or “OR”. Database-specific search strategies, date ranges, and number of returns can be found in Additional file 2 (Literature searches). The comprehensiveness of the search was tested against a collection of benchmark papers ($n=20$; Additional file 3) to ensure articles identified as relevant were being captured when possible. All searches were conducted in English.

Searches

Four bibliographic databases (i.e., ISI Web of Science, Scopus, ProQuest Dissertations & Theses Global, Federal Science Library (Canada)) were searched in July 2018 using English search terms and Boolean operators as defined in the published protocol [45]. Carleton University’s institutional subscription was used to search the three commercial bibliographic databases. See Additional file 2 for search settings. In addition to the bibliographic databases, searches were performed using Google and Google Scholar in October 2018. Due to limitations in the search capabilities, simplified search strings were used for both web-based search engines (see Additional file 2). To export search results from Google, Linkclump (a Google Chrome plug-in) was used to save individual page results and export into Microsoft Excel. Attempts were made to export the top 260 results from each search string (520 total results per search engine). Limitations in export capabilities allowed us to export the 512 and 459 most relevant results from Google Scholar and Google, respectively. Page results were manually screened online and it was determined that result relevance had significantly reduced after the first 100 results, and we were therefore not concerned with the decreased number of results screened overall. Specialist websites (i.e., Library and Archives Canada, Canadian Public Policy Collection, Government of Canada Publications, Fisheries and Oceans Canada) relevant to the topic were manually

searched using their built-in search facilities in August 2018 using eight simplified English search term combinations (e.g., Marine AND “Ecological Knowledge”, Coast AND “Indigenous Knowledge”; See Additional file 2). The top 30 search results from each search string, sorted by relevance, were screened for inclusion in this systematic map (240 total results per website). The reference sections of 43 articles identified as relevant reviews (24 from title and abstract screening, 22 from full-text screening, and 1 submitted review; see Additional file 4) were manually searched for any relevant articles that may not have been captured during the above searches.

Calls for evidence were circulated on social media platforms (i.e., Twitter, Facebook) and within the authors’ professional networks to capture articles, reports, and grey literature that are within the scope of this systematic map. Given the subject matter of this systematic map, a targeted evidence call was sent via a personalized email to the Aboriginal Aquatic Resource and Ocean Management (AAROM) recipient groups/organizations ($n=33$) and co-management boards in Canada with a coastal or marine mandate ($n=10$) in October 2018. These groups often conduct or support research projects that bring together Indigenous and science-based knowledge. In some cases, a follow-up call took place to discuss the nature of this systematic map, the type of information we were seeking, and how it would be shared with the public. Given the short time frame, no updates to the search were performed during the conduct of this systematic map.

Article screening and study eligibility criteria

Screening process

The results from the bibliographic databases were imported into Zotero and merged into one file when necessary (i.e., Scopus allows a maximum of 2000 articles per export). Results from each source were exported as an.RIS and imported into EPPI Reviewer 4 [48] where duplicates were removed prior to screening. Results from both Google and Google Scholar searches were screened at title and abstract directly in Microsoft Excel.

All articles were screened for relevance at two distinct stages, title and abstract and then full text using the pre-defined eligibility criteria outlined in the protocol [45] and summarized above. Prior to each stage of screening, a consistency check between reviewers (SMA, JFP, JIL) was performed using a subset of articles. At title and abstract, 378/9,523 articles (4%, as opposed to 5% as indicated in the protocol) were screened in two batches by three reviewers with inter-reviewer Kappa scores ranging from 0.244 to 0.659 (91.80%–94.71% agreement). All discrepancies were discussed and a fourth reviewer (JJT)

Table 2 Eligibility criteria

Population	Case studies that concern coastal or marine habitat, ecosystems, or species (incl. coastal birds, diadromous fish, and polar bears)
Study design	Articles that report empirical results, either qualitatively or quantitatively, and where integrative knowledge or knowledge integration practices and/or methods are discussed or inferred. Empirical studies included 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 science and Indigenous knowledge; e.g., [58]); (2) studies focused on the processes and practices of bridging knowledge systems in the context of decision making (e.g., narwhal co-management [38]); and (3) studies concerned with perceptions of ecological or environmental phenomenon (e.g., perceptions of ecosystem services [72])
Geographical scope	Case studies conducted from across Canada's three coastal and marine regions (i.e., Atlantic, Pacific, Arctic)
Language	English

was brought in to reconcile any differences and modify the inclusion criteria. While we recognize the Kappa score range is lower than typically accepted, due to time constraints it was decided that the reviewers would move forward as they were confident in the adjusted criteria after both batches. The reviewers worked closely and if an article's eligibility was unclear during screening, the article was flagged for a second opinion and then screened by one or more reviewers and eligibility was discussed with the review team. Attempts were made to find all articles included at title and abstract screening using the Carleton University library, and via interlibrary loans for those articles (including book chapters, dissertations, theses, reports, etc.) outside of the institutional subscriptions. For the consistency check at full text, 25/272 articles were screened by the same three reviewers with inter-reviewer Kappa scores of 0.444, 0.437, 0.525 indicating moderate agreement. Once again, the inclusion criteria were reviewed and clarified prior to screening the remaining full texts and the option to have an article with unclear eligibility screened by other members of the review team was exercised. Reviewers who authored articles to be considered within the review were prevented from influencing inclusion decisions through the appropriate delegation of tasks.

Eligibility criteria

Once results were compiled in the search strategy and duplicates removed, the articles were screened using a pre-established set of eligibility criteria (Table 2). To be included in the final dataset articles had to meet all four inclusion criteria.

Study validity assessment

Considering the broad scope of this systematic map, we did not appraise the validity of individual studies.

Data coding strategy

Following the full-text screening, the included studies were coded using a standard questionnaire (Additional file 5) by one of three team members (SMA, JIL, LN). The questionnaire was designed to capture key descriptive information about the studies regarding five general categories: (1) bibliographic information; (2) study location; (3) study purpose and scope; (4) research methods and mechanisms; and (5) Indigenous knowledge systems (Additional file 5). A Google Form—which automatically compiles the results—was developed to facilitate the coding and metadata extraction. The resulting data was exported and recorded in a comma separated file. Formatting of the data was standardized in R and analyzed using a customized script. The code and data files can be accessed via OSF [here](#). Prior to metadata extraction, a subset of articles (5/63 included articles; 8%) was used for a consistency check to ensure consistent and repeatable decisions were made regarding the meta-data coding. In addition, at the conclusion of meta-data coding, the lead author reviewed all coding decisions for consistency. Meta-data extraction and coding was conducted at the case study level—as compared to the article level. Accordingly, in some instances a single article (e.g., [38]) would contribute more than one case study.

Data mapping method

A narrative synthesis approach was used to identify trends in the evidence through the use of descriptive statistics, tables (including SM database), and figures (including a map with the studies geospatially referenced). The defining characteristic of narrative synthesis as noted by [49] "is that it adopts a textual approach to the process of synthesis to 'tell the story' of the findings from the included studies." So while it can include descriptive statistics, this approach largely uses words to summarize the findings [49]. Framework-based synthesis guided the development of a structured matrix which was used to identify knowledge gaps and knowledge clusters (e.g., [50, 51]). Specifically, two structured matrices were developed to identify and/or prioritize key knowledge gaps (underrepresented subtopics that warrant further primary research) and knowledge clusters (well-represented subtopics that are amendable to further qualitative synthesis). The first structured matrix examines the frequency with which the location of a case study fell within each jurisdiction and focused on a species found within twenty different genera (Fig. 16). The second structured matrix examines the frequency with

which each jurisdiction was the location of a study focusing on each ecosystem type (Fig. 17). In some instances, descriptive statistics helped to identify evidence gaps and key insights. The map depicting the locations of the study areas included in the systematic review was created using ArcMap 10.6.1 [52], bar graphs were made using base R, and the stacked bar graph and structured matrices were constructed using ggplot2 [53]. The Sankey data visualisations (Figs. 14 and 15) were produced in R using the networkD3 package that is publically available [54].

Results

Number and types of articles

A search of four bibliographic databases, Google and Google Scholar (See Additional file 2 Literature Searches) returned 12,583 individual records, which resulted in 9523 records after duplicates were removed. Of those, 272 articles were deemed relevant at title and abstract. All but two of the articles were retrieved through open-access, Carleton University institutional subscriptions, or through interlibrary loans for full-text screening. This left 270 articles to be screened at full-text, 211 of which were deemed out of the scope of this systematic map. The majority of articles were excluded on document type (i.e., not an empirical study) and content focus (i.e., did not include both scientific research and Indigenous knowledge). All excluded articles along with their reasons for exclusion can be found in Additional file 6 (Excluded at FT). A total of 59 articles were included in the systematic map from the bibliographic databases, Google, and Google Scholar.

A total of four additional articles were included from specialist and supplemental sources (e.g., reference lists of relevant reviews, organizational websites, contributed grey literature). The source of these is outlined as follows. Searching the reference lists of relevant reviews resulted in the inclusion of one additional article not previously captured in our searches. Searching organizational websites also resulted in the inclusion of one additional article. All grey literature submitted in response to an open call for contributions (i.e., via social media platforms and listservs), and from direct contacts with Aboriginal Aquatic Resource and Ocean Management (AAROM) Program recipient groups/organizations and co-management boards were screened, and resulted in the inclusion of two additional articles. While 63 articles were initially included, one article was identified as supplemental¹ during the screening process. Accordingly, 71 case studies

from 62 articles were included in this systematic map database and narrative synthesis (Fig. 1).

The 62 articles and 71 case studies were found to vary across several different metrics. Overall, very few articles were published prior to 2000 (Fig. 2). While the total number of articles published between 2000 and 2005 were relatively low, there was more consistency from year to year. There was a small, but notable, increase in the annual volume of articles published starting in 2006 (Fig. 2). However, aside from 2016 which seems to be an anomaly, the annual volume of articles published remains relatively consistent from 2006-2018 (Fig. 2). The majority of publications came from the commercially published literature (46/62) while the fewest were found in the grey literature (4/62; Fig. 3a). Articles from the commercially published literature were found across twenty-five different journals of which nineteen had a single article. Journals with more than one publication included: *Arctic* (n=9), *Conservation Biology* (n=2), *Ecology and Society* (n=6), *Human Ecology* (n=2), *Marine Policy* (n=3), and *Polar Record* (n=2). The majority of first authors were from academic institutions (41); government organizations were the second-most represented group with 14 (Fig. 4). Approximately 21% (n=13) of the publications included in the systematic map had Indigenous authors or authors who represent Indigenous communities, organizations, and/or governments (Fig. 5).

Systematic map

The core output from this research was a systematic map. This systematic map has two key components: (1) a systematic map database (Additional file 7) which contains meta-data and coding for all included studies; and (2) the geographical distribution and location of each case study (Figs. 6, 7, 8, 9, 10). The numbers found on Figs. 7, 8, 9, 10 reflect the case study ID found in the systematic map database (Additional file 7).

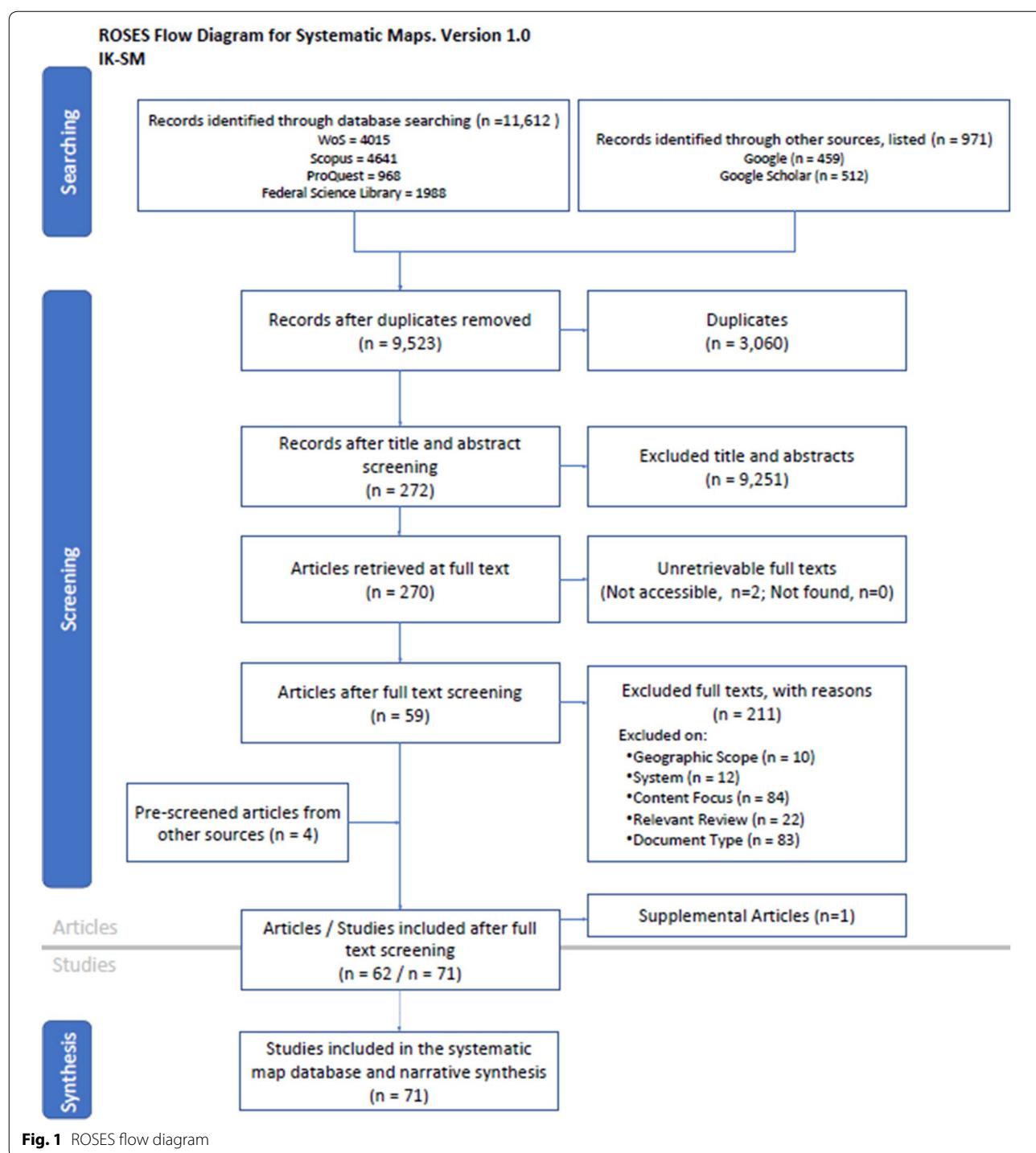
Geographic distribution of included case studies

The 71 case studies that were included in the systematic map span across Canada's three coasts (Fig. 6, 7, 8, 9, 10). Studies across the coastal and marine regions of Inuit Nunangat accounted for the majority of the studies (Figs. 6, 8, 9, 11, 12). At the sub-national level (e.g., province, territory, land claim agreement), just over one-third of the case studies were found in Nunavut (~39%; Fig. 12). British Columbia (~31%) and Inuvialuit Settlement Region (~23%) were also notable with regard to the number of case studies (Fig. 12).

Case study purpose and scope of included studies

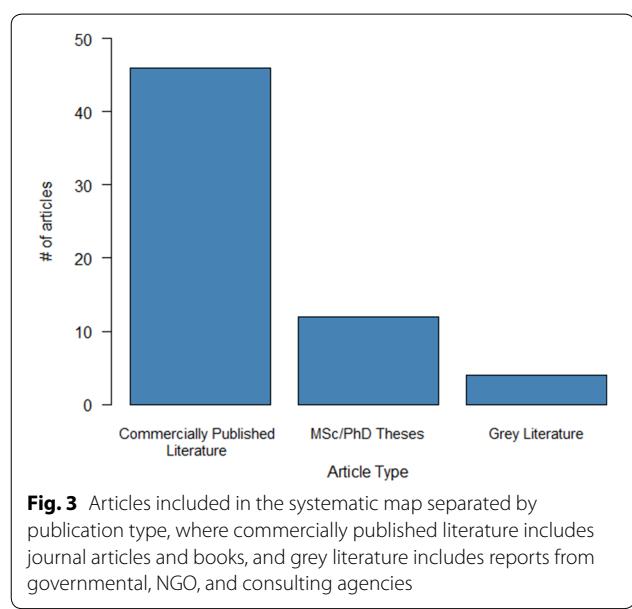
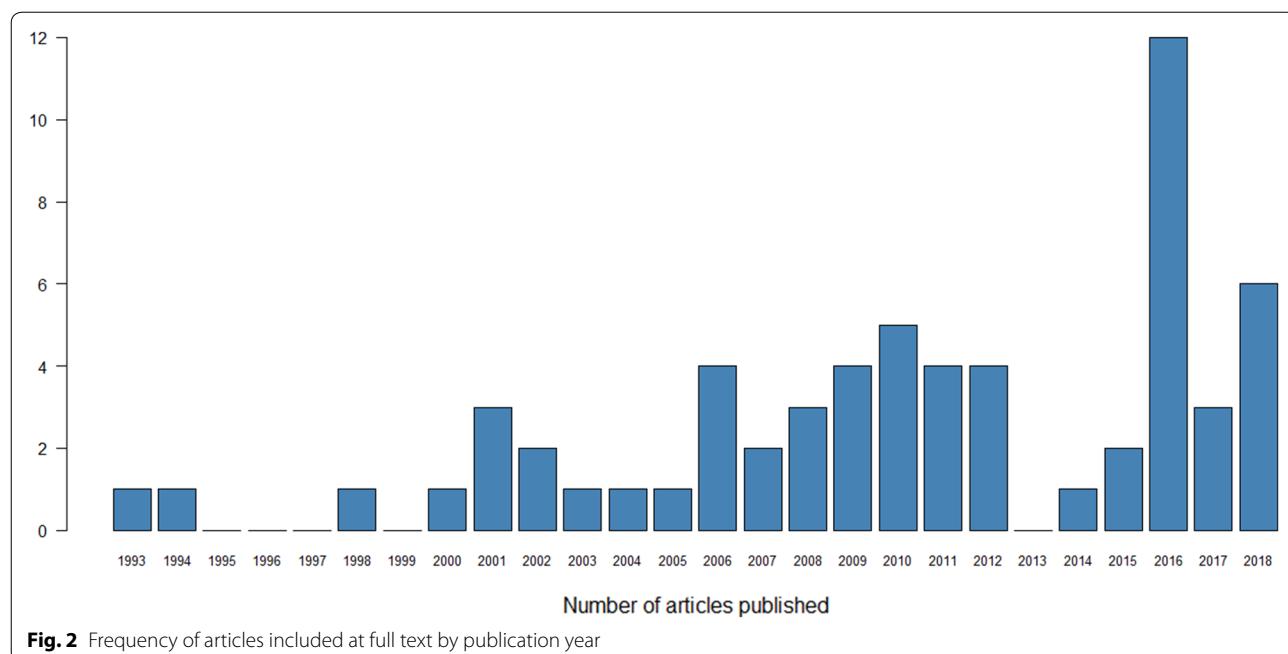
An examination of the research questions and/or objectives for the 71 case studies revealed that a number of

¹ A supplemental article is one which reports the same study and results. A commercially published journal article was based on a dissertation chapter. While both were included at full text, meta-data was only extracted from the commercially published journal article to avoid duplication.

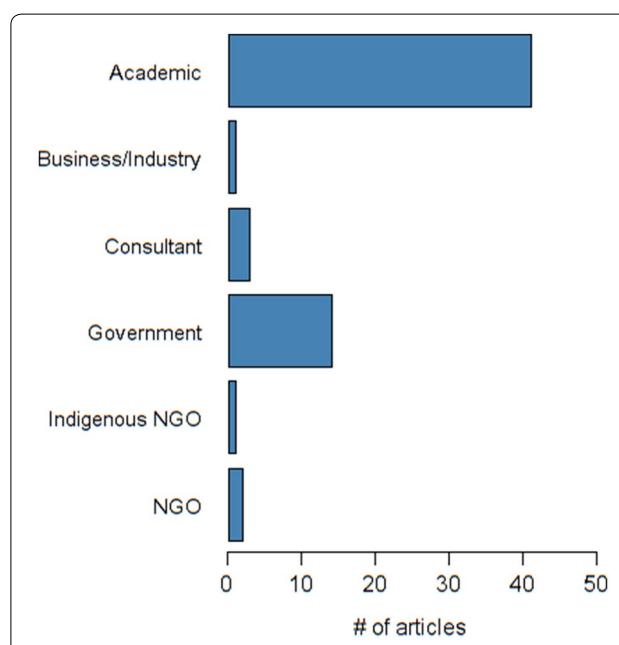
**Fig. 1** ROSES flow diagram

them were concerned with fundamental research (i.e., expand general body of knowledge) (~30%). The remaining ~70% were equally distributed between applied research (e.g., for management or development purposes) and case studies which included both fundamental and applied aims (Fig. 13). As an example of applied objectives, [55] aimed to “compare the concept of conservation

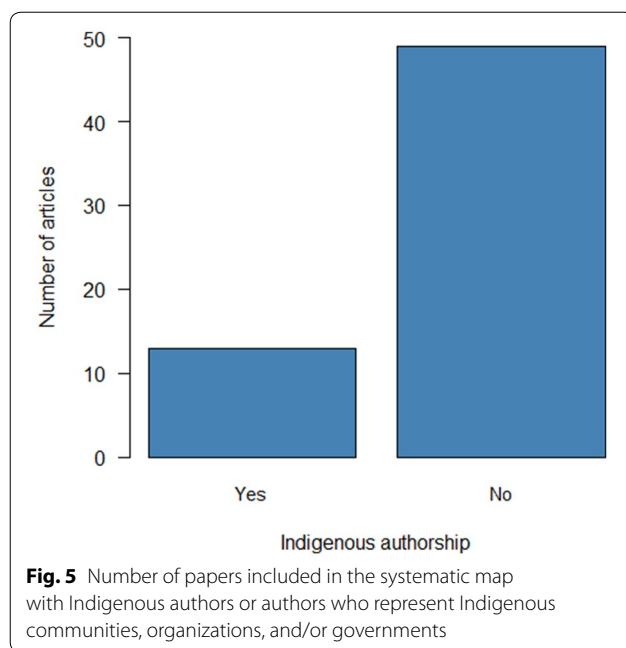
within Atlantic salmon management from a non-Aboriginal state perspective with a Mi’kmaq perspective, and offer recommendations on how to further develop governance initiatives related to Atlantic salmon based on these perspectives.” In contrast, [56] provide an example of a study with fundamental objectives as the Ecosystem Overview and Assessment Report was “intended to



provide a general overview of the major ecological components of the Bras d'Or Lakes watershed which encompasses land, freshwater, and marine features.” Even with the above examples where either applied or fundamental objectives were stated, we recognize that such objectives sit on a continuum rather than as discrete entities (*sensu* [57]) and that the majority of the studies reviewed have applied applications even when the objectives were presented in a fundamental nature. Further to this idea



of the continuum, over one-third of the studies included both fundamental and applied aims. For example, [58] had three specific objectives “to (i) use interviews to estimate relative changes in yelloweye rockfish size and abundance since the 1950s, (ii) identify factors perceived to have caused these changes (e.g. commercial fishing,



environmental shifts, etc.), and (iii) compare modern TEK [Traditional Ecological Knowledge] and LEK [Local Ecological Knowledge] observations with recent scientific surveys of yelloweye rockfishes by the Central Coast First Nations [59] and Fisheries and Oceans Canada (DFO)."

Case studies included in the systematic map fell into one of two broad categories regarding the empirical focus of the research. Studies focused on environmental/ecological research and monitoring (i.e., those reporting on direct or indirect observation or experience from science and Indigenous knowledge) accounted for just over half (~51%) while studies focused on the processes and practices of bridging knowledge systems in the context of decision making (e.g., narwhal co-management) accounted for just under half (~49%; Fig. 14). With regards to the ecological scale of research, an overwhelming majority of the case studies focused on scale of the species (49) with fewer focused on ecological communities (3) or ecosystems (19; Fig. 15). Across the studies there were 24 distinct coastal or marine species including fish ($n=16$), marine mammals ($n=10$), and coastal birds ($n=2$). A structured matrix analysis highlighted that Nunavut has the greatest taxonomic coverage as case studies conducted to date cover 13 different genera (Fig. 16). In addition, Nunavut had four particular knowledge clusters, including case studies concerning *Monodon* spp (narwhal, $n=6$), *Ursus* spp. (bears; $n=4$), *Somateria* spp. (ducks, $n=3$), and *Balaena* spp. (whales, $n=3$). Other knowledge clusters were identified in the Inuvialuit Settlement Region concerning *Delphinapterus* spp. (beluga, $n=5$) and in British Columbia concerning

Oncorhynchus spp. (salmon, $n=7$) and *Clupea* spp. (herring, $n=5$; Fig. 15). The vast majority of studies at the ecosystem level focused on coastal systems, with Nunavut and British Columbia being particular stand outs (Fig. 17).

Methods, models, and approaches

The main thrust and motivation for this systematic map was to identify the methods, models, and approaches that have been used in studies that seek to bridge Indigenous and science-based knowledge. Here we specifically bounded the context to coastal-marine research, monitoring, and management across Canada's three coasts. Specifically we focused our examination on two levels with regards to the included studies: (i) methodology (i.e., research design; e.g., case study, mixed methods, ethnography); and (ii) methods. For the latter, the focus was on methods used for acquiring/representing Indigenous knowledge and those used for collecting scientific data.

When it comes to methodology, we find that there were five different research designs used: (i) case study; (ii) community-based participatory research; (iii) mixed methods; (iv) ethnography; and (v) simulation modelling (Fig. 18). The predominant methodology employed was case study design, which accounts for over half of the studies (Fig. 18). Figure 18 situates the research methodology in relation to the ecological scale of research, focus of research, and coastal or marine region. A few key patterns emerge. Across the three coastal and marine regions, the focus on management and decision making versus research and monitoring is fairly evenly split (Fig. 18). Whether the focus was on management and decision making or research and monitoring, the predominant ecological scale was at the species level, accounting for over two-thirds of the studies included (Fig. 18). An examination of the relationship between the ecological scale of research and research methodology draws attention to those methodologies employed across all three ecological scales (case study, mixed methods) versus two ecological scales (community-based participatory research), and those that have only been employed for a single ecological scale (ethnography, simulation modelling).

A closer look at the specific methods employed in ecological research and monitoring revealed a few key insights. The first is that there is a suite of methods that have been employed when it comes to Indigenous knowledge, and an equally diverse tool box of methods when it comes to the collection of scientific data (Fig. 19). In addition, there are a subset of methods that can be found on both sides, including interviews, document review, surveys, and mapping (Fig. 19).



Fig. 6 Geographic distribution of case studies included in the systematic map ($n=71$; locations reflect the centralized point of each study area)

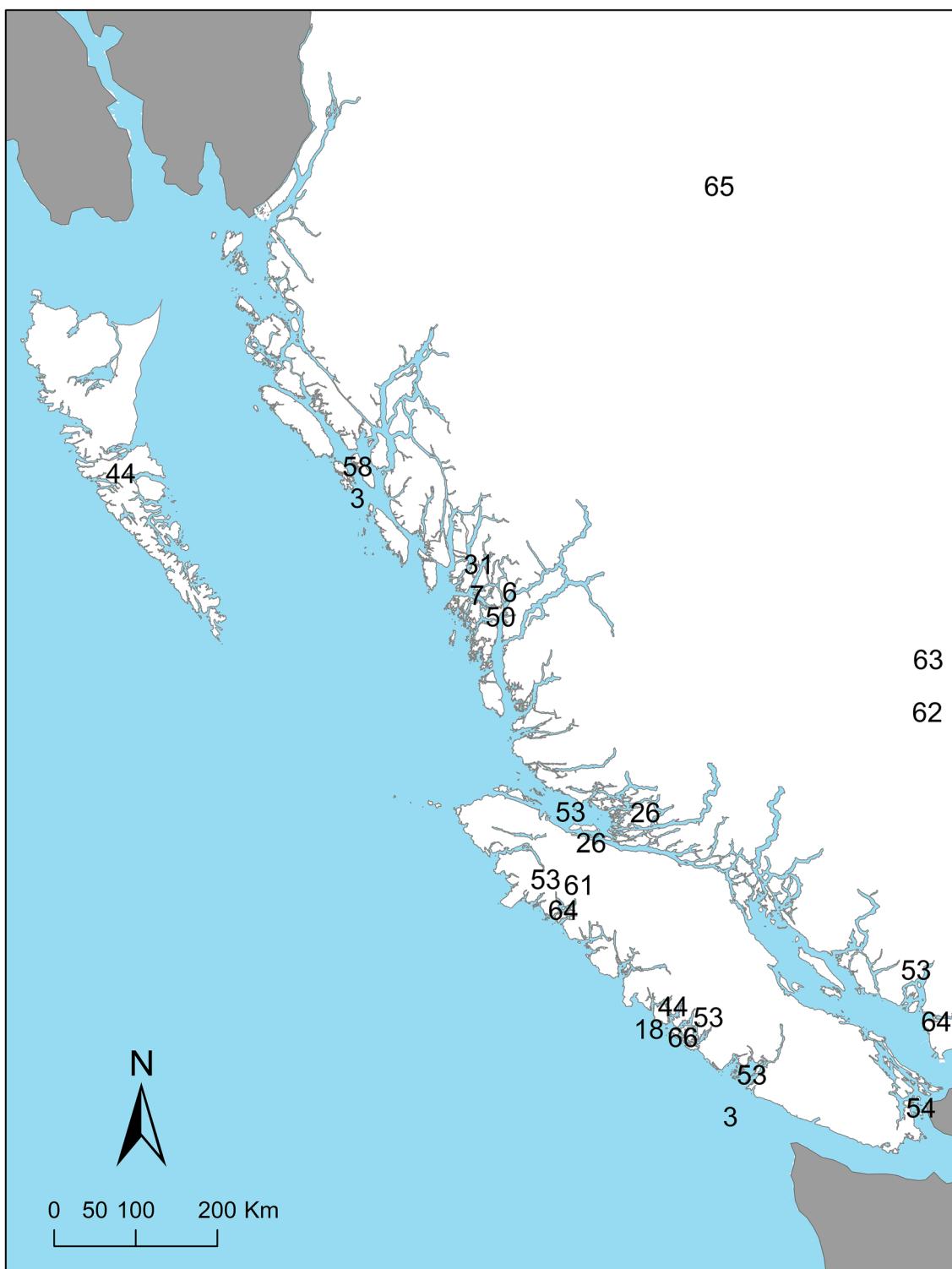


Fig. 7 Geographic location of case studies in the Pacific region. Note that some case studies have multiple locations. The numbers align with the case study ID found in the systematic map database (Additional file 7)

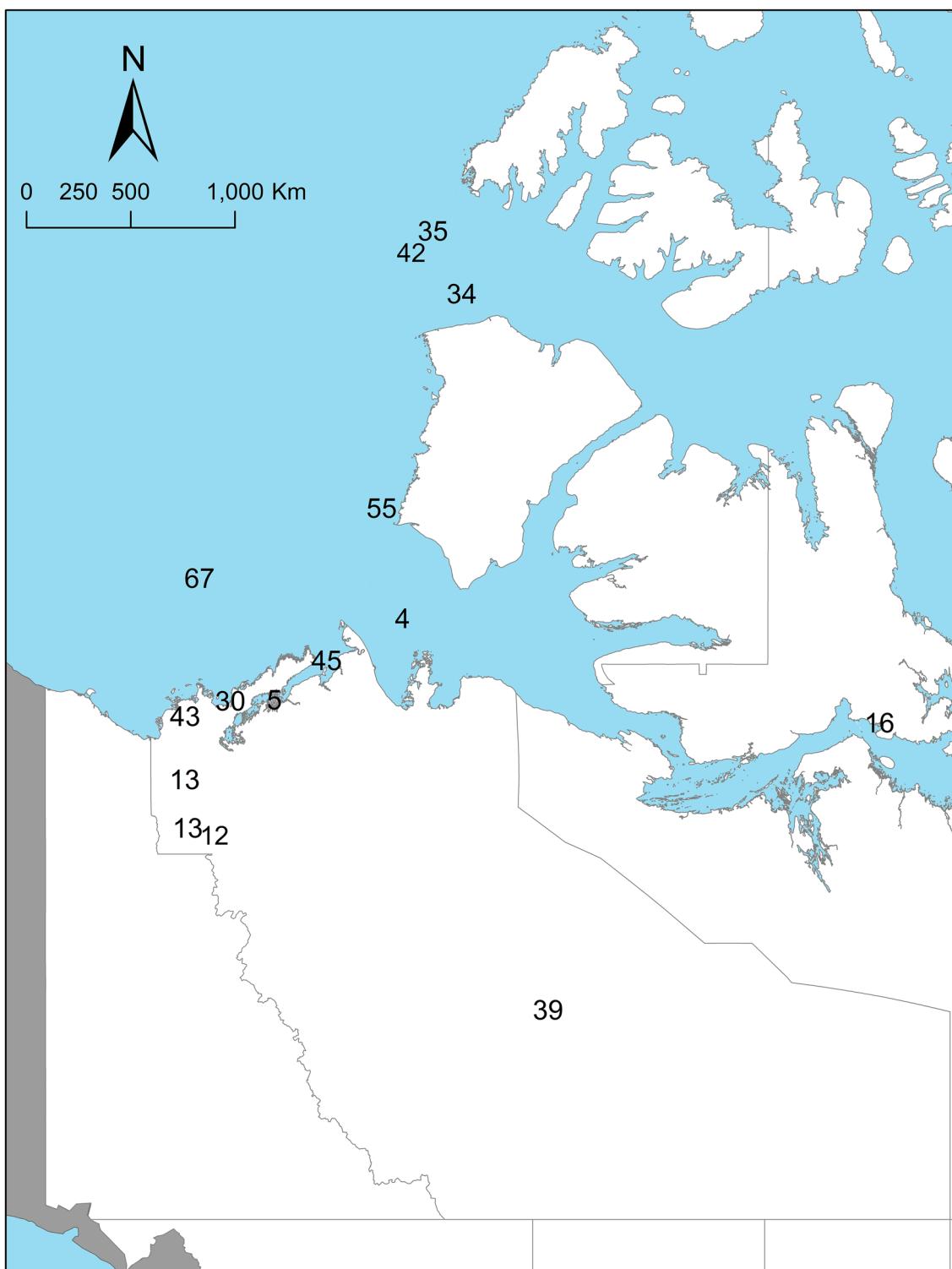


Fig. 8 Geographic location of case studies in the Western Inuit Nunangat region. Note that some case studies have multiple locations. The numbers align with the case study ID found in the systematic map database (Additional file 7)

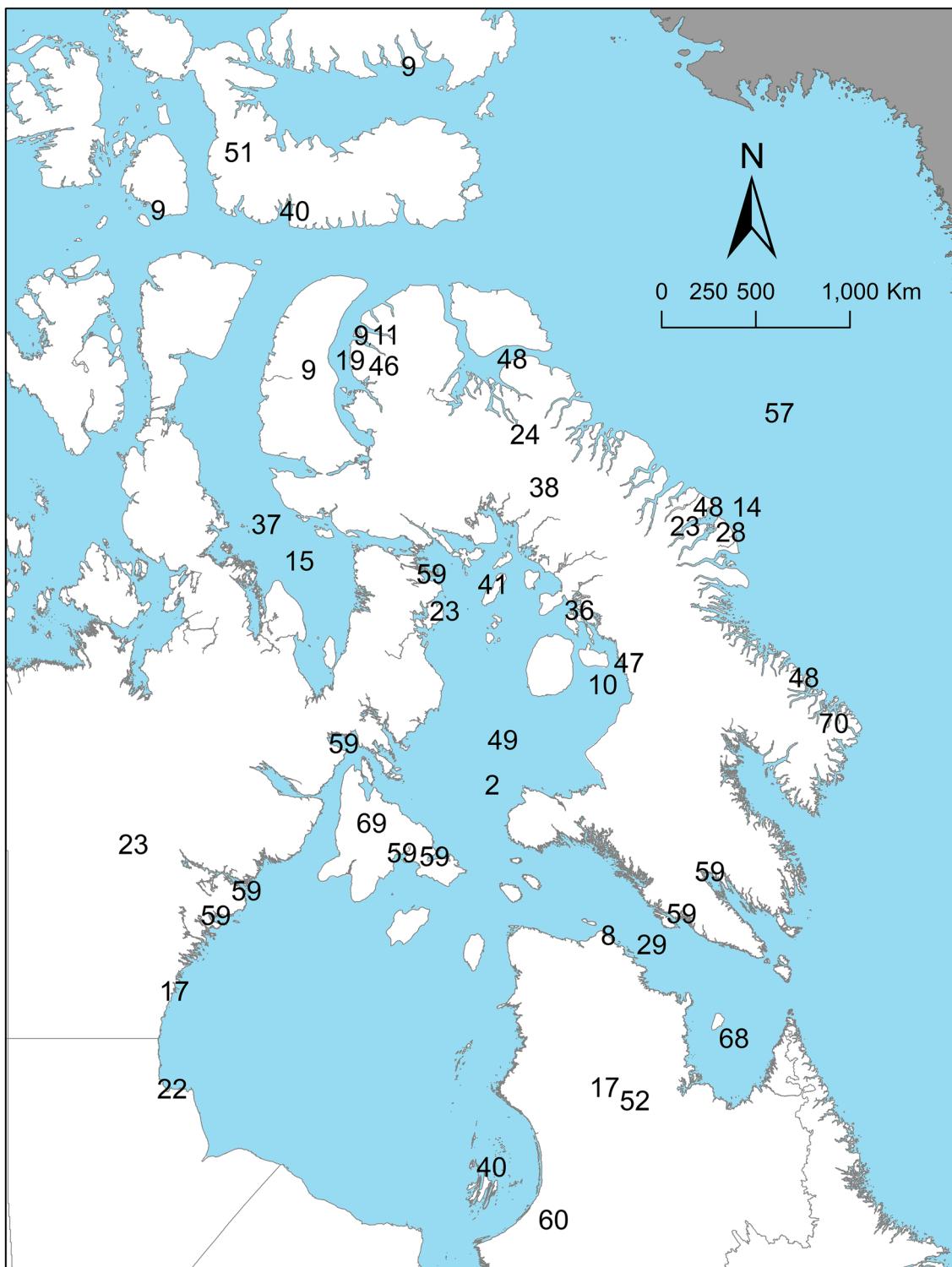


Fig. 9 Geographic location of case studies in the Eastern Inuit Nunangat region. Note that some case studies have multiple locations. The numbers align with the case study ID found in the systematic map database (Additional file 7)



Fig. 10 Geographic location of case studies in the Atlantic region. Note that some case studies have multiple locations. The numbers align with the case study ID found in the systematic map database (Additional file 7)

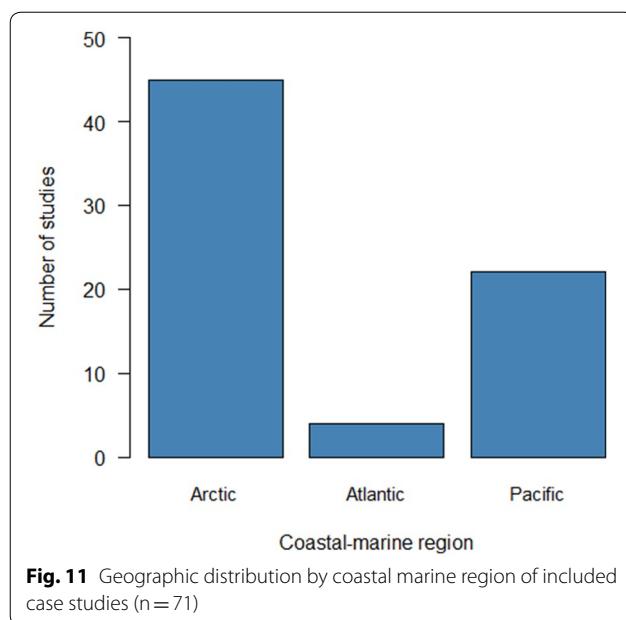


Fig. 11 Geographic distribution by coastal marine region of included case studies (n=71)

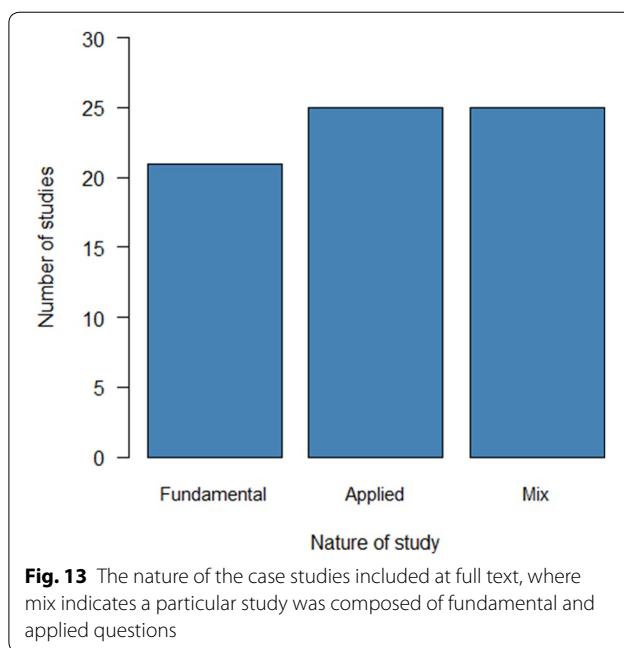


Fig. 13 The nature of the case studies included at full text, where mix indicates a particular study was composed of fundamental and applied questions

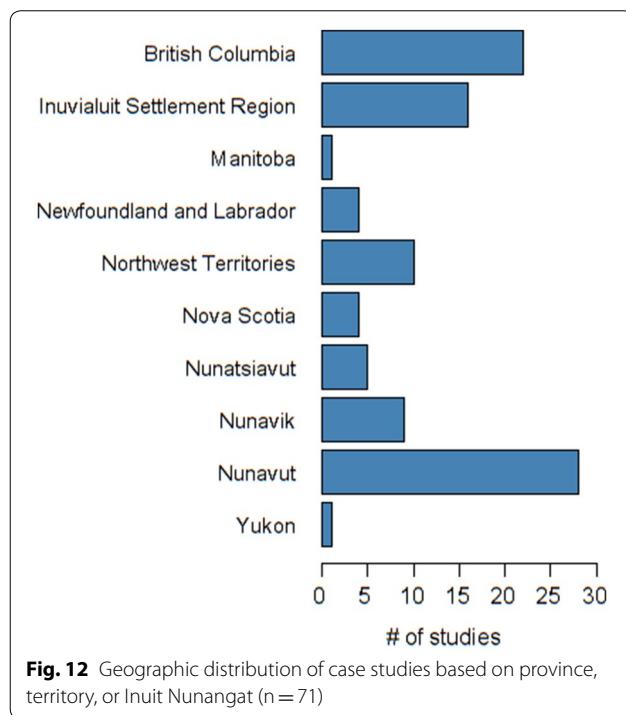


Fig. 12 Geographic distribution of case studies based on province, territory, or Inuit Nunangat (n=71)

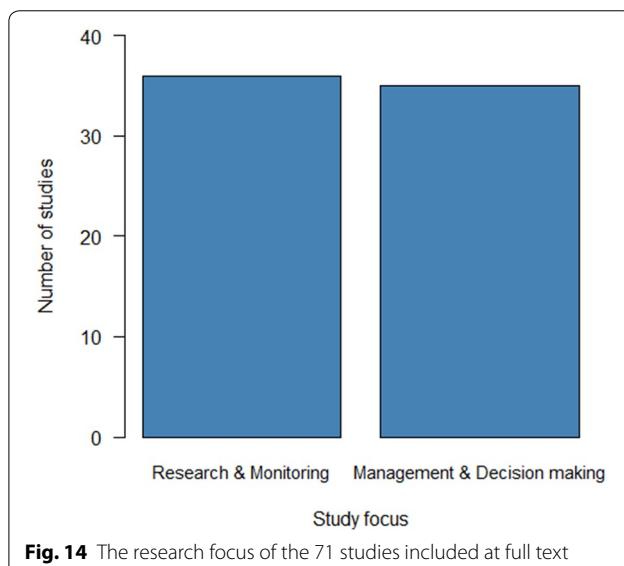
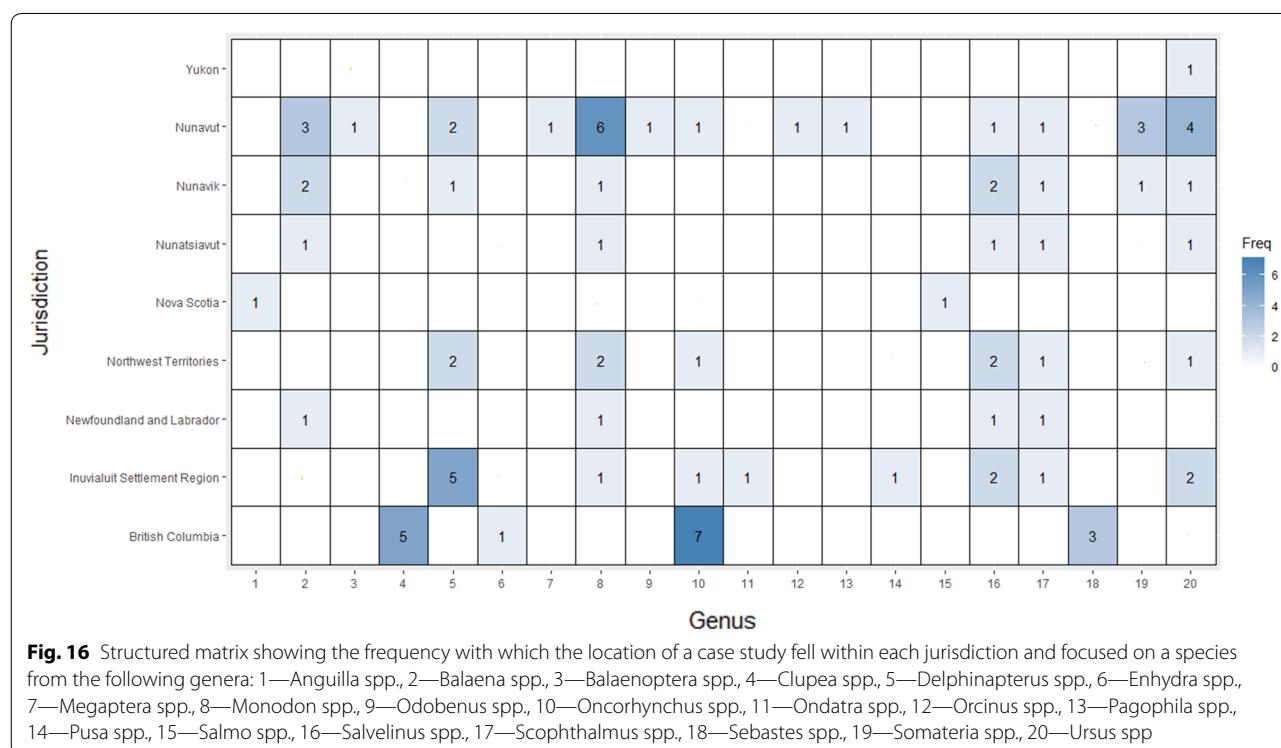
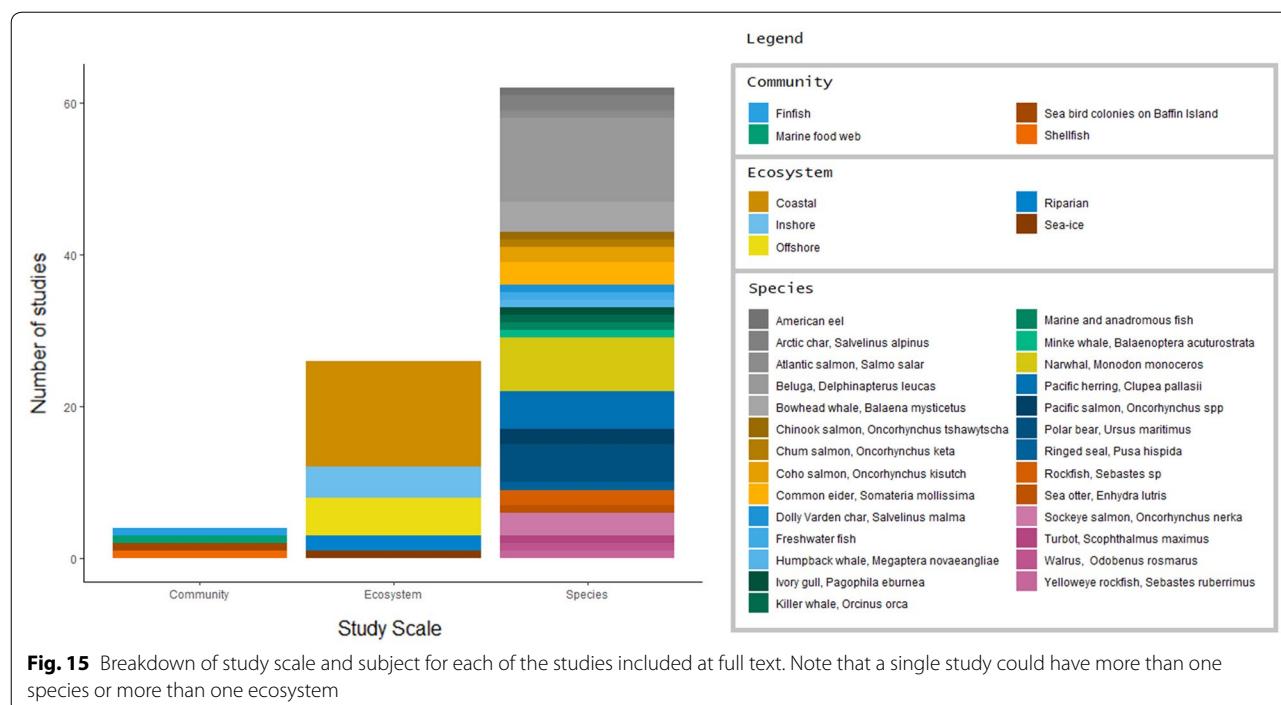


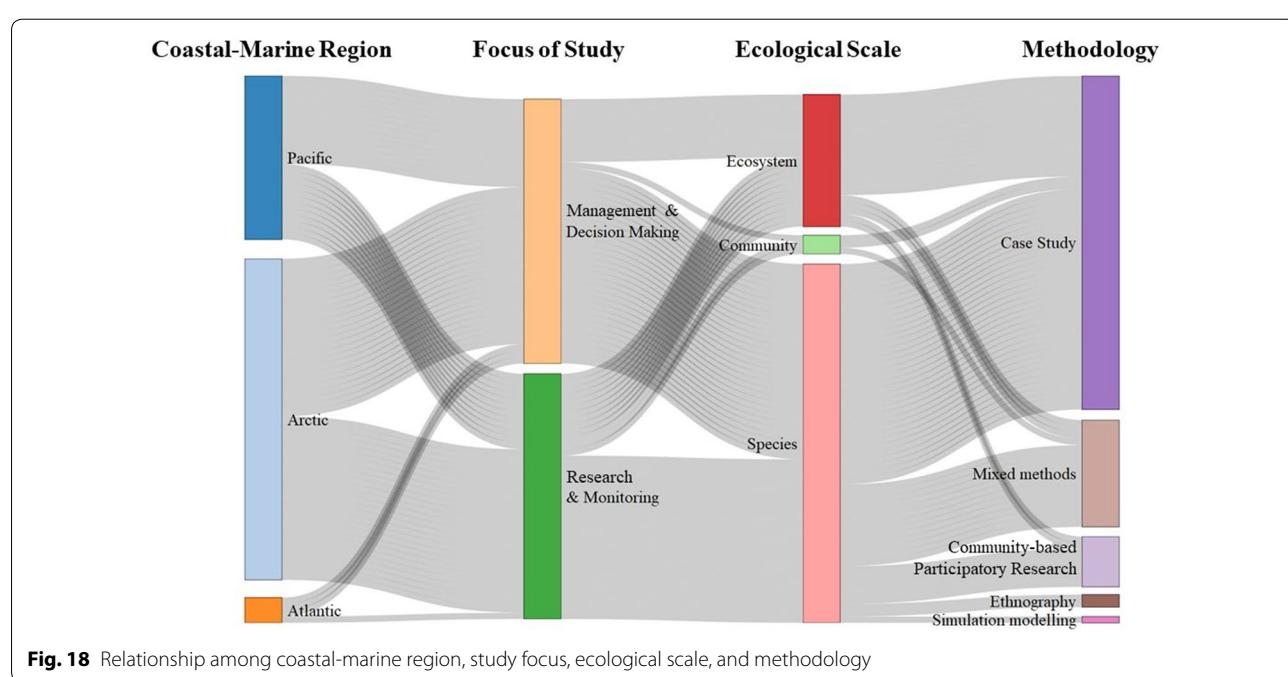
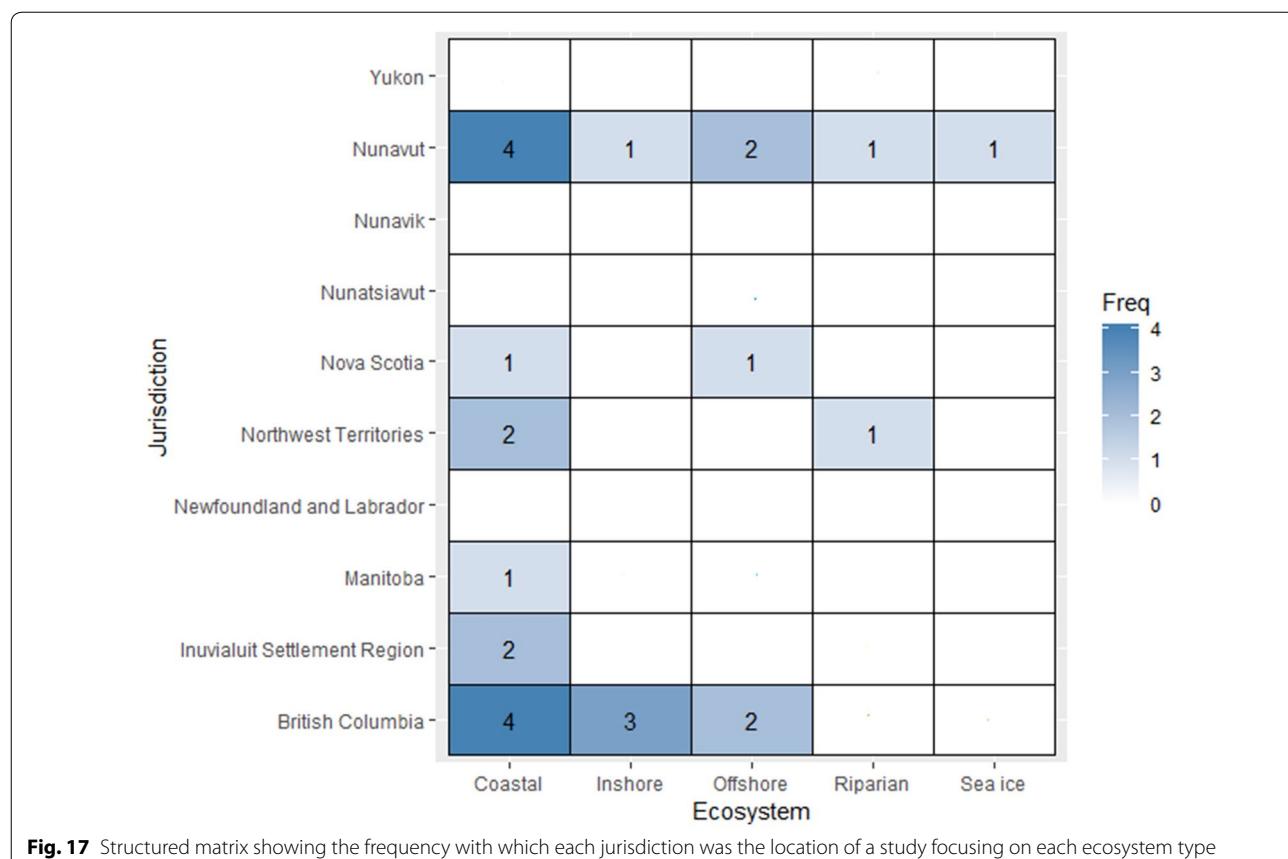
Fig. 14 The research focus of the 71 studies included at full text

Indigenous knowledge systems and demographics of knowledge holders

To gain a better understanding of the representation of Indigenous knowledge systems and knowledge holders, details regarding Indigenous participation were examined for each case study (Additional file 5, questions

35–42). The majority of case studies (47/71) did not report details about the age of knowledge holders who participated in the research (Fig. 20). For those studies that did provide details on the age of knowledge holders, they largely included middle age (22) and older (22) participants, while only five specifically included knowledge from youth (Fig. 16). With regards to the participation and/or contribution of elders, fewer than half did not report specific details (29/71), while 55% involved elders





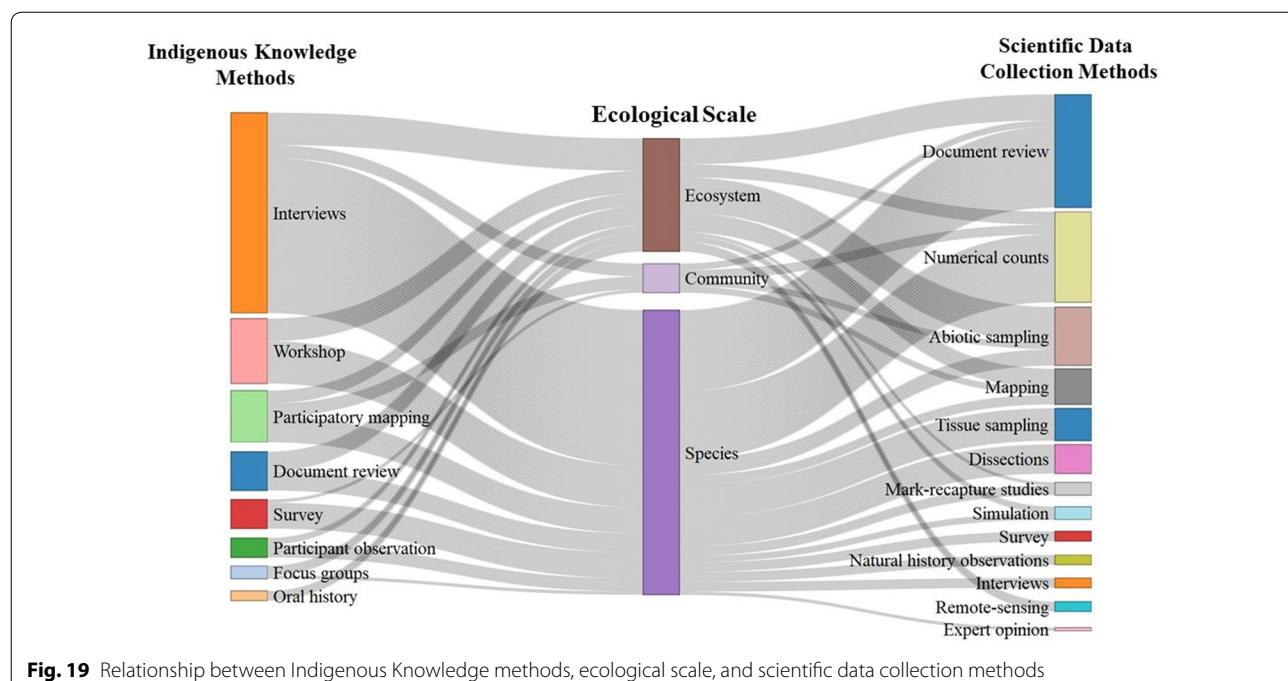


Fig. 19 Relationship between Indigenous Knowledge methods, ecological scale, and scientific data collection methods

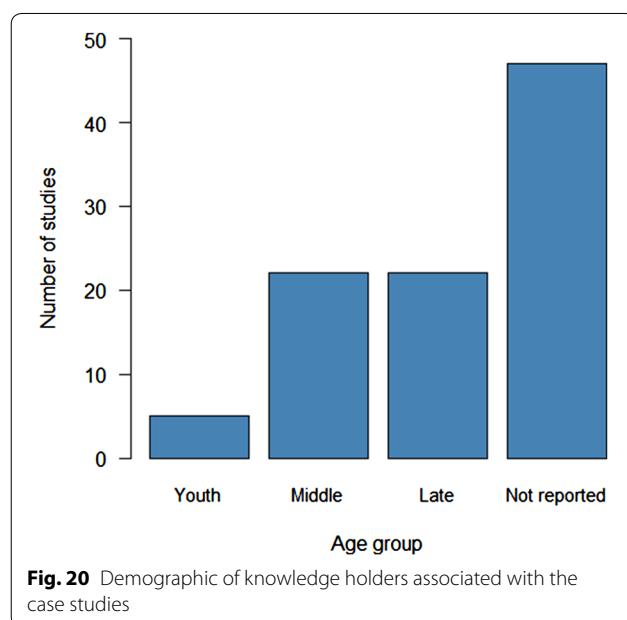


Fig. 20 Demographic of knowledge holders associated with the case studies

and three explicitly did not (Fig. 21).² The majority of case studies (50/71) did not report details about the gender of knowledge holders (Fig. 22). Of those that reported

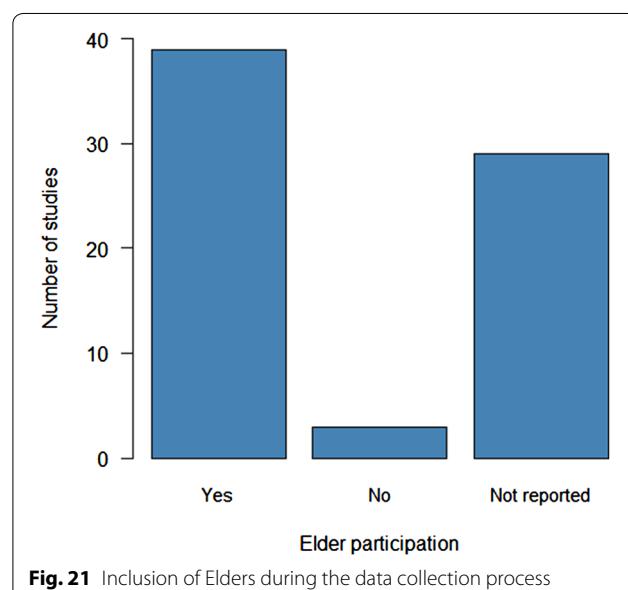


Fig. 21 Inclusion of Elders during the data collection process

the gender of the knowledge holders that participated in the research, 16 involved males and 15 included female knowledge holders (Fig. 22). Over half of the case studies involved Indigenous knowledge systems of the Inuit (41/71), while another significant proportion involved Indigenous knowledge systems of First Nations (28/71), reflecting 21 unique nations. There were three case studies that did not report whether the Indigenous knowledge

² Note that whether elders were included in a study was not based on the reporting of age of knowledge holders but rather whether the authors specifically referenced the inclusion of 'elders'.

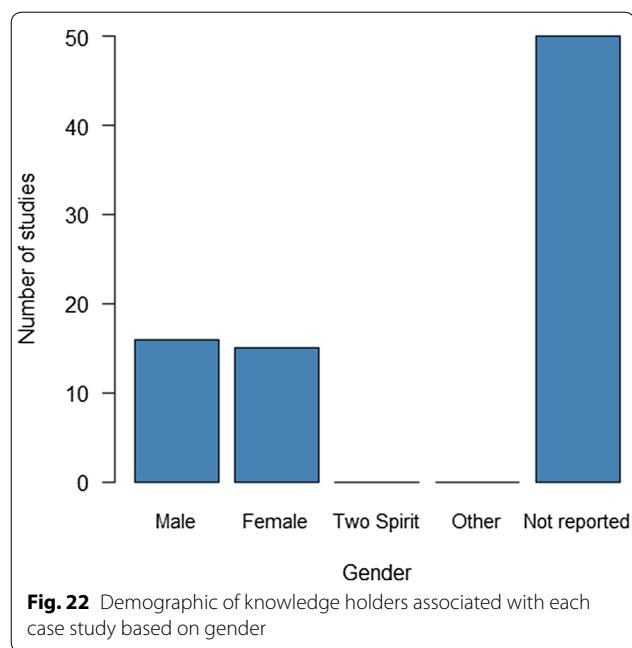


Fig. 22 Demographic of knowledge holders associated with each case study based on gender

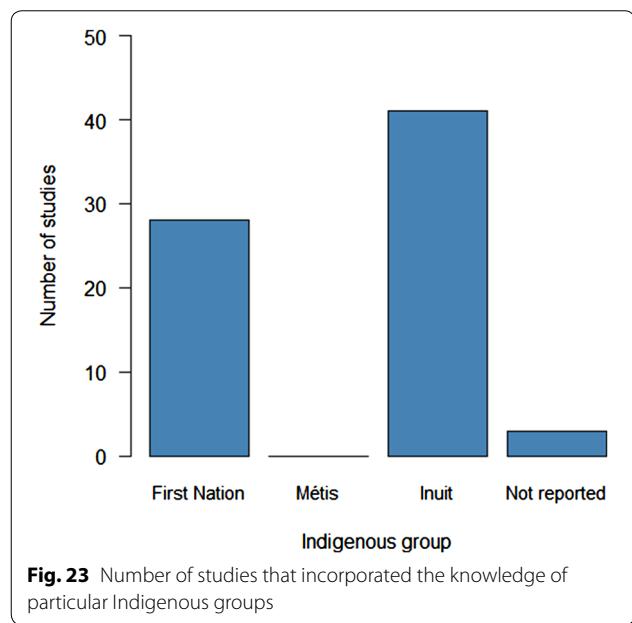


Fig. 23 Number of studies that incorporated the knowledge of particular Indigenous groups

system involved was First Nation, Métis, or Inuit and none of the studies specifically mentioned the involvement of Métis knowledge holders (Fig. 23).

Evidence gaps and insights

This systematic map and associated synthesis documents the extent, range, and nature of the published literature that seeks to respectively bridge Indigenous and science-based knowledge in coastal and marine research

and management in Canada. As a result of this exercise, a number of evidence gaps and insights regarding current research efforts (including biases) were identified. Two particular gaps identified include the lack of relevant published studies found along the Atlantic coast (especially compared to the significant number found along the Arctic coast) and the complete absence of studies that included Métis traditional knowledge (see Figs. 7, 19). For the latter, this may be due to the geographic focus on Canada's three coasts, regions which largely reflect the traditional territories of First Nations and Inuit [60]. Future efforts to add to this work by including inland aquatic systems and terrestrial environments is likely to yield different results. Insights on current research efforts include the lack of Indigenous authorship and representation (Fig. 5), and a lack of reporting on the gender of knowledge holders (Fig. 18), which [61] also found in their systematic review of demographics associated with local and traditional knowledge research in the circumpolar Arctic.

This systematic map also documents the diversity of methods and approaches that have been used in studies that seek to bridge Indigenous and science-based knowledge (Figs. 18 and 19). Despite the diversity of methodologies employed, this work draws attention to the significantly uneven distribution across the methodologies (Fig. 18). Accordingly, when it comes time to dive into the question of how, there are a plethora of examples for some methodologies (e.g., case study), while for others (e.g., ethnography, simulation) there are very few published examples that can be drawn upon (Fig. 18). Mapping and distinguishing between methods associated with Indigenous knowledge and those employed for science data collection drew attention to some limitations to such an approach (Fig. 19). First off, there are examples where a particular scientific method (e.g., tissue sampling, numerical counts) required and/or relied upon Indigenous knowledge holders (e.g., active or retired hunters) but may not have been articulated or presented as such in the study. Furthermore, the coupling of methods varied across the cases and is not revealed at this resolution. For example, in some instances there was one singular method employed with regards to Indigenous knowledge and one singular method employed with regards to the collection of science data. In other instances, there were multiple methods employed on both sides. A critical review of methods with the aim of exploring more specific pairings of methods within specific topics is needed to better provide guidance on possible study designs for future work.

An in-depth examination of practices, processes, and outcomes associated with bridging knowledge systems would be fruitful areas of further inquiry. For example,

this could include a focus on the extent of knowledge co-production and an assessment of Indigenous participation across different stages of the research process (e.g., question development, research design, analysis, interpretation) (*sensu* [62]). Such analysis may require additional information and data collection. For example, recognizing the limitations of available information in published studies, particularly with regard to process, [63] built upon a systematic realist review by conducting semi-structured qualitative interviews with the first authors and community participants of exemplar cases identified via the review.

Limitations of the methods used

The search strategy developed and used to conduct this systematic map was designed to be comprehensive but not exhaustive due to resource constraints. Accordingly, we have identified some potential limitations and biases in the systematic map results. The first limitation is that the search was limited to English language terms and results. In the Canadian context, this impacts the inclusion of studies published in French (e.g., franco-phone thesis, provincial reports from the Government of Québec). A second limitation concerns citation screening. While we searched the reference lists of 22 relevant reviews flagged throughout the screening process, we did not conduct any forward citation screening for empirical studies. A third limitation of the search strategy relates to the semantic challenges associated with interdisciplinary fields. As [64] note, compared to fields like medicine with a standard ontology, interdisciplinary fields often have high semantic diversity and rapid radiation of terms over quite short time periods (see [65, 66]). While the interdisciplinary team piloted and tested the search strategy to be inclusive, we note that some literature could have been missed due to specific terms not being included.

Limitations of the evidence base

We also highlight the limitations of the systematic map and associated evidence base associated with the plausibility of even being able to capture them in the published literature. In other words, there is likely much more work in practice where Indigenous and science-based knowledge have been brought together in the coastal and marine context across Canada's three coasts. First, there are likely more examples in the grey literature which we were unable to locate and uncover. For example, there could well be more that has been done by Indigenous communities, NGOs, or consultants that are not widely distributed or easily accessible. Second, no matter what search strategy is employed, it will not be able to capture long term studies that include Indigenous knowledge in practice (e.g., identifying species that are increasing or

decreasing), but is never acknowledged or discussed in the final published study when prepared by researchers. Third, the inability to capture projects and case studies where different ways of knowing were brought together but never reported as such due to the confines of publishing and/or approaches taken to publishing. For example, when it comes time to publish the research results they get parsed back into their respective domains (i.e., natural science/ecology study and a separate 'Indigenous Knowledge Study'). Fourth, the time lag of publishing some of this material that far exceeds annual funding cycles can increase the risk of the information not entering the literature.

Conclusion

Drawing upon diverse knowledge systems expands the evidence-base, increases legitimacy, and builds trust for decision making and environmental management (e.g., [1–4]). Furthermore, it improves our understanding of social-ecological interdependencies, can lead to innovation, and contribute to the identification of desirable pathways for the future [1]. Importantly, these aspects are critical to implementation of conservation actions and realizing tangible benefits for ecosystems and the communities that depend upon them.

Implications for policy/management

Better information for all sources leads to better policies developed with stakeholders who can see themselves reflected in the policies. This leads to increased confidence in governance and policies that are more likely to be implemented. Not only because they are more sound in a place-based way, but because they are reflective of the people who will actually implement them on the ground. There are a range of examples of how Indigenous and science-based knowledge have been used for decision making and policy development. These case studies should inform future discussions on how multiple knowledge systems can inform policy development.

Implications for research

The results of this systematic map provide two key insights to inform and improve future research. The first is the need to consider in more detail how Indigenous knowledge and science can be respectively bridged, but also recognize the specific place-based needs of Indigenous communities. We draw attention to the importance that one use this information in context and note that what worked once in one community may not work in another. However, by doing these broad examinations of case studies, we can consider options for successful paths that include Indigenous knowledge and science. Second, the work highlights the need to better report the

demographics of knowledge holders (*sensu* [61]). Further inquiry—as noted above—focused on the extent of knowledge co-production and assessing Indigenous participation across different stages of the research process (*sensu* [62]) would serve the research community well to improve future research and monitoring in support of, and to strengthen, evidence-based environmental management. Lastly, similar to the implications for decision makers, this map highlights the numerous methodologies and methods that can be employed by those working to bridge knowledge systems. This suggests that for researchers who wish to incorporate knowledge bridging in their work, there are a variety of methods that can be employed. While there are many outstanding questions on how to employ these different methods for each context, there is a growing body of knowledge for this field in Canada.

Supplementary information

Supplementary information accompanies this paper at <https://doi.org/10.1186/s13750-019-0181-3>.

Additional file 1. ROSES form for systematic map report.

Additional file 2. Literature searches.

Additional file 3. Benchmark list.

Additional file 4. Relevant reviews.

Additional file 5. Coding sheet.

Additional file 6. Excluded at full-text/unobtainable.

Additional file 7. Systematic map database.

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Authors' contributions

The review process was coordinated by SMA and JJT. SMA, JFP, JIL, and LN conducted the screening of articles and data extraction. JFP and JIL contributed to data analysis. The manuscript was drafted by SMA. JFP, DAH, JJT, JIL, LN, JTJ and SJC provided comments and revisions. All authors read and approved the final manuscript.

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Availability of data and materials

All necessary data is available in Additional file 7.

Ethics approval and consent to participate

Not applicable.

Consent for publication

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Competing interests

The authors declare that they have no competing interests.

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