



Untold Stories: Indigenous Knowledge Beyond the Changing Arctic Cryosphere

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Scientific attention to climate change in the Arctic has spurred extensive research, including many studies of Indigenous knowledge and the effects of climate change on Indigenous peoples. These topics have been reported in many scientific papers, books, and in the IPCC's 2019 Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC), as well as attracting considerable interest in the popular media. We assembled a set of peer-reviewed publications concerning Arctic Indigenous peoples and climate change for the SROCC, to which we have added additional papers discovered through a subsequent literature search. A closer look at the 76 papers in our sample reveals additional emphases on economics, culture, health and mental health, policy and governance, and other topics. While these emphases reflect to some degree the perspectives of the Indigenous peoples involved in the studies, they are also subject to bias from the interests and abilities of the researchers involved, compounded by a lack of comparative research. Our review shows first that climate change does not occur in isolation or even as the primary threat to Indigenous well-being in the Arctic, but the lack of systematic investigation hampers any effort to assess the role of other factors in a comprehensive manner; and second that the common and perhaps prevailing narrative that climate change spells inevitable doom for Arctic Indigenous peoples is contrary to their own narratives of response and resilience. We suggest that there should be a systematic effort in partnership with Indigenous peoples to identify thematic and regional gaps in coverage, supported by targeted funding to fill such gaps. Such an effort may also require recruiting additional researchers with the necessary expertise and providing opportunities for inter-regional information sharing by Arctic Indigenous peoples. As researchers who are visitors to the Arctic, we do not claim that our findings are representative of Indigenous perspectives, only that a more accurate and comprehensive picture of Arctic Indigenous peoples' knowledge of and experiences with climate change is needed. Our analysis also reflects some of the SROCC knowledge gaps and the conclusions provide suggestions for future research.

Keywords: Indigenous, Arctic, climate, adaptation, health, economics, culture, governance

INTRODUCTION

The Arctic is changing rapidly, spurring much scientific and media attention (e.g., Christensen et al., 2013; Arnold, 2018; NOAA, 2020). The Arctic cryosphere in particular is regarded as one of the most visible signs of global warming, as sea ice retreats, snow decreases, glaciers and ice caps melt, and permafrost thaws (Meredith and Sommerkorn, 2019). A changing cryosphere has

far-reaching implications for biology (Wassmann et al., 2020) and society in the Arctic (AMAP, 2017a,b,c) and beyond (Moon et al., 2019).

In addition to standard scientific studies in the Arctic, researchers have documented Indigenous knowledge about the Arctic environment and its changes (e.g., the publications listed in the **Supplemental Material**). Indigenous Peoples have lived in the region for thousands of years, accumulating extensive and detailed understanding of the environment and of human relationships with the lands, waters, air, plants, and animals to be found there (e.g., Watt-Cloutier, 2018). Such information is invaluable for its own sake as well as for the depth of time and breadth of coverage that can be found from no other sources (e.g., Berkes, 2012; Thornton and Bhagwat, 2021). Attention to Indigenous knowledge has been growing, from a dedicated chapter in the *Arctic Climate Impact Assessment* (Huntington and Fox, 2005) to more recent inclusion in the work of the Intergovernmental Panel on Climate Change (Meredith and Sommerkorn, 2019).

The recent IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC; IPCC, 2019) is a case in point. Martin Sommerkorn, one of the lead authors of the chapter on Polar Regions, contacted us to help his team gather available studies documenting Indigenous knowledge and related information about the cryosphere. The goal was to try to include as much of that information as possible in the chapter. Although we knew that many studies had been done, we did not know at the start how many publications would be available that met the IPCC criteria for inclusion: that the works be published or accepted for publication in the scientific or technical literature by a cut-off date specified for each report (e.g., IPCC, 2018). As described below in Methods, we assembled an annotated list of publications and sent that to the chapter authors for their use.

In assembling and reviewing these publications, we noticed some patterns. First, few if any of the papers stopped at reporting about the components of the cryosphere. They additionally discussed many other changes taking place in the Arctic, or the implications of cryosphere change for other aspects of Arctic communities. Second, the coverage of these additional topics was uneven around the Arctic, suggesting differences in relative importance or differences in the design and focus of the studies that generated the papers. Third, the narrative from many of the papers diverged from the common story of inevitable doom and gloom facing the Arctic and its inhabitants. The changes are serious and pose a major threat, but Arctic communities are also capable of responding to these changes (Huntington et al., 2019).

In this paper, we provide a brief review of the SROCC knowledge gaps and explore all three above-noted observations, based on the initial literature search for the SROCC and a subsequent expansion to include papers published since the SROCC deadline for the present review. Together, our findings suggest that the changing Arctic cryosphere has not been fully explored, either in terms of the understanding of cryospheric changes from the perspective of Arctic Indigenous Peoples, or with regard to the implications that change has for them. The increasing number of publications on Indigenous knowledge and perspectives provides more material reflecting their views,

and the inclusion of this information in assessments such as the SROCC is a welcome step. Nonetheless, greater attention is needed across the full range of effects on Arctic communities and across the entire Arctic. In addition, we note that the perspectives of Arctic Indigenous Peoples as reflected in these publications often suggest a degree of hope that is typically missing in visitors' assessments of the prospects for Arctic communities in a changing climate.

METHODS

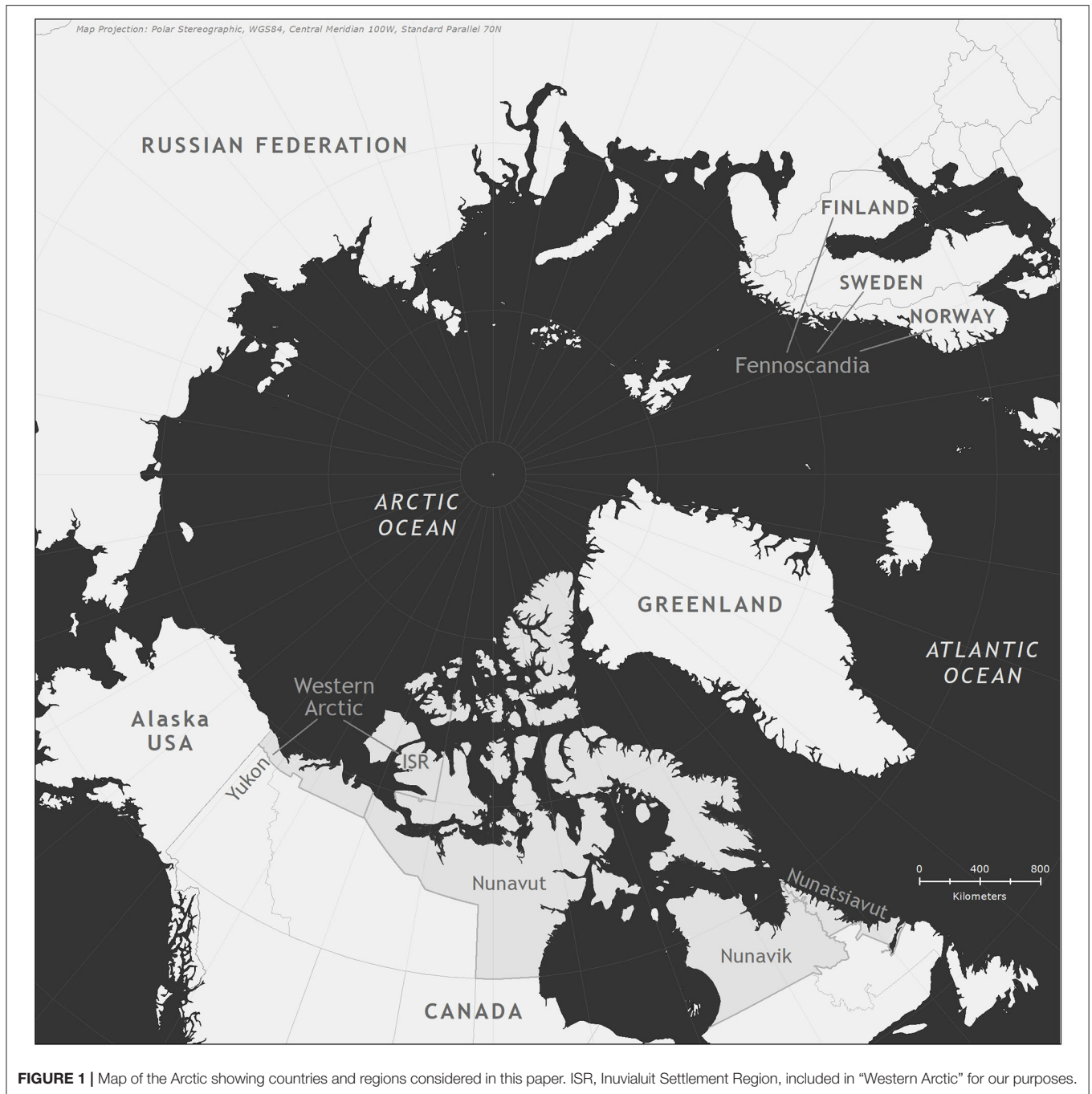
Positionality

In a paper about Indigenous knowledge in the Arctic, we are obliged to point out that neither author is an Arctic Indigenous person. We are scholars who live outside the Arctic (LEM in Victoria, British Columbia, Canada, and HPH in Eagle River, Alaska, USA), though we both travel to the Arctic frequently for work and more. Our findings and views thus reflect our position as outsiders or visitors, and may not match those of Arctic Peoples. This paper focuses on academic reporting about Indigenous knowledge and views in the Arctic. We feel qualified to speak to academic treatment of the topic, though we recognize that what is reported in academic papers may not reflect the full scope of views of Arctic Indigenous Peoples. We thus conclude the paper by recommending further work to better engage Arctic Peoples, in their own voices, to better include their experiences, conclusions, and recommendations (Pfeifer, 2018).

SROCC Preparation

We were asked to help find sources of Indigenous and traditional knowledge relevant to the Polar Regions chapter of the SROCC (Meredith and Sommerkorn, 2019). No resources were available to support our work, but we decided that we could nonetheless make a useful contribution within the limits of the time and effort we could volunteer. We conducted a chain-referral search, starting with colleagues whom we knew to be active in this field. We asked for any papers meeting the IPCC criteria: peer-reviewed papers or books, published between 2010 and 2017. We also asked our colleagues to forward our request to others who might be able to help. In addition, we conducted a search on Google Scholar. In the end, we received 110 papers from many colleagues, active in the field in all Arctic countries. We reviewed the 110 papers and selected 56 that met the IPCC criteria and were on topic for the Arctic cryosphere, in that they included traditional knowledge about or Indigenous views on snow, sea ice, permafrost, and the implications of change for Arctic Peoples and communities. A few papers published prior to 2010 were included if the material was particularly pertinent. We added our own notes about each of the papers, including selected quotes that seemed particularly pertinent to the SROCC chapter, and sent the annotated list to the chapter's authors.

While conducting this exercise we realized that to varying degrees the papers reflected Indigenous People's views related not only to climate but also to other environmental, social, economic, political, health, mental health, and cultural factors affecting them.



Literature Search

Noting that in some cases the papers we compiled for the SROCC chapter reflected some of the interconnectedness that Indigenous people mention when they share their traditional knowledge, we decided to expand the initial search and update the initial list of papers to include what else had been published since 2017. In one way, the literature search on its own might have been sufficient to create the sample of papers used here, since most or all of the papers on our SROCC list were also found during the literature search. In another way, though, the SROCC list was important

because it started us thinking about the additional topics we consider here. In our SROCC work, we had seen a clear difference from country to country in terms of involvement of Indigenous people in biophysical research. We thus targeted the subsequent search by country. Because of the relative sparsity of such studies in the European Arctic region, we searched for Fennoscandia (i.e., Norway, Sweden, and Finland) as a whole (**Figure 1**).

The focus of SROCC Chapter 3: Polar Regions is the ocean and the cryosphere. In dealing with Indigenous Peoples, the focus was primarily on lowland and coastal communities, regarded as the

most exposed and vulnerable to cryospheric changes (Meredith and Sommerkorn, 2019). Thus, the main Indigenous groups we considered in our search were coastal and lowland communities, which are predominantly the various Inuit groups in Alaska, Canada, and Greenland. In the case of Russia and Fennoscandia, there are not as many Indigenous coastal communities affected by changes in the cryosphere. In those regions, the SROCC report focused on herders instead. Following this approach, we designed our Google Scholar search accordingly and carried it out between May and July 2020. Our search method approximates that used by Petzold et al. (2020) and others, adapted to the limitations imposed by our lack of external resources.

Our criteria for inclusion at this stage were strict. We only considered papers in peer-reviewed scientific journals, so that books and book chapters were not included. This choice was made because the degree to which books are peer reviewed is often unclear. We also included only papers published since 2010. And we included only papers that report original results about Indigenous knowledge and the cryosphere. Many of the papers found in our literature search, including some of our own, are commentaries on topics related to Indigenous knowledge, such as the degree to which Indigenous and scientific knowledge overlap or connect. While such papers are important for other reasons, they are not directly relevant for the purposes of the present paper and were thus excluded. Our criteria also meant that some of the publications included in the list we sent to the SROCC authors were removed at this stage. In one way, we were surprised at the number of papers we found, which show a robust academic interest in Indigenous knowledge and a strong commitment by many scholars to publishing the results of their studies in peer-reviewed journals. In another way, we were surprised at the number of papers that we were aware of that did not meet our criteria. Their absence may also reflect limitations of our search process.

For Russia we focused on the words: Russia + climate change + traditional knowledge. We found 4,240 results, but most of these papers did not focus on cryosphere issues affecting Indigenous Peoples. The search was narrowed to focus on: Russia + traditional knowledge + reindeer herding + snow, which produced 496 results. The next search was Russia + traditional knowledge + reindeer herding + permafrost, which returned 279 results. An additional search was conducted using the term Indigenous knowledge as follows: Russia + Indigenous knowledge + reindeer herding + snow 301 results. The last search was Russia + Indigenous knowledge + reindeer herding + permafrost, which yielded 169 results. A search was conducted for glaciers using the following words: Russia + traditional knowledge + reindeer herding + glaciers, which returned 160 results. An additional search was conducted using the term Indigenous knowledge as follows: Russia + Indigenous knowledge + reindeer herding + glaciers, which gave 92 results. After reviewing the first two pages of results for the latter two searches, we determined that none of the papers specifically addressed glaciers, but instead focused in general on the Sami or on northern communities.

From these results, we identified 16 papers that met the criteria of addressing cryosphere-related changes in the Arctic

and including Indigenous knowledge gathered by field work or interviews, not simply referring to it from other papers or documents or as a matter of policy rather than original research. Most of the results referred to papers that were government reports and assessment, theses, or other documents that were not peer reviewed, or publications in political papers or scientific publications that directly include traditional, Indigenous or local knowledge, or they were not in English. In other cases, the results referred to papers in which the key words appeared only in the references cited.

The same approach was followed for Fennoscandia as follows: Fennoscandia + traditional knowledge + reindeer herding + snow + ice, which produced 45 results. The next search included the following words: Fennoscandia + traditional knowledge + reindeer herding + permafrost, which returned 74 results. Fennoscandia + Indigenous knowledge + reindeer herding + snow + ice brought us 79 results. A search focusing on Fennoscandia + Indigenous knowledge + reindeer herding + permafrost, resulted in 53 results. The next search included the words: Fennoscandia + traditional knowledge + reindeer herding + glaciers, which returned 35 results, and the search for the words: Fennoscandia + Indigenous knowledge + reindeer herding + glaciers brought us 44 results. Using the same selection approach as was done for the Russian results, we found no additional papers that met our criteria.

For Greenland, where the cryosphere changes affect fishing and hunting for walrus and narwhal, whales, seals, and polar bears, our search included similar terms: Greenland + Inuit + traditional knowledge + snow + sea ice. The search produced in 1,090 results. An additional search, Greenland + Inuit + Indigenous knowledge + snow + sea ice, gave us 442 results. Of these, seven met our criteria for inclusion. The terms: Greenland + Inuit + Traditional Knowledge + glaciers, returned 761 results. Looking at the first three pages of results, two papers were already on our list and an additional one was identified that met our criteria. Searching for: Greenland + Inuit + Indigenous knowledge + glaciers returned 449 results. These results were similar to the previous search. No additional publications were identified when looking at the first three pages of results.

For Alaska the search terms Alaska + Inuit + traditional knowledge + snow + sea ice, producing 965 results. A second search, Alaska + Inuit + traditional knowledge + permafrost, gave us 761 results. An additional search was conducted, Alaska + Inuit + Indigenous knowledge + snow + sea ice, yielding 976 results. The search for Alaska + Inuit + Indigenous knowledge + permafrost returned 526 results. After reviewing these papers, we selected 19 that met our criteria for inclusion in the review. A third search, Alaska + Inuit + traditional knowledge + glaciers, gave us 1,300 results. An additional search was conducted, Alaska + Inuit + Indigenous knowledge + glaciers, yielding 887 results. No additional results were identified in the first three pages on either search. The next search removed the word Inuit and just focusing on: Alaska + glaciers + traditional knowledge. This search showed 1,370 results. No additional papers meeting our criteria were identified in the first three pages of google search.

For Canada, the search terms were Canada + Inuit + traditional knowledge + snow + sea ice, giving 1,160 results. The

TABLE 1 | Number of papers in the sample, by country and by region of Canada, showing coverage of cryosphere (equal to the total number of papers), additional topics, and responses to change.

Country/Region	Cryosphere (total papers)	Additional topics	Responses to change
Alaska	20	19	20
Canada	27	24	27
Fennoscandia	8	8	8
Greenland	8	8	8
Russia	13	13	12
Canada-wide	3	2	3
Nunatsiavut	7	7	7
Nunavik	1	8	9
Nunavut	9	1	1
Western Arctic	7	6	7

search for Canada + Inuit + traditional knowledge + permafrost produced 1,080 results. An additional search, Canada + Inuit + Indigenous knowledge + snow + sea ice, returned 767 results, and the search Canada + Inuit + Indigenous knowledge + permafrost found 692 results. From these results we identified 24 papers that met our criteria. A search followed for: Canada + Inuit + traditional knowledge + glacier. This search produced 554 results. An additional search was conducted for Canada + Inuit + Indigenous knowledge + glaciers, yielding 383 results. Once again, no additional papers meeting our criteria were identified in the first three pages of the results.

The total number of papers found was 76, which included those already compiled for the SROCC that met our new and more restrictive criteria. The final total also includes a few papers added through additional recommendations from colleagues. The references for all the papers in our sample is provided in the **Supplemental Material** of this paper, along with tables showing which papers were placed into which categories for our analyses of cryosphere coverage, additional topics, and responses to change. The **Supplemental Material** also provide a breakdown of which papers discuss which features of each component of the cryosphere, with graphs showing regional patterns, as described in section Patterns in the Coverage of Cryosphere below.

A summary of the number of papers and the topics covered, by country and by region of Canada (which had the highest total), is presented in **Table 1**.

Analysis and Limitations

All papers addressed at least one component of the cryosphere. From the descriptions in the papers, we identified several features of each component of the cryosphere and noted which papers addressed which features. The number of features identified ranged from two (glaciers) to ten (snow), depending on the amount of detail collectively provided by the papers that addressed each cryosphere component.

We next did a word search of the papers in our sample, using terms such as culture/cultural, society/social, economics, health, mental health, and policy/governance. Some of these

terms had emerged in our previous work on the Adaptation Actions for a Changing Arctic report (Huntington and Eerkes-Medrano, 2017), for which we compiled a variety of stakeholder perspectives about changes in the Bering-Chukchi-Beaufort region of the Arctic. In addition to describing changes in the physical and biological environment, contributors to that report from Arctic communities discussed political, social, and economic factors affecting their lives. Looking more closely at those contributions and at the papers in our sample, we added culture, health, and mental health to the list of categories. Starting with the word search, we examined the context of the terms where they were found in each paper to confirm that we were assigning the papers to the right categories (e.g., that the use of “health” was not a passing comment or a reference to wildlife, but in fact a discussion of the topic with regard to humans). We define the topical categories used in section Patterns in the Coverage of Additional Topics as follows:

- *Social*: Issues relating to Indigenous people adjusting their hunting and gathering practices in response to change, including new techniques in the practice of their activities or the need to learn new ways to harvest, implying a social change in their activities.
- *Economic*: Effects on Indigenous activities related to financial costs and resources, such as having to use more fuel or to purchase larger boats to deal with increasing wave action or a change in reindeer practices that favor financial rewards from meat production rather than the aims of traditional husbandry.
- *Culture*: Changes that affect the ability to pass on Indigenous knowledge, such as use of new technology, new or adjusted hunting practices, loss of language, and others.
- *Policy*: Government regulations, policies, or practices that affect the practice of traditional activities.
- *Health*: Human health issues such a disease, heat-related concerns, respiratory issues due to air pollution or other physiological effects related to climate, diet, activities, and more.
- *Mental Health*: Issues resulting from the “sense of place” or “sense of worth” that is attached to the activities of Indigenous Peoples, as well as issues related to lack of housing or changes in culture or income.

In addition, we looked for discussions of responses, to understand how people in Arctic communities are reacting to the changes they see. This idea came again from many observations and comments by Arctic residents to us in our work over the years that adaptation is necessary and not a matter of choice. We also considered the ways in which the topic was discussed, for example how responses were described. We identified six categories of response, which are used in section Responding to Change:

- *Use IK*: Relying on Indigenous knowledge both for specific factual information and for more general attitudes about a healthy mindset for being productive. In some cases, papers emphasized sustaining IK, and others called for restoration or revitalization of IK.

- *Acknowledge variability and flexibility*: The awareness that the environment has always been variable, and that Arctic Peoples have long cultivated the flexibility to deal with that variability.
- *Shifts in practices*: Ways that people are or could be adjusting their hunting, fishing, gathering, and traveling practices in response to environmental change. This may mean using new times or areas or techniques, or learning to harvest different species entirely.
- *Cooperation with outsiders*: Working with government agencies and others to develop effective responses to change. This is a recognition of the limits of autonomous response (e.g., Huntington et al., 2017) and also often a call for partnerships in solving problems rather than a request to have problems solved for Arctic communities.
- *Cooperation with scientists*: A specific form of cooperation with outsiders, involving two-way sharing of information to help develop more effective responses. Again, this often emphasizes equal partnerships rather than visiting scientists making the decisions about what to study and how, or providing unilateral advice.
- *Sharing innovations*: Learning from one another as individuals and communities in the Arctic to develop new ways of doing things. Here the emphasis is on learning from peers, including those who may already be using species or techniques that are newly relevant in other areas.

Our sample of 76 papers provides the basis for our analysis of topics and patterns. We recognize, however, that this sample has a number of biases and limitations. First, only peer-reviewed scientific journal articles are included, which means a great number of other sources are excluded. Our search was limited to English-language publications, which likely excludes a number of papers, especially from Russia and also by scholars working in other languages elsewhere. The use of other search engines instead of or in addition to Google Scholar may produce different results, too. We have no reason to think that the peer-reviewed publications are a random sample of the topics and areas where studies have been done, and even less reason to think that existing studies provide an accurate and comprehensive picture of the views of Arctic Indigenous Peoples. Our conclusions thus concern only what has been reported in a particular fashion, and are more than likely to omit a great deal more that has been written and said in other ways. We do, however, believe that our sample, though certainly not exhaustive, is reasonably representative of the peer-reviewed literature about Indigenous knowledge and the Arctic cryosphere.

Second, published papers appear late in the lifespan of a research project or after the project itself has been completed. Our sample thus does not include many recent or current research efforts, and thus is inevitably out of date with regard to current patterns in research topics and areas. We are not aware of any major changes in the direction of research involving Arctic Indigenous Peoples, but the field is constantly evolving.

Third, our sample started with the criterion that papers address some aspect of a changing Arctic cryosphere. This topic is only a small portion of the research being done in and with Arctic communities. Our finding that there is a dearth

of studies examining the mental health aspects of a changing cryosphere does not necessarily mean there is a dearth of mental health studies in the Arctic. An assessment of the adequacy of such studies in general is beyond the scope of this paper. Our concern is solely with the degree to which studies involving the changing cryosphere have made connections to related aspects of that topic.

Fourth, the focus on Inuit in Greenland and North America and on herders in Eurasia limits the degree to which the results are comparable, especially in terms of covering the various components of the cryosphere. Inland communities in North America, including Dene in Canada's Northwest Territories, First Nations in Canada's Yukon, and Athabascans in Alaska, are poorly represented in our sample and in the SROCC chapter. These communities are also affected by changes in permafrost, fresh water and lake ice, snow cover, and glaciers, though typically not to the same degree as the coastal communities who rely on sea ice. Similarly, coastal communities in Chukotka, Russia, are not represented, nor are the Sea Sami of northern Norway. Further research is needed to determine how much documented material related to the cryosphere is available concerning these Peoples. With regard to additional topics and responses to change, we believe comparability is greater, but should still be treated with caution.

We note that these limitations stem primarily from the terms imposed on authors of IPCC reports, which rely, with few exceptions, on publications that have appeared in the peer-reviewed literature by a cutoff date set for each IPCC report. The SROCC chapter to which we contributed focused on the cryosphere changes and its impacts on particularly vulnerable human populations, limiting the range of papers that were appropriate for consideration. The limitations of our study, therefore, are likely to match closely those of any IPCC report or any reports using similar criteria for identifying acceptable evidence. A wider-ranging review of research involving Arctic Indigenous Peoples will no doubt identify a great many more papers in each of our categories, but we expect that the vast majority of those additional papers will lack an explicit link to the changing cryosphere.

RESULTS

Patterns in the Coverage of Cryosphere

The combined searches for recent papers concerning Indigenous and traditional knowledge of the Arctic cryosphere yielded a total of 76 that met the IPCC criteria for consideration (not including the SROCC cut-off date) and that substantively engaged with Indigenous and traditional knowledge. Since the search emphasized environmental terms, it is not surprising that all of the papers consider environmental issues. The various cryosphere components were not covered equally in all countries (considering Fennoscandia as a unit on par with the others; **Figure 2**). Not surprisingly, sea ice did not come up in Fennoscandia and only rarely in Russia, as our search there focused on herders, and there are few coastal communities with extensive use of sea ice. Observations concerning freshwater were not documented in Greenland. Permafrost was not mentioned in

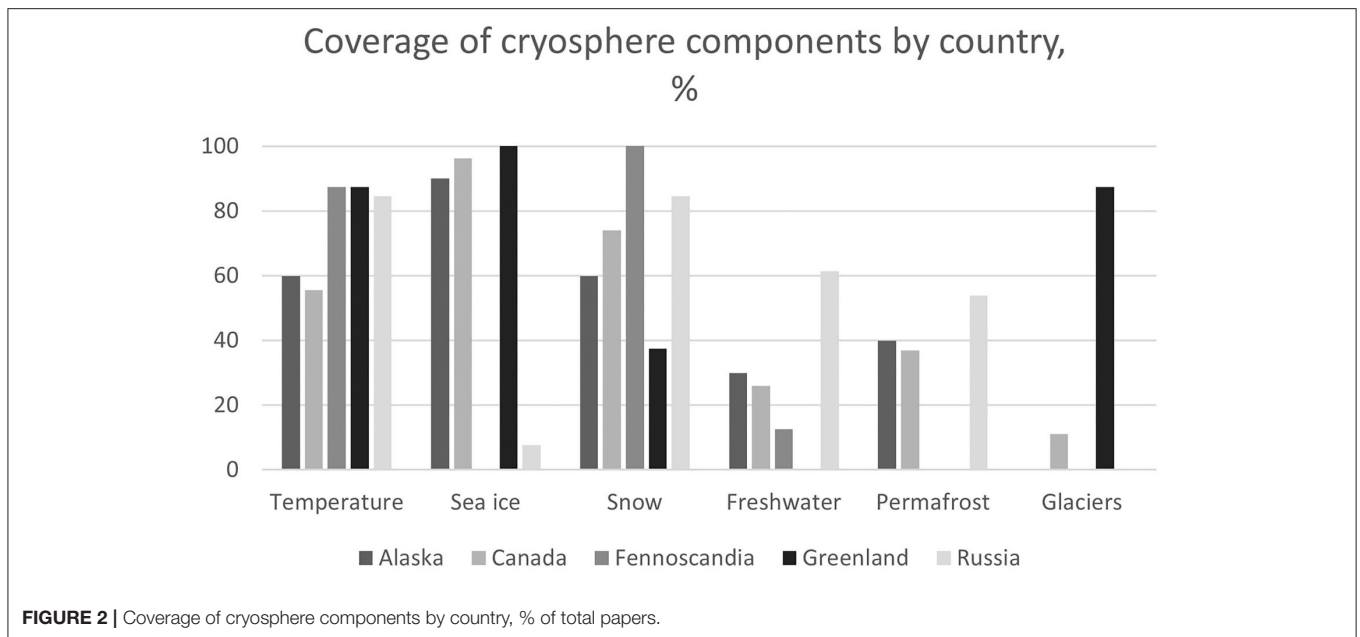


FIGURE 2 | Coverage of cryosphere components by country, % of total papers.

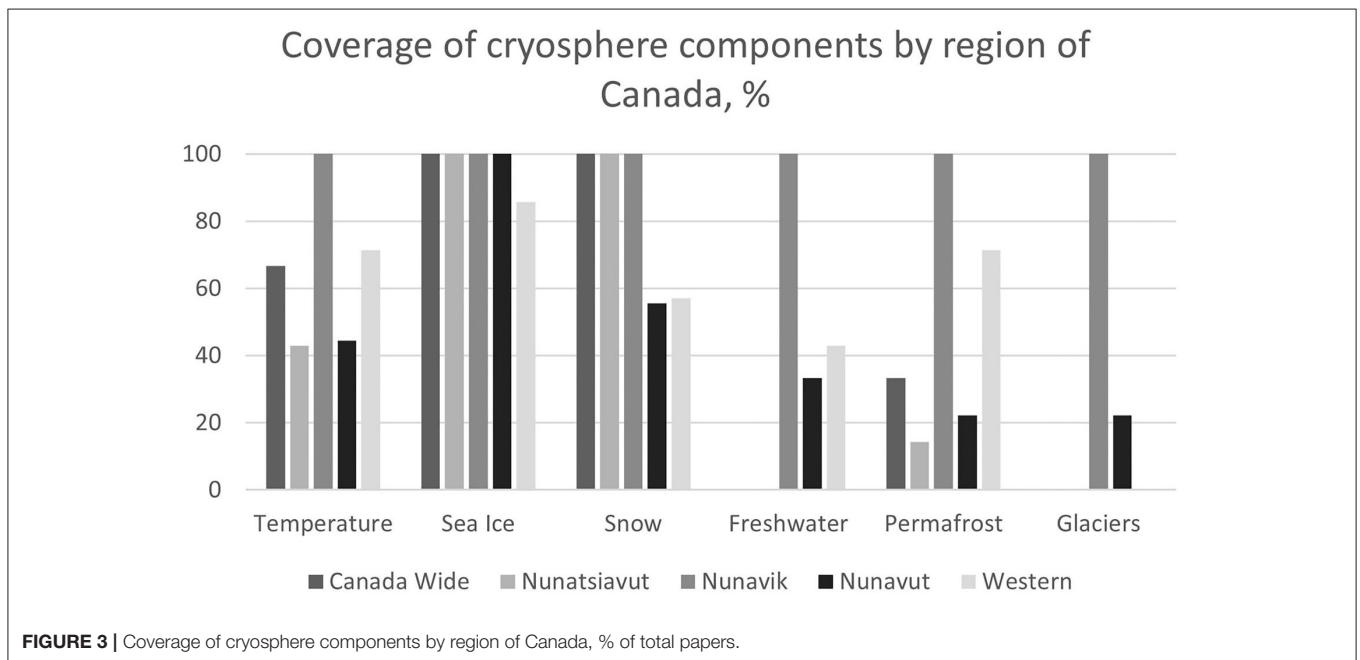
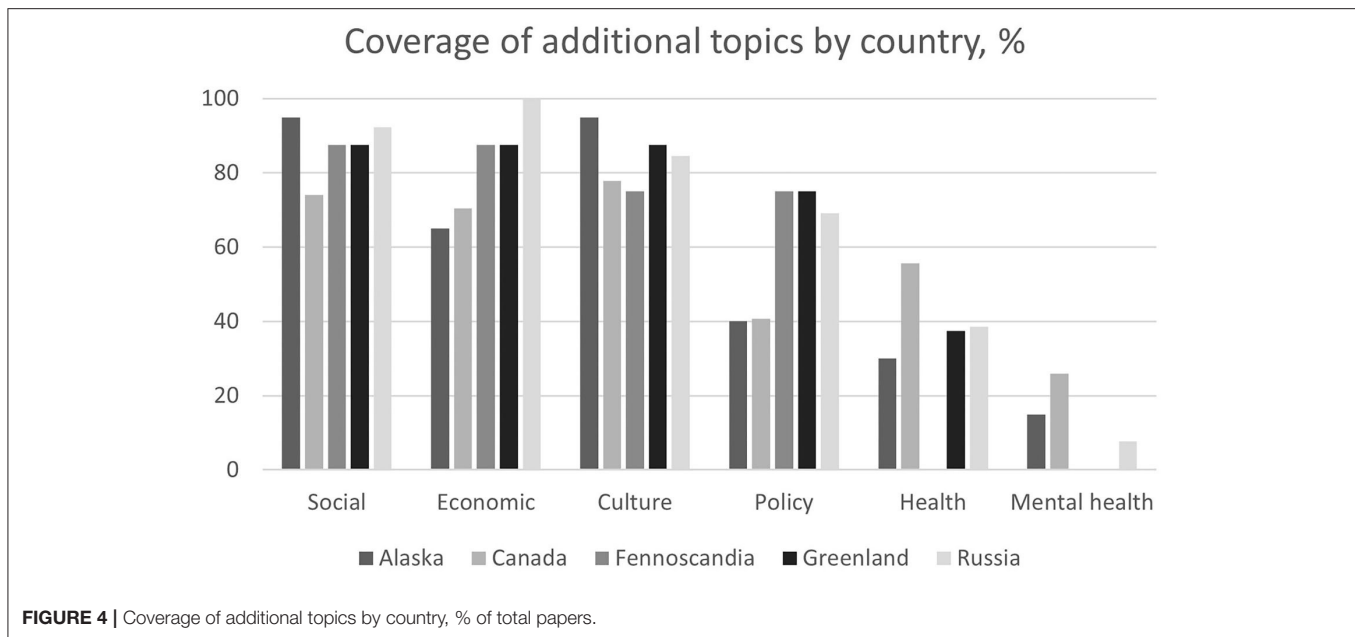


FIGURE 3 | Coverage of cryosphere components by region of Canada, % of total papers.

either Fennoscandia or Greenland. Glaciers were mentioned only in Canada and Greenland.

Given the size of the Canadian Arctic and the number of papers from Canada, we separated the Canadian papers by region into Nunatsiavut, Nunavik, Nunavut, and the Western Arctic (including the Inuvialuit Settlement Region and the northern Yukon). With the exception of one paper from the Western Arctic, all the papers were focused on Inuit and Inuvialuit. The exception examined the Vuntut Gwich'in from Old Crow, Yukon. As with the circumpolar overview, the treatment of cryosphere components (**Figure 3**) varies by region. Not surprisingly, sea ice and snow were covered in the majority of papers.

We also examined the degree to which different features of each cryosphere component were discussed or described in the papers in our sample. For sea ice, thickness, extent, freezeup, breakup, and shorefast ice received the most attention, among countries and regions of Canada. For snow, depth/thickness, less snow, and different timing were the most noted features across countries. For Canada, the order of coverage among those three features was reversed. Fennoscandia stands out for a high level of interest in compaction, different snow characteristics, ice-on-snow events, and late snow, which received little or no attention elsewhere. For freshwater, river break-up, shallow rivers, and thin ice were the most widely noted features. Among



the three countries for which permafrost observations were reported, thawing and warming were most prevalent, followed by stability and thermokarst. The latter two were not mentioned in Canada, and thermokarst was only mentioned in Russia. Glaciers received the most coverage in Greenland, where all of the papers addressed glacial retreat. Three papers mentioned glaciers in Canada, two of which discussed effects from glacial melt, and one of which discussed glacier retreat. The details of the coverage of cryosphere features are provided in the **Supplemental Material** accompanying this paper.

Patterns in the Coverage of Additional Topics

What is interesting for the purpose of this paper is the degree to which other topics are included (**Figure 4**). Social issues were mentioned most frequently, closely followed by cultural issues and economic issues. Policy, health, and mental health were also included, though to a lesser degree. At the national level, different patterns emerge. All the Russian papers mentioned social issues, as did all but one of the papers concerning Alaska and all but one concerning Fennoscandia. A smaller majority of the papers from Canada and Greenland also mentioned social issues. The pattern was broadly similar for cultural issues. For economic issues, the proportion of papers in Alaska dropped, but remained similar elsewhere. Policy, on the other hand, was mentioned in fewer than half of the Alaska and Canadian papers, but in most of the papers from Russia and Fennoscandia, and all of the Greenland ones. Health received the most attention in Canada, followed by Russia, whereas mental health was only addressed in papers from Canada and from Alaska, with the former having twice as many as the latter.

In Canada (**Figure 5**), papers from the Western Arctic were less likely to make connections between the cryosphere and other topic areas. Mental health was addressed primarily in

Nunatsiavut, with an additional mention in one paper about the Canadian Arctic generally. Policy and health were addressed more widely, but still at a lower overall level than social, economic, and cultural matters.

Responding to Change

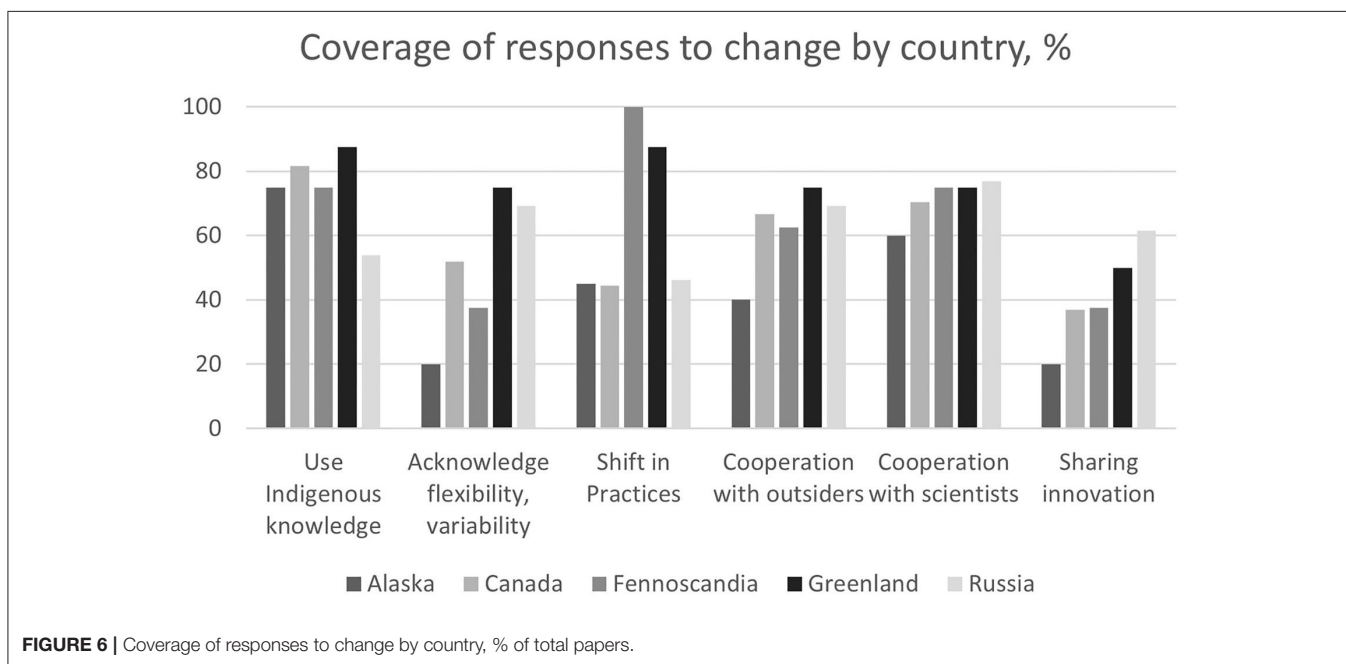
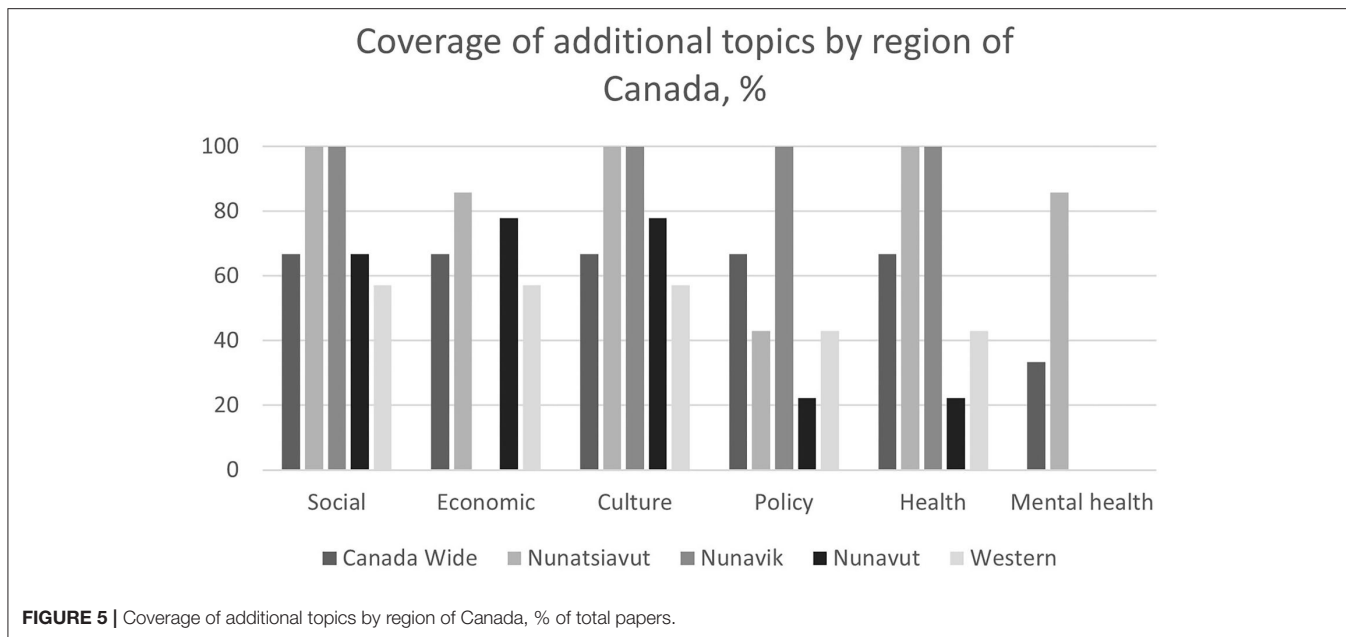
In addition to discussing the connections between a changing cryosphere and other topics, most of the papers also described one or more response actions being taken or being suggested by the people in the study areas.

There appears to be a widespread recognition of all six response categories (**Figure 6**), though considerable variation by country. Papers from Alaska, for example, have infrequently described the acknowledgment of variability or the sharing of innovations, whereas papers about Russia are most likely to identify acknowledging variability as a response. Overall, and acknowledging the small sample size, papers about Greenland are most likely to refer to a wide range of responses. These differences may be an artifact of the relatively small sample sizes, or a reflection of our different search foci in the Inuit region and in Eurasia, or of differences in the societal and geographical contexts of the different regions.

Within Canada, there is again regional variation (**Figure 7**). The use of Indigenous knowledge is widespread, as is cooperation with scientists. Papers from Nunatsiavut and the Western Arctic were less likely to report responses to change than papers from Nunavik and Nunavut, though again the small sample size may be a factor.

DISCUSSION

Climate change does not occur in isolation. A changing cryosphere affects Arctic Indigenous Peoples across many intersections of social and cultural change, economic challenges,

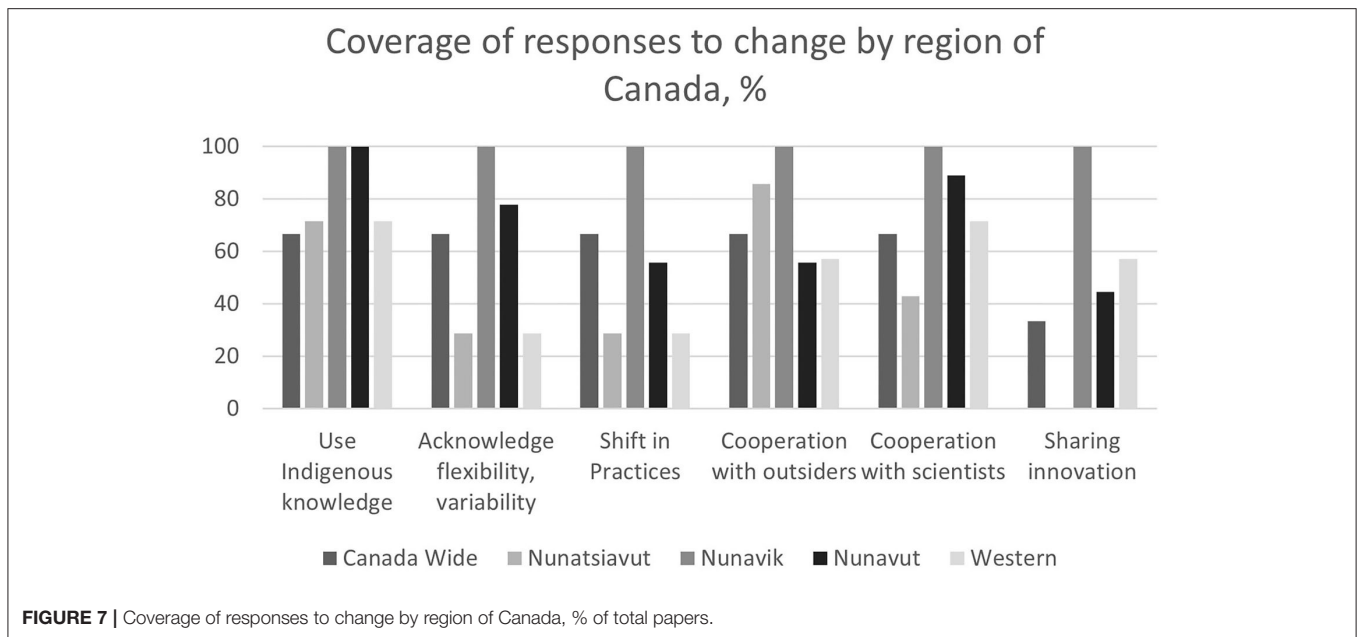


limited access to services such as health care, and more. Climate change is also not the whole story. As far-reaching as the effects of thawing permafrost, melting sea ice, and reduced snow cover are, human responses still have great scope to determine the ultimate outcomes of these changes. We now discuss the themes of cryosphere, other topics, responses to change, and what we believe to be the “untold stories” of a changing cryosphere.

Cryosphere Coverage

As seen in **Figures 2, 3**, the different elements of the Arctic cryosphere and the inclusion of Indigenous knowledge in

identifying impacts on Indigenous people are all addressed, though to varying degrees in different countries and across the regions of Canada. When we carried out our literature search for the SROCC, we were pleasantly surprised at the range of papers from all around the Arctic that document and discuss Indigenous knowledge about the changing cryosphere, even with the limiting criteria we used. Perhaps this is a reflection of low expectations on our part, but nonetheless our findings for the SROCC and the additional papers presented here offer a strong counterargument to claims that Indigenous knowledge is missing or sparse in the peer-reviewed literature (e.g., Arsenault et al., 2019; Petzold et al.,



2020). Even 76 papers, however, fall far short of the available peer-reviewed literature from the natural sciences. Thus, it appears fair to state that Indigenous knowledge remains underrepresented in scientific publishing, greatly limiting its availability to the work of the IPCC and other bodies that rely primarily or exclusively on peer-reviewed scholarly publications.

We should also not be surprised by some of the patterns in coverage from country to country. The Sami of Fennoscandia have little interaction with sea ice, so it is not surprising that although the SROCC has an in-depth analysis of sea ice and impacts on aquatic ecosystems, fishers, tourism, and other topics, no studies from that area address changes in sea ice. Most Indigenous Peoples in the Russian Federation are not maritime, either, so again it is not surprising that there are few peer-reviewed papers looking at knowledge of and experiences with sea ice in Russia. Similarly, ice-free ground in Greenland is typically rocky, so there are likely to be fewer concerns about permafrost than would be in regions such as western Canada and Alaska, where thawing ground is likely to turn to mud or water threatening some coastal and riverbank communities especially in Alaska (e.g., Melvin et al., 2017; Meredith and Sommerkorn, 2019), or in Russia where the thermokarst lakes are also disappearing, transforming the grassland landscape required for herding activities (Istomin and Habeck, 2016; Crate et al., 2017). More surprising perhaps is the comparative dearth of studies about snow in Alaska that met our criteria, and about freshwater anywhere outside of Russia, though the latter may be a reflection of the focus on herders and the lack of corresponding inland information from North America. Both suggest opportunities to fill geographical gaps in the documented record of the changing Arctic cryosphere from Indigenous Peoples' perspectives or to expand the scope of the study to include all communities throughout the Arctic. Of the cryosphere components we examined, permafrost has received the least

attention, again suggesting a gap to be filled. Even in Russia, where the prevalence of permafrost-related studies is highest, only 7 of 13 papers address it.

A finer-scale analysis could also be done of cryosphere coverage, both in terms of geography (e.g., how much of Russia do the seven permafrost papers actually cover?) and depth of treatment (e.g., what aspects of snow are actually addressed and in which locations?). We cannot anticipate all of the detailed questions that cryosphere researchers might ask, and thus cannot provide here all of the details and nuances that might be desired. Nonetheless, we can at least point out that studies documenting Indigenous knowledge and use of sea ice and snow typically consider many specific aspects of those topics. For example, studies of sea ice and snow terminology illustrate the aspects of each that matter to people, depending on the activities they are engaged in. Marine mammal hunters are concerned with safety (cracks, thin ice, potential for shorefast ice to break off), with animal habitat (where breathing holes or lairs may be, the types of ice floes where marine mammals are likely to be found), with platforms for butchering animals (thickness of shorefast ice for large whales, stability of ice floes for walrus and bearded seals), and other aspects of sea ice. Reindeer herders are concerned with travel (snow depth and crust strength), the animals' ability to reach food under the snow (rain-on-snow events or icing at the bottom of the snowpack), the way a breakable crust may damage the legs of the animals, and other aspects of snow. Of course, Indigenous knowledge is not strictly utilitarian, either, so a great deal more will be known to those who spend their lives on snow and ice. We also note that those documenting Indigenous knowledge cannot anticipate what other researchers will be interested in, so a great deal remains undocumented even in places where studies have already been conducted.

While there is a good analysis of permafrost issues from the physical sciences perspective in the SROCC, connections

between permafrost and Indigenous Peoples are largely absent. Such an analysis is beyond the scope of this paper, but could be a fruitful line of inquiry in support of the next major assessment of the changing Arctic cryosphere and impacts on Indigenous Peoples, as well as to allocate research funding to fill specific gaps in addition to addressing major geographical ones. We note also the difficulty of determining whether the lack of coverage reflects a lack of knowledge or just a lack of scholarly inquiry and writing. For example, permafrost is present in Fennoscandia, but in the absence of further information, we cannot tell whether thawing permafrost simply does not affect Sami to any degree, or whether no researchers have asked and gone on to publish the answers. Even if the answers are negative, the questions are worth asking to make sure a substantial body of knowledge is not simply being ignored.

Additional Topics

The connections between the cryosphere and other aspects of life in the Arctic make it all but inevitable that discussions about a changing cryosphere will entrain other topics as well. As can be seen in **Figures 4, 5**, a wide range of such topics is addressed in the papers in our collection. Social, cultural, and economic issues are widely discussed, as these are broad categories (as we use the terms) encompassing a wide range of outcomes and influences. Recognizing that some of the differences could be an artifact of our classification, it is nonetheless interesting to note that in Canada only three-quarters of the papers mentioned economics, with the Western Arctic region least likely to do so. These differences may reflect different systems of land access and management across the four regions of the Canadian Arctic, resulting in different priorities and perspectives from region to region. The result could also be an artifact of the types of studies done in that region, rather than an actual lack of economic aspects of a changing cryosphere.

Among the other three topics, policy received the least coverage in Alaska, while health generally lagged other topics, and mental health had the least coverage in all regions. As with economics in the Western Arctic of Canada, we cannot tell if the relative lack of attention to policy in Alaska is a result of where researchers chose to focus their efforts, or a systemic disconnect between policy and cryosphere. The latter seems unlikely, given the attention to coastal erosion and sea ice loss among other topics in Alaska (e.g., Marino, 2015; Melvin et al., 2017), but more work is required to understand what may be missing. Mental health is perhaps the clearest-cut case of researcher influence. The topic is covered to the greatest extent in Canada, and even there in only one quarter of the papers considered. Of the six papers addressing mental health in Canada, five are from Nunatsiavut, and one researcher (Ashlee Cunsolo) was a co-author on all six. We consider it highly unlikely that the connections between the cryosphere and mental health are most pronounced in Nunatsiavut, and far more probable that the uneven distribution of mental health papers is a result of Cunsolo's leadership in studying this topic. In other regions and for other topics, we saw a greater range of researchers involved in studying Indigenous knowledge and the cryosphere. The participation of more researchers, however, does not necessarily

mean that more topics are covered, as researchers may well continue along similar paths as their predecessors and colleagues.

A comprehensive understanding of the ramifications of a changing cryosphere for Arctic Indigenous communities requires more than chance attention to related topics. As is the case for the cryosphere components themselves, there are major geographical and other gaps in the treatment of additional topics. The most notable, if not the most pressing, gap is the lack of attention to mental health. Other topics, too, deserve a more thorough discussion across countries and regions to identify with greater confidence the patterns in how a changing cryosphere affects community and individual well-being.

We also recognize that our topics are broad and, to some extent, overlapping. Further analysis is needed to assess the degree to which the various topics are addressed fully. For example, "economics" spans income, employment, comparative costs, taxation structures, subsidies, development, and many other aspects of access to money and other resources. To say that many papers discuss economics does not in any way mean that economics has been fully covered in any country or region. Further work would be needed to examine any of these topics in detail. Our findings simply show that Arctic Indigenous Peoples' views on issues other than climate change are relevant and are starting to be reflected in the scientific literature.

As noted in section Analysis and Limitations, our sample of 76 papers does not include a great many more papers addressing various aspects of life in Arctic Indigenous communities. An additional area for future work is to cast a wider net than cryosphere-related papers, to consider for example the degree to which mental health or economics or other topics have been addressed overall around the Arctic. Additional scholarship would then be needed to connect a potential wider body of work on any of these topics with the cryosphere-related work examined here. Doing so could add a great deal of depth to our understanding of the context in which cryosphere change affects Arctic Indigenous Peoples, and thus form the basis for a much more thorough examination of such issues in future assessments of the effects of a changing cryosphere.

Responding to Change

Concerning the various responses to change, we have to keep in mind that Arctic Indigenous Peoples have a history of adaptation from long before the current environmental changes they are facing (Krupnik, 1993). Indigenous Peoples have inhabited these regions for thousands of years (Coates and Broderstad, 2020). For example, the Bering-Chukchi-Beaufort region has been inhabited for more than 10,000 years (e.g., Anderson, 1988). Commercial exploitation of the region's resources began in 1848 with the hunt of bowhead whales by Yankee whalers (Haycox, 2020). Subsequent activities included walrus hunting and fur trapping (Bockstoce, 2010), the development of the Northern Sea Route (AMSA, 2009), oil and gas exploration (AMAP, 2010), construction of national defense systems such as the Distant Early Warning (DEW) Line across northern North America (Jenness, 1962), mining, tourism, and commercial fishing (Arnold et al., 2011). These economic developments have been accompanied by far-reaching social and political changes, from the exercise of

national jurisdiction throughout the area by Canada, Russia, and the United States; to the settlement of Indigenous land claims in Alaska and Canada and the creation of local governments in northern Alaska and self-rule government in Greenland (Nuttall, 2008; Zellen, 2020); from the advent of modern technology and communications to the ongoing loss of Indigenous languages (Barry et al., 2013).

In this context, recent environmental change is seen by many Indigenous persons as simply one of many forms of change they are experiencing. For example, a study by Johnson et al. (2016) outlines that to date Inuit have been able to adapt to thinning ice the best they can, but their concern is the potential change from increased shipping activities and northern development. In Russia, an additional factor affecting them is the lack of mobility to their ancestral lands, as well as changes in subsidies and government support (Nakada, 2015). In the Barents region, the Sami have always adapted to weather conditions but now they are affected by government regulations and the loss of land for agriculture, forestry, mining industry, construction of dams for power generation, tourism, and new market economy (Ksenofontov et al., 2017; Kirchner, 2020). In addition to the effects of cryosphere change on traditional activities, further attention may be warranted on all aspect of life in Indigenous and other Arctic communities. For example, thawing permafrost can damage infrastructure such as roads and buildings, reducing quality of life, and even threatening health and safety. Studies of Indigenous knowledge tend to focus on traditional activities, but these are only part of today's lives and livelihoods in the Arctic. More work is needed to make an explicit connection between Indigenous knowledge, a changing cryosphere, and the full range of today's activities and concerns in the Arctic.

In our review, we use the term of “responses to change” as a non-judgmental alternative to “adaptations,” and present it as an additional category to be explored. Much has been done on the topic of responses to climate change, often using approaches such as adaptation (Berkes and Jolly, 2002; Armitage et al., 2011; Ford et al., 2014, 2015; AMAP, 2017a,b,c), resilience (Crane, 2010; Forbes, 2013; Ford et al., 2020), and vulnerability (Ford and Smit, 2004; Ford et al., 2008; Keskitalo, 2016). The types of response we have identified are intended mainly to illustrate the range of options being pursued (Figures 6, 7), noting many other attempts to categorize responses and response mechanisms (e.g., Thornton and Manasfi, 2010; Walker and Salt, 2012). What we find most noteworthy is the divergence between a popular narrative of gloom and doom in the Arctic (e.g., Van Tuyn, 2013; Herrmann, 2018) and the descriptions of many robust mechanisms being pursued or suggested by Arctic Indigenous Peoples today.

The research reported in the papers in our collection did not necessarily set out to document responses to change, just as the studies did not necessarily set out to address topics beyond the cryosphere, either. Nonetheless, many papers have much to say in both areas. Regarding responses to a changing cryosphere, some patterns stand out. Overall, the use of Indigenous knowledge is the most common response, closely followed by cooperation with scientists. The latter is perhaps not surprising in papers written by scientists, though we recognize that information from scientific

work is valued in many Indigenous communities. Cooperation with outsiders is most commonly reported in Greenland and Russia, as is, to a lesser degree, acknowledgment of variability, and flexibility. We are reluctant to read too much into these differences, recognizing the potential for artifact in a small sample, but further work might explore the role of societal context as well as researcher interests.

Untold Stories and Their Relevance to Future IPCC Reports

In addition to what we have examined so far, we noted another pattern in many of the papers in our sample. Beyond the general results presented, we came across many personal stories of adaptation reflecting that, for Indigenous Peoples, adaptation to environmental change is a constant in their lives and they will continue to adapt. These stories stand in contrast to many reports of doom and gloom from the Arctic, in both the popular media (e.g., Herrmann, 2018) as well as in scholarly publications (e.g., Van Tuyn, 2013; Moon et al., 2019). While these views may not quite be “untold,” they appear not to be widely recognized or acknowledged. Future assessments of a changing Arctic could benefit from including personal stories by Indigenous individuals that convey what people are experiencing and what those experiences mean for them and their communities. We do not suggest that such stories should be given greater weight than the results of broad surveys that are likely to be more representative of large groups, but rather that stories can illuminate details and nuances that may be essential to the accurate interpretation of broad patterns. Furthermore, the tone of such stories can provide valuable insight into attitudes toward change and response, attitudes that may themselves make the difference between lasting hardship and successful adaptation.

To illustrate our point, we present some of the stories from different regions of the Arctic.

In Greenland, Indigenous people have seen over their lifetimes varying sea ice conditions including periods of heavy ice but also light or even no ice. For example, near Aasiaat in the 1940s, the sea ice was thin and unstable and people could not travel by dog team to villages in the south (Niaqornaarsuk and Iginniarfik). They had to use their boats to get to southern locations, and in the winter of 1946–1947, the area had no sea ice (Holm, 2010). In contrast, years later, there were extreme low temperatures and the sea ice formed fully. Erik Røde Frederiksen, a sheep farmer interviewed in 2006, mentioned that their forefathers used to say that if it is calm now, it will be windy in the future, “eqiterpaageeq anerlertarnissaminut silaannaap qatsingarujussuarlini,” “the weather is collecting the future winds by being calm,” reflecting a cycle of weather and climate (Holm, 2010).

Sami herders in the Barents region talk about how they have adapted to cyclic variations in the natural environment. These herders consider that they are handling climatic variations better than other cultures because herding knowledge requires effective adaptation to rapid and unexpected changes and variable conditions (Reinert et al., 2008). A herder in the Kaldoaivi cooperative in the Barents region said: “I’m not at all afraid of

climate change; for reindeer, it signals a good direction, until now” (Vuojala-Magga et al., 2011).

In Alaska (Huntington and Eerkes-Medrano, 2017), George Noongwook from Savoonga pointed out that he has been more concerned about the quota imposed on bowhead whalers by the International Whaling Commission (IWC) than about climate change. Other contributors to the same report were concerned about the impacts that oil and gas development in the Chukchi and Beaufort Seas may have on the whales and food sources due to pollution, noise, and other disturbances. In Shaktoolik, Eugene Asicksik mentioned that government regulations also pose more of a problem to the fishing industry than does climate change.

Similar views were identified in a study by the Inuit Circumpolar Council in 2014 (Johnson et al., 2016). Hunters from Alaska, Canada, Greenland, and Chukotka (Russia) were interviewed and their key messages reflect that Inuit have been adapting throughout their history to extreme fluctuations and conditions and are confident that they will succeed in adapting to changes in climate and sea ice because they are adaptable and strong. The uncertainties they feel are about future impacts of increased development and shipping activities.

In the case of Russia, political issues such as the treatment of Indigenous Peoples, policies concerning mineral and petroleum development, and the availability of government support may be more immediate concerns than climate change. Reindeer herders in the Oymyakon District report that the reindeer numbers have been increasing, as of the time of the study, but recent air temperatures have not been increasing, and so their concerns have more to do with government policies than with the climate (Nakada, 2015).

For many Indigenous Peoples, a key to adapting to changing conditions has been the ability to move freely. For some, this has now changed. For the Sami in Norway, Sweden, Finland, and Russia, government regulations and modern infrastructure limit the reindeer herders’ ability to access ancestral and private lands for pasture or to alter their patterns in response to change (Vuojala-Magga et al., 2011). In Greenland, today’s modern settlements have many conveniences but are not mobile, in contrast to seasonal camps used previously, and so Inuit have far less ability to move their camps to new hunting grounds according to their needs and the changing seasons. This lack of mobility makes them feel that changes are now more visible and affect them more profoundly than in the past (Holm, 2010).

The format and rules governing reports such as the SROCC do not leave much room for personal reflections. First, contributions are expected to be concise, and many quotes and stories use more words than may be available. Second, the expectation of defensible objectivity makes it difficult to include individual voices, even to illustrate more general points. Some reports have included short quotes as illustrative material (e.g., Meltofte, 2013), but we find this practice superficial rather than satisfactory. Furthermore, attempting to fit Indigenous knowledge and voices into a predetermined structure and topic is better than ignoring those voices, but still requires taking information from one context and using it in another. Providing space for Indigenous authors to present their own views in their own voices is one alternative, which has recently been used in the

annual Arctic Report Cards issued by the National Oceanic and Atmospheric Administration in the U.S. (Slats et al., 2019).

The funding sources and motivations for climate change research and media coverage are also a factor in shaping the stories that are told. Efforts to document and report the magnitude of climate change have, understandably, tended to emphasize the scope of change and the risks that human communities and societies are facing. We do not wish in any way to detract from the excellent work that has been done or the seriousness of the topic. Nonetheless, as Arnold (2018) points out, information that does not fit the prevailing narrative often receives less attention. For example, the record sea ice minimum of 2007 received considerable media attention, but did not create a major impression on residents of the north coast of Alaska, closest to the newly open water, a fact that received far less coverage (Christensen et al., 2013). Part of the story of Arctic change is being told, but part remains obscured or missing. Further work is needed to remedy this imbalance.

CONCLUSIONS

Global attention to the changing Arctic cryosphere has helped spur interest in the knowledge and experiences of Arctic Indigenous Peoples on this topic. Through a combination of researcher interest and Indigenous self-expression, the 76 studies we found that examine a changing cryosphere from the Indigenous perspective also present connections to other aspects of community and individual life, describe a range of responses to change, and include some “untold stories.” We are grateful to the authors of all of these papers for taking a wide look at their topics and providing a fuller view of life in a changing Arctic. It is particularly important that Indigenous voices are heard and that Indigenous ideas are part of the discussion about Arctic change and its meaning.

That said, we also recognize that scientists and journalists often focus on the evidence that matches their ideas (Arnold, 2018), rather than questioning their assumptions and the prevailing narrative. When it comes to the Arctic cryosphere, the prevailing narrative is often one of unstoppable, catastrophic change (e.g., Moon et al., 2019; Huntington et al., 2020). While a changing cryosphere does indeed affect people’s lives in many ways large and small, that is far from the whole story. The papers in our collection collectively suggest a different narrative, one emphasizing connection and response, rather than inevitability and loss.

Out of thousands of scientific papers concerning the Arctic cryosphere, the ones that we found are both welcome and inadequate. Welcome, because they offer insight that is otherwise lacking, and a chance to see the Arctic through Indigenous eyes, even if indirectly. Inadequate, because there is so much more to be said. In the section Discussion above, we identified major gaps in the coverage of the cryosphere, additional topics, and responses to change. The gaps we note are mainly geographic, in that coverage is uneven around the Arctic, suggesting that much remains to be learned. We also note that further work should look more closely, to identify gaps at a finer scale, within topical

categories and at sub-national levels, as we have begun to do here for Canada. Additional work is needed to examine the papers in our sample, and other sources as available and appropriate, in more detail concerning specific topics such as the nuances of cryosphere characteristics and change, or the many ways in which a changing cryosphere affects all aspects of today's life in Arctic Indigenous communities. We have merely indicated the range of topics covered in the papers in our sample, and further studies could go into much greater depth on any one of these points.

Our review has shown that climate change is not always the primary threat to Indigenous well-being in the Arctic, one spelling doom for Arctic Indigenous peoples. Their own narratives offer a contrasting story of response and resilience. We suggest that the IPCC continues its efforts in partnership with Indigenous peoples to identify thematic and regional gaps in coverage, and that the required time and funding is allocated to fill such gaps. Such an effort may also require recruiting additional researchers with the required expertise and providing opportunities for inter-regional information sharing among Arctic Indigenous Peoples. As part of this effort, more work should be put into providing platforms for telling the untold stories of Arctic change and Indigenous Peoples, so that change can be understood in the context of culture and history as well as that of climate and geography.

At present, we have the ability to tell a partial story, based on what a number of individual researchers have taken upon themselves, in cooperation with Indigenous communities around the Arctic. A more systematic effort is needed to develop a more complete, comprehensive story built from a concerted effort to address core topics consistently. Doing so will help us move scholarly documentation of Indigenous knowledge and experiences from an important but uneven contribution

to an essential foundation for understanding and addressing a changing cryosphere, on Indigenous terms and in service of Indigenous aspirations for their own futures. The SROCC is a step in that direction, and future work can and should continue along this path.

DATA AVAILABILITY STATEMENT

The original contributions generated for the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

LE-M and HH conceived of and wrote the paper. LE-M carried out the literature search and textual analysis. Both authors accountable for the content of the work.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fclim.2021.675805/full#supplementary-material>

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Conflict of Interest: HH is the owner of the company Huntington Consulting.

The remaining author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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