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# Resilience-based steps for adaptive co-management of Arctic small-scale fisheries

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Supplementary material for this article is available online

## Abstract

Arctic small-scale fisheries are essential for the livelihoods, cultures, nutrition, economy, and food security of Indigenous communities. Their sustainable management in the rapidly changing Arctic is thus a key priority. Fisheries management in complex systems such as the Arctic would benefit from integrative approaches that explicitly seek to build resilience. Yet, resilience is rarely articulated as an explicit goal of Arctic fisheries management. Here, we first describe how marine and anadromous fisheries management throughout the North has used the notion of resilience through a literature review of 72 peer-reviewed articles. Second, we make a conceptual contribution in the form of steps to implement adaptive co-management that aim to foster resilience. Building on resilience-based insights from the literature review and foundational research on adaptive co-management and resilience, the steps we propose are to initiate and carry out (1) dialogue through a discussion forum, (2) place-based social-ecological participatory research, (3) resilience-building management actions, (4) collaborative monitoring, and (5) joint process evaluation. Additionally, we propose *action items* associated with the steps to put adaptive co-management into practice. Third, we assess two case studies, Cambridge Bay and Pangnirtung Arctic Char commercial fisheries, to explore how the five steps can help reinforce resilience through adaptive co-management. Overall, we propose novel guidelines for implementing adaptive co-management that actively seeks to build resilience within fishery social-ecological systems in times of rapid, uncertain, and complex environmental change.

## 1. Introduction

Small-scale fisheries are crucial for Indigenous and local communities of the Arctic, where they sustain economies, food security, health, and cultures (e.g. GN 2016). Among these, Arctic Char (*Salvelinus alpinus*) is among the most important species that northern small-scale fisheries target (Zeller *et al* 2011). In Inuit Nunangat (Inuit homeland in Canada), Arctic Char supports three types of fisheries: subsistence, commercial, and recreational (or sport fishing). It is a staple food in Inuit diets, supporting food security and health, and is central to cultures and identities (e.g. Priest and Usher 2004, Lemire *et al* 2015). Arctic Char fisheries further contribute to economic vitality in the North. In Nunavut, the total food replacement value of Arctic Char subsistence fisheries is an estimated $7.2 million a year, while commercial fisheries—the main ones being in Rankin Inlet, Pangnirtung, and Cambridge Bay in the territory of Nunavut—had a market value of $1.8 million in 2015 (GN 2016). Given all the benefits that Arctic Char fisheries provide to northern communities, the demand for Char is high and exceeds the current supply. This indicates the need for improvements in the management system to ensure the sustainability of Arctic Char and other small-scale fisheries in the rapidly changing Arctic.

Climate change leads to important transformations of Arctic marine systems with cascading effects on fish and fisheries (e.g. Arctic Council 2016, IPCC 2019, Huntington *et al* 2020). Climate change has both direct and indirect effects on Arctic Char, whose anadromous form (targeted by most fisheries) migrates to the ocean in the summer to feed in lipid-rich Arctic marine food webs (Dutil 1986). The clearest direct impacts of climate warming include the negative physiological effects of increasing water temperatures on Arctic Char (Gilbert *et al* 2020). Indirect impacts include those through food web interactions. In particular, shifts in the diet of Arctic Char have been reported in different Arctic regions, often as a result of the northward expansion of southern species (Yurkowski *et al* 2018, Ulrich and Tallman 2021), and this may have implications for fish quality (Falardeau *et al* 2022). Climatic changes can also impact harvesting practices, such as by impacting harvesters' ability to access certain fishing sites due to thawing permafrost, changing sea ice conditions (Nickels *et al* 2005), and changes in the migration timing and distribution of fish in marine habitats. While climatic changes are transforming Arctic marine systems and associated fisheries, current management of Arctic Char does not formally integrate the impacts of climate change on fish ecology and the broader system in which fish are caught, herein referred to as a fishery social-ecological system. This will increase the uncertainty for management, challenging the sustainability of these fisheries (Roux *et al* 2011).

Adaptive co-management was developed to support sustainability and build resilience (Folke *et al* 2005, Armitage *et al* 2011), the ability to deal with unexpected changes while ensuring sustainable supply of ecosystem services such as fisheries (e.g. Biggs *et al* 2015, Arctic Council 2016). It has been recommended for the management of small-scale fisheries in the Arctic including Arctic Char (Kristofferson and Berkes 2005) and more broadly to resource management in the changing Arctic (Arctic Council 2016). Adaptive co-management builds on co-management, the 'sharing of power and responsibility between the government and the local resource users' (Carlsson and Berkes 2005). It adds to it active, continued, and dynamic learning to effectively manage in the face of social-ecological change (Nadasdy 2007, Plummer *et al* 2012, Plummer and Baird 2013). Through collaborative processes and social learning, adaptive co-management seeks to increase the coherence between social processes, management, and ecosystem dynamics, which is a prerequisite to support sustainable resource use and build resilience in social-ecological systems (Plummer and Armitage 2007, Plummer *et al* 2012).

Resilience thinking offers a conceptual lens through which to evaluate and improve adaptive co-management (Plummer and Armitage 2007). It seeks to disentangle complexity in social-ecological systems—which can be shaped by uncertainty, non-linear effects, and feedbacks—and to provide guidance for managing these systems. Here, we use the Arctic Resilience Report's (Arctic Council 2016) notion of resilience, which encapsulates several ways of defining resilience including the seven key principles for building resilience (Biggs *et al* 2012, 2015). Indeed, this definition encompasses both ecological and social dimensions of resilience, as well as agency of humans to purposely influence their system (an important feature of 'community resilience'; Magis 2010). Resilience is considered as the capacity to absorb change, adapt and transform (Arctic Council 2013, 2016). Adaptive co-management that further embraces resilience thinking would help support sustainable, adaptable, small-scale fisheries in the Anthropocene. Lacking resilience capacity can, among other things, increase the risk of ecological or social-ecological shifts due to unforeseen impacts from ecosystem degradation or environmental change, which can cause fisheries to collapse (e.g. Thrush and Dayton 2010). Even though resilience is, in theory, fundamental to adaptive co-management, there is little guidance for how to articulate resilience-building through adaptive co-management (e.g. Plummer and Armitage 2007).

While Arctic Char is already co-managed in most of the Canadian Arctic—current management in Northern Canada being ensured by a mix of government, territorial and local organizations along with diverse stakeholders (e.g. DFO 2014)—there is room to move towards adaptive co-management that embraces resilience thinking. However, there is little guidance on how to implement adaptive co-management that has the explicit aim to foster resilience in small-scale fisheries. Some Arctic Char fisheries already feature aspects of adaptive co-management, such as learning-by-doing (Galappaththi *et al* 2019). But many resilience-building principles are not at all, or not fully, applied in the management of these fisheries, such as managing diversity, redundancy, and connectivity (Biggs *et al* 2012, 2015). Even co-management is not fully operationalized in Canada's North, partly due to unequal consideration for Indigenous Knowledge in informing management decisions (Schott *et al* 2020). Current fishery management focuses largely on a single species, whereas adaptive co-management uses a social-ecological lens that considers ecological and social dynamics and their interactions. Furthermore, current management does not fully recognize the complexity inherent in social-ecological systems, often assuming that research and modelling can resolve uncertainties. By contrast, adaptive co-management, while also integrating insights from data and models, embraces complexity, navigating it through experimentation and learning from experience (e.g. Armitage *et al* 2007).

Our objectives are to: (1) describe how the notion of resilience has been used in marine and anadromous fisheries management throughout the North; and, (2) determine how adaptive co-management of Arctic Char and other small-scale Arctic fisheries can be implemented in ways that foster resilience. A key consideration when seeking to build resilience is to define the 'resilience of what, to what' (e.g. Arctic Council 2016). In the context of Arctic Char fisheries, for instance, it includes the ecological resilience of Arctic Char and the ecosystems supporting it, that of the fishing communities, and the capacity of managers, scientists, and stakeholders to learn and use their knowledge to sustainably manage fishery resources.

We address our objectives in two parts: first a literature review and second a conceptual contribution in the form of a guideline for implementing adaptive co-management in small-scale fisheries. First, a literature review to describe how resilience has been conceptualized and used in the context of marine fisheries management at a circumpolar scale. Second, we propose revisited steps to implement adaptive co-management in small-scale fisheries such as Arctic Char, with the explicit goal of resilience-building. We conceptually revisit and expand the original steps developed by Kristofferson and Berkes (2005) to implement adaptive co-management in Arctic Char fisheries, by building on insights from the literature review, and on seminal research and key guidelines on adaptive co-management (e.g. Folke *et al* 2005, Armitage *et al* 2011) and resilience (e.g. Biggs *et al* 2012, 2015, Arctic Council 2016). The initial guidelines by Kristofferson and Berkes (2005) were broad in scope and did not explicitly focus on resilience-building. We thus bring a resilience lens to augment the steps with concrete resilience-building strategies. Finally, by examining two case studies in the Canadian Arctic, Cambridge Bay and Pangnirtung, Nunavut, we explore how our proposed steps could be implemented to reinforce the resilience of fishery social-ecological systems.

## 2. Methods

### 2.1. Literature review

We did a narrative review that considers, through an informal process, a mix of quantitative and qualitative literature (e.g. Berrang-Ford *et al* 2015, Xiao and Watson 2019), to broadly describe how fisheries management has used resilience across the North. First, using the search engine Web of Science, we gathered English peer-reviewed literature at the intersection of Arctic fisheries management and resilience, including literature from the eight Arctic Council member countries that cover both Arctic and boreal fisheries. We conducted the search in October 2020 (see table S1 for the search string used). The initial output included 210 unique publications. We screened all titles and abstracts to determine which publications to analyze based on the inclusion criteria (table S2). Then we conducted a full-text screening if needed. In the end, we kept 72 articles (figure 1; complete list of the 72 articles is in data table DS1).

Second, we developed 43 coding questions (table S3) to guide the literature review analysis, structured around key themes (box S1) relevant to the topic areas: adaptive co-management and resilience. Developing coding questions to extract data from literature is common in systematic literature review and can be based on preexisting concepts (i.e. deductive coding; Xiao and Watson 2019). Here, these coding questions allowed us to extract important information as related to resilience, management, and their interaction (box S1).

As a quality assessment of the literature review, we assigned a 'relevance score' to each coded article based on its level of relevance to the review questions (e.g. Teufel and Moens 2002, Xiao and Watson 2019). The criteria for assigning relevance scores were based on the total score to seven coding questions deemed most critical to the topic areas (adaptive co-management and resilience; table S4). Articles had the highest relevance score if their total score was >6, a medium score for a total of 4 or 5, and a low score if their total was <4.

Third, using descriptive statistics and qualitative content analysis, we analysed literature review data. We provide descriptive information, expressed as percentages of articles (relative to the total sample size of 72), to give an overview of the sample in terms of geographic areas, scope, and approaches used. Then, we carried out a qualitative content analysis, widely used to analyse selected text (Graneheim and Lundman 2004, Yow 2014, Vaismoradi *et al* 2016, Krippendorff 2018). The key techniques were 'manifest' and 'latent' content analysis (Krippendorff 2018) supplemented with 'critical discourse' analysis (Fairclough 2010) to develop themes and their linkages emerging from the studies (figure S1). Manifest content analysis is aimed at the objective, surface, or concrete content. For example, assume that the phrase 'climate change' appears many times in a text. Latent content analysis is aimed at the underlining or implicit meanings, e.g. whether 'climate change' is mentioned in the text in an approving or disapproving manner. Critical discourse analysis explores the connections between the

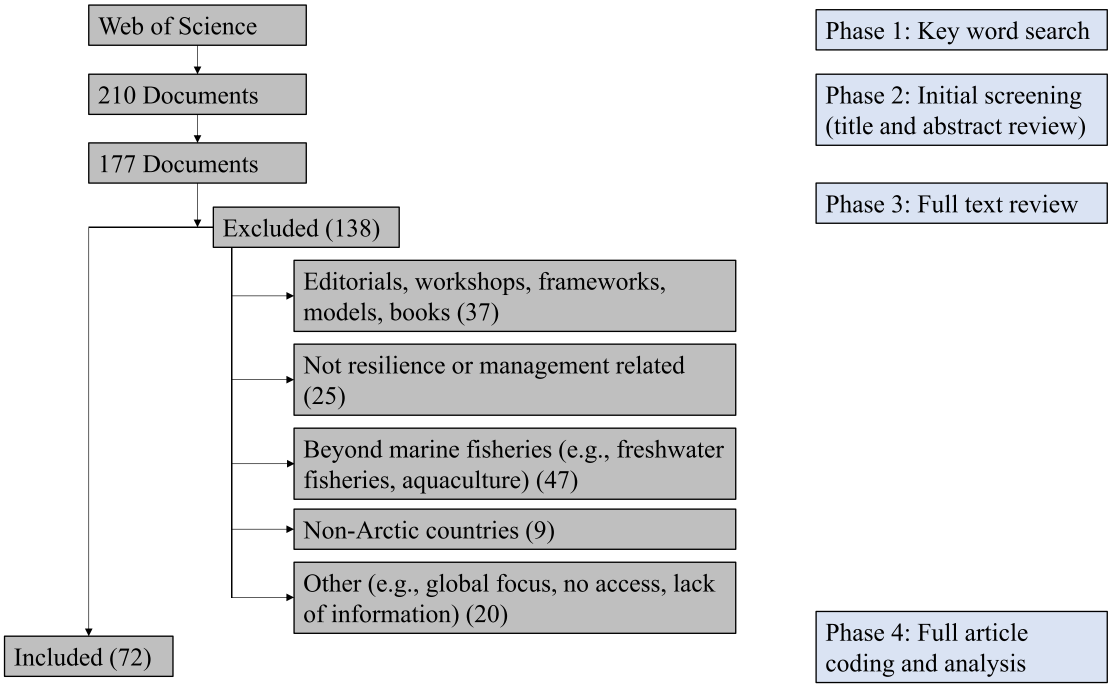


**Figure 1.** Summary of the literature review steps, adapted from PRISMA flow diagram. Adapted from Stovold *et al* (2014). CC BY 4.0.

use of language and the social and political contexts in which it occurs. It explores issues such as cultural differences, gender, ethnicity, ideology, and identity, and how these are all constructed and reflected in texts.

### 2.2. Conceptual development of resilience-building steps

In the second part of the paper, we revisit the steps developed by Kristofferson and Berkes (2005) to implement adaptive co-management of Arctic Char fisheries. Our conceptual lens to expand the steps is resilience thinking, and we build on insights from the literature review as well as from seminal research and guidelines on adaptive co-management and resilience (e.g. Folke *et al* 2005, Armitage *et al* 2011, Biggs *et al* 2012, 2015, Arctic Council 2016). We aimed to gear the steps more specifically to building resilience within fishery social-ecological systems, thus modifying the original names of the steps to better reflect the revisited scope. The original five steps were: (1) dialogue, (2) field study and analysis, (3) design of alternative management actions, (4) monitoring and assessment of management actions, and (5) evaluation. For example, we renamed one of the steps 'place-based social-ecological participatory research' instead of 'field study and analysis' to emphasize the importance of using, as part of adaptive co-management, place-based and participatory research approaches that recognize the linkages between ecological and social systems. We further added broad and adaptable management action items to help implement the steps in ways that support resilience.

### 2.3. Case study analysis

Finally, we applied our proposed steps to implementing resilience-building adaptive co-management to two case studies in the Canadian Arctic, where the largest commercial fisheries for Arctic Char in Nunavut operate: Cambridge Bay and Pangnirtung. We broadly used peer-reviewed and grey literature, including government reports, related to these two fisheries to assess the extent to which the different steps are already being implemented and how they could be further applied in these contexts to foster social-ecological resilience.

## 3. Results

We found that, of the 72 articles included in the final analyses, 47% had a high relevance score ($n = 34$), 46% a medium relevance score ($n = 33$), and 7% a low relevance score ($n = 5$). Scores were spatially disproportionate, with most relevant publications based in Canada, the U.S., and Norway, which together represented 79% of the highly relevant studies and 84% of those of medium relevance (figure 2). All the high relevance score studies had a social-ecological lens to studying fishery systems instead of strictly ecological or social lenses. Medium relevance studies had a mixed focus of social-ecological (67%, $n = 22$), ecological (27%, $n = 9$), and social (6%, $n = 2$). Box S2 contains the sample profile of the 72 analyzed articles.

Five categories of management approaches emerged from the coding of articles, which we defined as: conventional (17%, $n = 12$), participatory

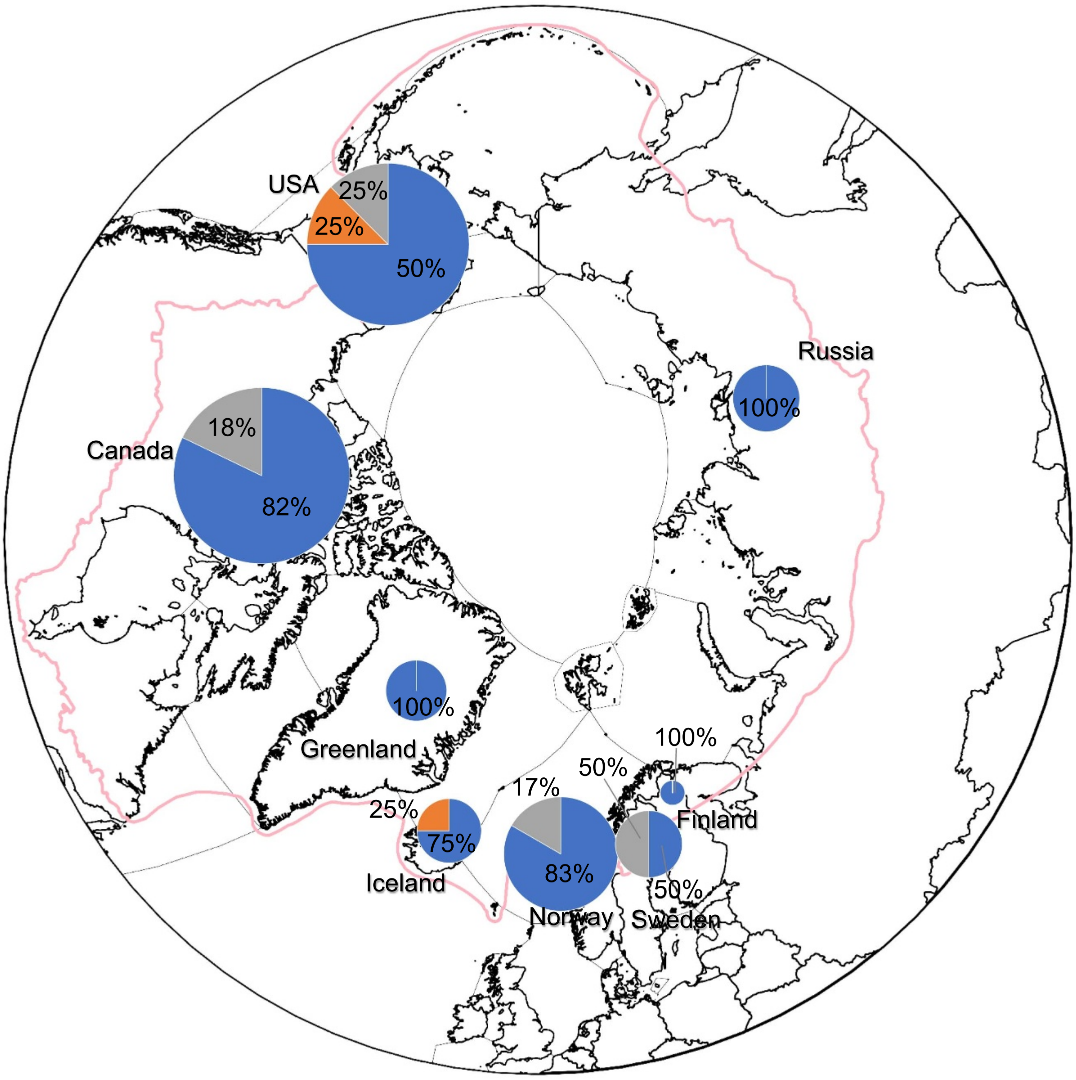


**Figure 2.** Type of ‘lens’ of analysis and geographical distribution of studies analyzed in the literature review in the eight Arctic Council member countries (i.e. Canada, U.S., Greenland (Denmark), Iceland, Norway, Sweden, Finland, Russia). The red line shows the CAFF biophysical boundary for the Arctic (CAFF 2017). The size of each circle pie chart is proportional to the sample size from that specific country. Specifically: Canada ($n = 28$ articles); U.S. ($n = 24$ articles); Norway ($n = 12$ articles); Iceland ($n = 4$ articles); Russia ($n = 4$ articles); Sweden ($n = 4$ articles); Greenland ($n = 3$ articles); Finland ($n = 1$ article).

(36%, $n = 26$), adaptive (18%, $n = 13$), ecosystem-based (13%, $n = 9$), and conservation-oriented (11%, $n = 8$; table 1). Some of these management approaches were integrated with multiple approaches (19%, $n = 14$). For example, Ban *et al* (2019) combined participatory and conservation-oriented management, in the context of a community-based conservation approach examining Indigenous marine governance of the Kitasoo/Xai'xais First Nation in the northeast Pacific Ocean. Furthermore, various institutions were involved in Arctic fisheries management processes, grouped into government (74%, $n = 53$), communal (68%, $n = 49$), private (39%, $n = 28$), and non-governmental (6%, $n = 4$) organizations. Other institutions included Indigenous organizations, research institutions and foundations, and intergovernmental organizations such as the Arctic Council (table S5).

### 3.1. How has the concept of resilience been used as part of fisheries management in the North?

Based on how studies defined the notion of resilience in the context of fisheries management in the North, we identified four resilience categories: social-ecological (36%, $n = 26$), community (28%, $n = 20$), capacity (19%, $n = 14$), and ecological (18%, $n = 13$) resilience (table 2). For example, to assess Indigenous governance and stewardship to build resilient northern abalone (*Haliotis kamtschatkana*) fisheries in northwest Canada, Lee *et al* (2019) defined resilience as an ability to adapt or transform in the face of social-ecological change in ways that continue supporting human well-being, which we categorized as social-ecological resilience.

Four themes emerged as supporting important relationships between marine fisheries management and resilience. First, identifying and understanding

**Table 1.** Five main categories of management approaches that emerged from the articles analyzed ($n = 72$).

| Management category | Description | Examples of specific management type |
|---|---|---|
| Conventional | Focusing on individual species and individual human activities. Management led by individual sectors, with narrowly focused scientific monitoring programs (Rodoshi *et al* 2020). | Top-down government-led management |
| Participatory | Communities, government institutions, civil society, private sector, donors and other stakeholders acting together to protect species, sites, habitats or ecosystems (Oviedo and Bursztyn 2016; Sims and Sinclair 2008). | Co-management, community-based management |
| Adaptive | A multi-purpose approach developed to navigate complex resource management problems, by building resilience and increasing the fit between ecological dynamics and management. Learning, continuously monitoring the effect of management actions, and collaboration are central to this approach (Armitage *et al* 2007, Armitage *et al* 2009; Berman *et al* 2012; Plummer *et al* 2012). | Adaptive management, adaptive governance, adaptive co-management |
| Ecosystem-based | Recognizes the full array of interactions within an ecosystem, including humans, and aims to restore and protect the health, function, and resilience of ecosystems for the benefit of all organisms. It is often a place-based approach to ecosystem management (Long *et al* 2015; Pinkerton *et al* 2019). | Ecosystem-based management |
| Conservation-oriented | Integration of preservation and protection of species and habitats into natural resource management through species and place-specific scientific guidelines and strategies towards sustainability (Ban *et al* 2019; Snelgrove *et al* 2008). | Community-based conservation, marine protected areas |

**Table 2.** General definitions of resilience informed by how the concept of resilience has been used in the context of Arctic fisheries resilience and management, based on literature review articles.

| Key definition areas | General definition | Unique Identification Numbers from the articles (see data table DS1) |
|---|---|---|
| Social-ecological resilience | The ability of a social-ecological system to change continually and adapt, while remaining within its essential functions, structure, identity, and feedbacks. | 2, 5–6, 7–9, 10–11, 14–15, 16, 18–24, 26–36, 38–44, 46–48, 50, 52–53, 55–57, 59, 62–64, 66–68 |
| Community resilience | The collective ability of an interdependent system (place and species) to maintain its essential functions to adapt and self-organize in the face of social-ecological change. | 26, 28–29, 33–35, 37–38, 40, 42–45, 48–49, 52, 58, 62, 71 |
| Resilience as capacity | A combined result of coping, adapting, and transforming processes (using coping, adaptive, and transformative capacities) to respond to a disturbance and change. | 1, 4–6, 12–13, 15, 31, 34, 44, 49, 56, 59, 66–68, 72 |
| Ecological resilience | The ability of ecosystems to absorb a disturbance while maintaining the same functions, structure, and feedbacks. | 3–4, 12–13, 19, 49, 51, 54, 60–61, 69, 71 |

specific drivers of change shaping fishery social-ecological systems is critical. This involves developing locally relevant indicators to monitor the influence of drivers of change on fisheries. For example, regular observations of Rainbow Trout (*Oncorhynchus mykiss*) through scale growth analysis could enable to manage a species with complex life history and growth patterns in the Situk River in Southeast Alaska (Catterson *et al* 2020). Second, using learning as a central vehicle to navigate change is important. We identified different but overlapping ways of learning in Arctic marine fisheries management (table S6). For example, Indigenous-led conservation strategies to steward marine resources (e.g. fish, shellfish, marine mammals, and algae) in Central Coast First Nations of British Columbia (Wuikinuxv, Heiltsuk, Kitasoo/Xai'xais, and Nuxalk Nations) primarily build on culturally transmitted Indigenous learnings that developed over thousands of years of observation (Eckert *et al* 2018).

Third, a sound understanding of enablers and barriers to building resilience in a specific fishery context is critical for effective management. For instance, drawing on Indigenous governance and stewardship of northern abalone fisheries in Canada's northwest coastal communities, Lee *et al* (2019) identified features of First Nations fisheries governance regimes that could enhance resilience, including managing social connectivity, encouraging learning and experimentation, and broadening participation. In the same abalone fisheries, Lee *et al* (2019) also identified potential barriers to resilience, such as little learning from management actions due to ineffective monitoring of fisheries closures and limited participation of resource users in management processes for over two decades. Although stakeholders, managers, and researchers should work to uncover resilience barriers and enablers specific to their fishery context, we identified general enablers and barriers of fishery resilience (table 3). Resilience enabling factors included close collaborations with Indigenous and Local Knowledge (ILK) holders for effective decision-making, flexible participatory management that can confront unexpected change, and collective action to manage risk. Barriers to building resilience included limited data and information on social and ecological systems to inform management, lack of inclusion for different perspectives, and limited local management capacities (table 3).

The fourth theme is the importance of bringing together different knowledge systems and fostering knowledge co-production to manage fisheries and advance their resilience. Many studies documented ILK's contribution to fisheries management (61%, $n = 44$). Most (94%, $n = 32$) of the high relevance studies reported collaborating with various types of ILK in fisheries management. Yet only 36% ($n = 12$) of medium and none ($n = 0$) of the low relevance studies documented ILK. Articles documenting ILK used various terminologies, including local (or place-based) knowledge, Traditional Knowledge, Inuit Qaujimajatuqangit, and Traditional Ecological Knowledge. ILK informed fisheries management in many ways, such as to improve understanding of natural environments through monitoring, as a source of resilience, to contribute directly to fisheries co-management, and to contribute to knowledge co-production to develop innovative fishing gear (table S7).

### 3.2. Resilience-based steps to implement adaptive co-management in small-scale fisheries

The five revisited resilience-based steps to implement adaptive co-management that we propose are: (1) discussion forum, (2) place-based social-ecological participatory research, (3) design of resilience-building management actions, (4) collaborative monitoring, and (5) joint process evaluation (table 4). We make three major modifications to the original five steps. First and overall, we make resilience-building an explicit goal of this guideline and fine-tune the original steps (Kristoffersen and Berkes 2005) with a resilience thinking lens that is built on insights from the literature review (including the four themes identified as supporting important relationships between fisheries management and resilience) and foundational scholarship in the topic areas. More specifically, we sought to add explicit resilience-building notions (e.g. Biggs *et al* 2012, 2015, Arctic Council 2016) to the adaptive co-management steps. Second, we propose action items under each step to inspire managers, policy-makers, stakeholders, and scientists on ways to implement adaptive co-management. The proposed action items are broad and adaptable because there is no single *exact* way to implement adaptive co-management, and it is essential to modify and develop context-specific plans. Third, we further emphasize the importance of an iterative approach to implement adaptive co-management where the steps can be repeated periodically. This way, outcomes from step 5—joint process evaluation—and the learning gained throughout the process, can continually help improve how the fishery social-ecological system is monitored and managed adaptively to advance resilience.

### 3.3. Case studies to implement the steps

To explore how our revisited steps can reinforce adaptive co-management of Arctic fisheries, we focus on two case studies: Cambridge Bay and Pangnirtung, both in Nunavut, Canada (figure 3). These represent two of the largest commercial fisheries for Arctic Char in the Canadian Arctic, meaning that a wealth of published information is available about the management of these fisheries. In particular, the two fisheries feature adaptive co-management characteristics (Roux *et al* 2011, Galappaththi *et al* 2021). In fact, Kristofferson and Berkes (2005) developed their steps to implement adaptive co-management in Cambridge Bay. Moreover, both communities are in regions where ILK and Western science have reported important environmental changes (NTI 2001, Idrobo and Berkes 2012, Galappaththi *et al* 2019, Falardeau *et al* 2022).

#### *3.3.1. Case study contexts*

Residents of Cambridge Bay (population of 1766 in 2016; 82% Inuit; Statistics Canada 2017) and Pangnirtung (population 1481 in 2016, 94% Inuit;

**Table 3.** Themes that emerged from the literature review coding as related to enablers and barriers to resilience of fishery social-ecological systems, along with specific examples from selected articles.

| Themes | Examples | References from the articles |
|---|---|---|
| **Enablers** | | |
| Place attachment and monitoring | Place attachment/sense of belonging; investments in community infrastructures such as small harbours and fish processing plants; environmental monitoring including early understanding of drivers of fish abundance. | Galappaththi *et al* (2019), Lloret *et al* (2020), Whitney and Ban (2019) |
| Participatory and evidence-based governance | Effective partnerships and community participation in management; explicit use of reference points and harvest control rules; contemporary co-management with risk assessments; accountability of fisheries management plans. | Burgass *et al* (2019), Lavoie *et al* (2019a), Schott *et al* (2020) |
| Multiple knowledges | Attention to respect, reciprocity, intergenerational knowledge, and knowledge co-production; promotion of ILK as fundamental to management strategies. | Ban *et al* (2019), Gauvreau *et al* (2017), Tiller *et al* (2015) |
| Agency | Fostering education and innovation; strengthening traditional Indigenous marine management systems; maximizing community resilience through high agency of local organizations. | Jackley *et al* (2016), Kokorsch and Benediktsson (2018) |
| Diversification | Livelihood diversification within and beyond fisheries; use of diverse management strategies; integration of diverse portfolio of activities (e.g. harvesting multiple fish species, hunting, wage labour); ecological diversity (e.g. genetic and phenotypic diversity) and cultural diversity. | Catterson *et al* (2020), Chan *et al* (2017), Galappaththi *et al* (2019), Paterson *et al* (2018), Watson and Haynie (2018) |
| Communication and learning | Transparency of fisheries management; regular communication among managers and stakeholders; encouraging learning and experimentation; technology (e.g. GPS, marine VHF radios). | Hutchings *et al* (2020), Lee *et al* (2019), Salomon *et al* (2019), Tejsner and Veldhuis (2018) |
| Collaboration and connectivity | Adaptive social networks; decentralized decision-making involving strong social networks of ILK holders; economic connectivity of fisheries; food sharing systems among extended family and beyond; knowledge integration; use of stakeholder analysis to understand social linkages; connectivity among government and local institutions. | Barnett (2018), Bruckmeier (2014), Criddle and Juneau (2017), Lavoie and Himes-Cornell (2019a), Reedy-Maschner and Maschner (2013) p., Rybråten *et al* (2018) |
| **Barriers** | | |
| Financial constraints | Budgetary constraints and limited access to capital; long-term effects of economic downturns; high price of fuel. | Beier *et al* (2008), Himes-Cornell and Kasperski (2016), Klain *et al* (2014) |
| Limited information | Limited scientific data and information (e.g. poor monitoring of fish abundance through time, little knowledge of fisheries interactions); lack of tools to measure SES resilience; disappearing Traditional Knowledge due to social transformations and limited support for preservation. | Bailey *et al* (2016), Paterson *et al* (2018) |
| Ecological deterioration and uncertainty | Reductions in spawning habitats due to habitat disruptions; mortality associated with climatic changes along with fishing and marine predation may limit recovery; complex spawning dynamics. | Okey *et al* (2014), Paterson *et al* (2018), Tejsner and Veldhuis (2018) |

(Continued.)

**Table 3.** (Continued.)

| Themes | Examples | References from the articles |
|---|---|---|
| Governance conflicts and lack of participation and inclusivity | Limited access and allocation restrictions to local harvest; mismatches/disconnect of local and national development goals; exclusion of ILK from fisheries management; power dynamics; exclusion of diverse perspectives such as that of fisherwomen. | Lavoie *et al* (2019b), Robards and Greenberg (2007), Rybråten *et al* (2018), Whitney and Ban (2019) |
| Market conflicts and technological challenges | Market rivalry for fish; limited access to technology; limited adaptability to new technology; risk posed to oral tradition by technology. | Criddle (2012), Himes-Cornell and Hoelting (2015), Tejsner and Veldhuis (2018) |
| Social and cultural gaps | Lack of recognition of Indigenous rights; mismatch between government procedures and Indigenous ways of knowing. | Barnett and Anderies (2014), Barnett and Eakin (2015), Reedy-Maschner and Maschner (2013) |
| Physical constraints | High-risk infrastructure standing on melting permafrost (e.g. bridge, housing); remoteness and accessibility of certain fishing grounds; limited community infrastructures; encroaching mining industry. | Drejza *et al* (2011), Ford and Goldhar (2012), Salomon *et al* (2019) |

Statistics Canada 2017) fish Arctic Char for many purposes through three fishery types: commercial, subsistence, and recreational. These fisheries have long been central to culture, livelihoods, food security, and health. In the Cambridge Bay region, archeological evidence dating back thousands of years indicates that settlements formed around rivers with important Arctic Char runs (Friesen 2002, 2004). Inuit Knowledge, or Inuit Qaujimajatuqangit (IQ), about the land, sea, and wildlife is vibrant in both regions (Stewart *et al* 2004, Idrobo and Berkes 2012, Pedersen *et al* 2020, Kitikmeot Heritage Society 2021a), where Inuit have long monitored and managed Arctic Char.

Cambridge Bay hosts the largest commercial fishery for Arctic Char in the Canadian Arctic, with a market value of $4.1 million for the 2008–12 period (DFO 2014). Pangnirtung fishery is also one of the largest Arctic Char fisheries in Canada and coexists with a Greenland Halibut (*Reinhardtius hippoglossoides*) commercial fishery. Cambridge Bay and Pangnirtung have fish processing plants that export fish products throughout Canada and internationally (GN 2016). These community fish plants provide a few year-round jobs and many seasonal jobs in fishing, fish processing, and shipping, while contributing to community life such as the community soup kitchen in Pangnirtung (Galappaththi *et al* 2019).

Before delving into the application of the steps, we compared Indigenous versus current management of Arctic Char fisheries (table 5). We then focus our assessment on how the steps are currently applied in commercial fisheries. We aim to stimulate adjustments within commercial fisheries co-management that is formally designed and enforced at multiple decision-making levels (DFO 2014). Subsistence fisheries are self-managed by Inuit and are not subject to the DFO quota limitation given that the Nunavut Land Claims Agreement guarantees harvesting rights to Inuit beneficiaries under certain conditions (see Lysenko and Schott 2019).

*3.3.2. How are the revisited steps currently applied?*

*3.3.2.1. Step 1. Discussion forum*

Creating a discussion forum and some of the action items within this step, such as building cross-scale partnerships, are well featured in the Cambridge Bay and Pangnirtung fisheries that have been co-managed for decades. Indeed, Nunavut Arctic Char commercial fisheries are co-managed in conformity with the Nunavut Land Claims Agreement and the Fisheries Act, collaboratively by Fisheries and Oceans Canada (DFO), the Nunavut Wildlife Management Board (NWMB), local Hunters and Trappers Organizations/Associations (HTOs/HTAs), as well as other designated Inuit organizations including Regional Wildlife Organizations that overlook the harvesting practices of HTOs (e.g. DFO 2014). Stakeholders are also at the table, including commercial fishers, the fish plant managers/employees, and other local resources users. The NWMB is the main body for wildlife management, but DFO may have the power to amend or reject decisions made by the NWMB if there is a clear conservation concern. The HTOs can also implement management measures in response to local issues and concerns (DFO 2014), such as temporary fishery closures in both space and time (DFO 2021). An Integrated Fisheries Management Plan (IFMP) was co-developed for the Cambridge Bay fishery to determine short- and long-term fishery objectives, as well as management actions required to achieve them (DFO 2014). This is the first IFMP for Arctic Char in Canada.

**Table 4.** Resilience-based steps to implement adaptive co-management of Arctic Char and other small-scale fisheries, building on Kristofferson and Berkes (2005). Examples of action items are provided in italic. See table S8 for the detailed aim and description of each step as well as the full list of action items to promote implementation.

| Steps | Overall aim *(examples of action items)* |
|---|---|
| 1. Discussion forum | Initiate a discussion forum among fishery stakeholders at multiple scales to set management goals, among which should be building resilience within the fishery social-ecological system, as well as ways to achieve and monitor goal achievement. Spur open dialogue on ILK and Western science (commonalities, differences, ways to meaningfully collaborate). This forum should be a space to build trust, mutual respect, and shared understanding. *(Initiate group discussions; Dedicate ample time to earning mutual trust and respect; Document ILK related to the resource; Identify information and data gaps)* |
| 2. Place-based social-ecological participatory research | Interweave knowledges and jointly seek to understand connections between fish, people, and place—herein referred to as fishery social-ecological systems—and what key drivers of change are affecting the system. This step aims to unravel feedbacks and cascading effects that influence the social-ecological system and supports the co-development of a community-based participatory research framework to monitor the system. *(Use Indigenous methodologies; Design and implement participatory research projects; Interweave different perspectives and ways of knowing; Mobilize and co-produce knowledge)* |
| 3. Design of resilience-building management actions | Explore alternative adaptive co-management actions to those currently in place, which should minimize vulnerability and improve resilience. Managers and stakeholders can jointly identify resilience-building opportunities by recognizing context-specific barriers and enablers of resilience. *(Share power and responsibilities; Identify opportunities; Identify resilience barriers and enabling factors specific to the system; Assess the risk of management actions)* |
| 4. Collaborative monitoring | Collaboratively monitor how the fishery social-ecological system responds to environmental changes and management actions via the participatory research framework co-developed in step 2. This step embraces an adaptive approach where experimentation—i.e. new management actions identified in step 3 with a potential to foster resilience—are taken and closely monitored, to learn and improve the next iteration. *(Establish a community-based monitoring system; Use locally relevant indicators)* |
| 5. Joint process evaluation | Evaluate, based on the jointly defined evaluation approach for goal achievement (step 1), whether adaptive co-management succeeds in its goals, including to build resilience in the fishery social-ecological system. Co-define lessons learned and assess ways to iteratively improve achievement of the goals identified in step 1 based on the information collected through participatory monitoring. *(Re-assess past management actions; Document lessons; Use identified lessons; Up-scale lessons)* |

The commercial fisheries are operated by Inuit fishers in partnership with local fish processing plants (e.g. DFO 2014), and both fishers and fishing plants' managers are involved in consultation processes (Bernauer 2022). Community consultations are important to co-management processes, where 'TEK [Traditional Ecological Knowledge] is used with scientific knowledge for effective fisheries decision-making and in the development of scientific research and fishery management plans' (DFO 2014, p 10). Though TEK holders are regularly consulted, DFO's stock assessments are based mostly on Western science methods, such as morphometric measurements and modelling. However, knowledge plurality in management is rapidly evolving and the Government of Nunavut is working to ensure that IQ directly feeds into research and management (GN 2016). Lastly, although these co-management schemes aim to support sustainable fisheries, resilience-building could be featured as a more explicit goal of management (e.g. the IFMP neither mentions nor addresses resilience; DFO 2014). The IFMP could target specific resilience-building actions, for example by implementing collaborative monitoring of social-ecological resilience indicators and by recording and applying social learning from past and new disturbances.

*3.3.2.2. Step 2. Place-based social-ecological participatory research*

The place-based, participatory dimensions of this step are well developed and expanding in both regions, where government documents recognize shared stewardship, local participation, and the importance of bringing together two ways of knowing (i.e. IQ and Western science) for fisheries decision-making (DFO 2013a, 2014, GN 2016). For instance,

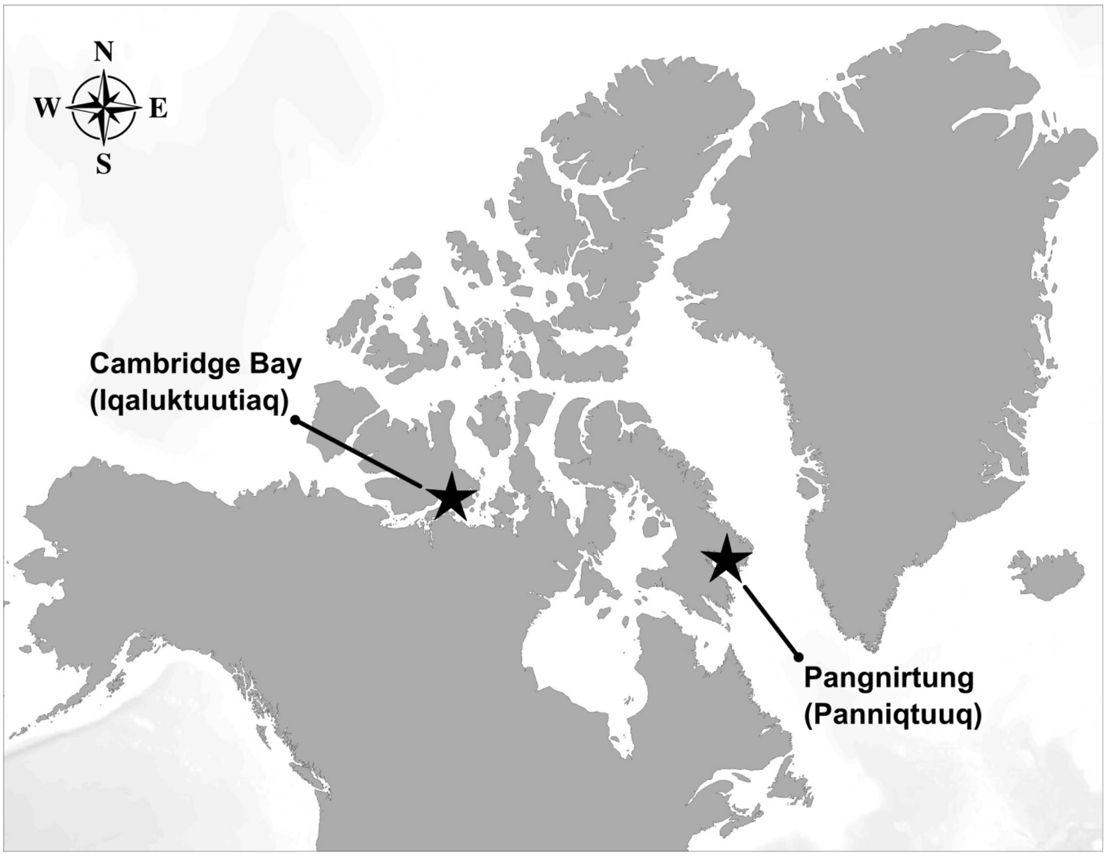


**Figure 3.** Map of case study locations, Cambridge Bay (Iqaluktuutiaq) and Pangnirtung (Panniqtuuq), in Nunavut in the Canadian Arctic. Created in Ocean Data View (Schlitzer 2021) and InkScape (Inkscape project 2021).

in Pangnirtung, fish quotas are based on the best available science advice and IQ (Laidler *et al* 2010, Idrobo and Berkes 2012, Roux *et al* 2019). As indicated in step 1, however, stock assessments are based mostly on Western science methods. The baseline status of these fishery systems, as assessed by Western science methods, suffers from information gaps, with the Cambridge Bay fishery being 'identified as a typical data-poor or data-limited example' (DFO 2021). Nonetheless, stock assessments are accumulating to help inform management, the most recent of which for the Cambridge Bay fishery occurred in 2021 (Halokvik and Jayko; Harris *et al* 2021, Zhu *et al* 2021) and 2020 (Lauchlan; DFO 2020). There, the last regional stock assessment incorporating all commercial waterbodies was in 2013 (DFO 2014) although an assessment performed by Zhu *et al* (2014) used data from all stocks but provided advice for the fishery for one unit. The most recent published stock assessment for Pangnirtung was in 2015 (DFO 2018). Furthermore, although DFO recognizes the connections between ecosystems, Arctic Char, and humans (DFO 2014), valuation of the commercial fishery could transcend economic value and include parameters indicative of resilient livelihoods (Plummer and Armitage 2007). Given the vibrant IQ available in both regions about fishery social-ecological systems (e.g. Stewart *et al* 2004, Idrobo and Berkes 2012, GN 2016, Pedersen *et al* 2020, Kitikmeot Heritage Society 2021b), this suggests that additional efforts to interweave knowledges through adaptive co-management processes could help fisheries co-managers assess stocks and, more broadly, how stocks are and will be affected by climate-related changes in social-ecological systems.

Ongoing movements indicate that knowledge interweaving to support sustainable management is expanding in Inuit Nunangat. Indeed, Inuit have a strong desire for IQ to be meaningfully paired with Western science to monitor ecosystems and wildlife, as exemplified by the SciQ concept—'the balance between the tools, technologies and methods of science, and the knowledge, customs, and values of IQ' (Pedersen *et al* 2020, p. 332)—developed by the Ikaarvik youth, who hosted the Cambridge Bay SciQ summit in 2018 to develop recommendations for incorporating IQ in research including specific actions that researchers can take before, during, and after research projects, like getting community feedback at the outset and being flexible throughout (Pedersen *et al* 2020). The Government of Nunavut is also leading promising initiatives in that line, such as the Nunavut Community Aquatic Monitoring Program (N-CAMP), which provides community training to monitor aquatic systems with protocols containing strong IQ principles (GN 2016). They also

**Table 5.** Comparison of Indigenous and current management systems as well as ways to reinforce adaptive co-management (building on Berkes 2018, DFO 2014, Galappaththi *et al* 2019, GN 2021, GC 2020, Kristofferson and Berkes 2005, Reid *et al* 2021). See main text for the full institutions' names.

| | Indigenous management | Current management | Reinforcing adaptive co-management |
|---|---|---|---|
| What data are collected? | Long-term accumulated qualitative data (observations going back to 1000s of years), e.g. Inuit Qaujimajatuqangit (IQ) about fish biology (such as size, life cycle, and the timing and locations of spawning). | Long-term (dating back to the ~1970s) fishery-dependent harvest/catch and quantitative biological datasets (e.g. length, weight, age) collected through commercial plant sampling programs. Fishery-dependent effort data are only recently being collected. Short-term (~5 years in length) fishery-independent quantitative biological and catch/effort datasets (length, weight, age but also sex and maturity) sporadically collected at specific waterbodies. Other ecological factors considered such as migratory behaviour and habitat use. | Place-specific qualitative and quantitative data that represent both short-and long-term social, cultural, and ecological dynamics as well as slow and rapid variables. |
| Who collects the data? | Inuit exclusively | Government institutions (e.g. DFO, NWMB, GN), researchers (e.g. academic, consulting, governmental) and community-based monitors; input from and sharing of IQ from Elders and local IQ holders. | Inuit, government institutions, and researchers. |
| What management actions are in place? | No distinction between fishery types (subsistence, commercial, recreational) for management actions, e.g. rotational fishing practices, harvest waterbodies and let it recover. Nowadays, community by-laws can be established to regulate Inuit fishing (see Subsistence under 'Current management'). | • Commercial: Includes waterbody-specific annual commercial quotas, regulating gillnet mesh size (e.g. the NWMB passed a resolution to limit Arctic Char commercial and exploratory commercial fishing by gillnet to 139 mm), defining open and closed seasons, commercial fishing license requirements, harvest tracking systems.<br>• Recreational: Includes license fee, daily catch limits, possession limits.<br>• Subsistence: Not ensured by the government. Communities can establish by-laws for specific management actions (e.g. specific locations, gear types). | Collaborative management action between Inuit and government institutions, other stakeholders and resource users following the five resilience-based steps and taking inspiration from the action items. |

(Continued.)

**Table 5.** (Continued.)

| | Indigenous management | Current management | Reinforcing adaptive co-management |
|---|---|---|---|
| How are the management actions determined and who makes the decisions? | Inuit make their own decisions—nowadays through Inuit designated institutions under land claims and treaties—because they have customary and legal rights. Actions are socially enforced. Decisions are based on long-term qualitative monitoring and observations of human-nature interactions, including from IQ transmission. | DFO and HTOs/HTAs, along with the NWMB and other designated Inuit organizations, are co-managers of the fisheries in Nunavut, as outlined in the Nunavut Land Claims Agreement and the Fisheries Act. Consultation is required for decision-making. | Joint decision making among Inuit and government characterized by: (a) equal power balance, (b) accepting coexisting knowledge systems, (c) not trying to test one kind of knowledge against another, (d) respect each other, (e) interweave different knowledge systems with a Two-Eyed Seeing approach. |
| What experimentation is done? | Experimentation can include, for example:<br>● Rotating fishing spots<br>● Pulse fish intensively for a burst of time<br>● Use methods that result in the harvest of a wide range of fish sizes. | Restrictions and rights-based management limit space for experimentation. Quantitative data are used to monitor and set management measures, with considerations for IQ. | Include resilience-building management actions through knowledge weaving and co-production, experiment actions and monitor their outcomes through participatory approaches. |

put in place the Nunavut Coastal Resource Inventory (NCRI) to assist co-management partners in accessing IQ on aquatic species. With these efforts, monitoring programs supporting Arctic Char commercial fisheries management are advancing in co-producing knowledge that embraces a social-ecological lens.

*3.3.2.3. Step 3. Design of resilience-building management actions*

Even though resilience has yet to become an explicit goal of the management of these fisheries, both cases are already putting in place some resilience-building actions as part of co-management processes. For instance, in Cambridge Bay, the HTO, the fish plant, and DFO are building capacity among fishers so that commercial fishers themselves can lead the monitoring program (DFO 2014). The N-CAMP program, developed by the Government of Nunavut, also seeks to strengthen community capacity to monitor and manage aquatic resources (GN 2016). Promoting fishery-related education, including among Inuit youth, seems to be a shared priority (DFO 2021). For example, DFO partnered with a Western science and IQ camp in the Cambridge Bay Region that brought Inuit youth and Elders on the land to share knowledge on Arctic Char (Thorpe, Moore and the EHTO 2019).

Furthermore, Pangnirtung is diversifying its fishery portfolio, thus reducing vulnerability to market fluctuations, as the fish plant is involved in both Arctic Char and Greenland Halibut commercial fisheries (Galappaththi *et al* 2019). The fish plant has recently been able to pay more attention to Greenland Halibut, as their Arctic Char markets have been shrinking, partly due to competitive aquaculture Char production in the south (Galappaththi 2020). In addition, joint action such as community consultations for actions like determining quotas, enforcement, and harvest data collection are key features in both fisheries (DFO 2014).

*3.3.2.4. Step 4. Collaborative monitoring*

Monitoring in both cases is increasingly conducted collaboratively through tight partnerships between managers, scientists, fishers, and fish plants. In Cambridge Bay, real-time (daily) harvesting data and quota monitoring are completed by the fishers and fish processing plant, who report back to DFO (DFO 2014). DFO also conducts annual monitoring programs of fishery data and plans to ultimately measure catch-per-unit-effort (CPUE), although CPUE data is currently limited (DFO 2014, 2021). In Pangnirtung, both government scientists and Inuit are involved in ecosystem monitoring activities. DFO carries out formal stock assessments (DFO 2013b), while harvesting data and quota monitoring related to Arctic Char commercial fisheries are collectively managed by the HTO, NWMB, fish plant, and DFO. As assessed under step 2, monitoring is moving towards more community-based, transdisciplinary, approaches based on IQ principles, which could contribute, among other things, temporal information on changes in fish and their social-ecological implications with a finer scale of detail that Western science-based DFO stock assessments do not capture. Indeed, real-time ecosystem monitoring is a traditional practice of Inuit through regular observations of the land and wildlife (e.g. Char habitats, fishing spots, weather and ice changes, Arctic Char taste/colour/size, meat texture; Laidler *et al* 2010, Brooks *et al* 2019).

*3.3.2.5. Step 5. Joint process evaluation*

Process evaluation is strongly implemented in both cases. In Cambridge Bay, all those involved in managing Arctic Char fisheries seem disposed to learning together about improving fishery sustainability. The evolution of the co-management approach over the past decades towards better responses to fishery issues illustrates this shared willingness of co-managers and stakeholders to collaboratively learn and improve. Prior to and after each fishing season, multi-stakeholder meetings are held to assess how the fishery aligns with short- and long-term sustainability objectives and to ensure that local priorities are considered (DFO 2014, 2021). Here, the fact that objectives are defined jointly by co-managers and stakeholders increase their chances of being achieved, as they are more likely to be supported by the community. Also, in Pangnirtung, at the decision-making level, stakeholder meetings reassess each fishing season and incorporate lessons for the following season. Regular decision-making meetings occur among government entities (DFO, NWMB, Government of Nunavut; GN) and ILK holders (Galappaththi *et al* 2019). Frequent process evaluation is one of the key places where the 'adaptive' part of management occurs: when objectives are iteratively updated, or when strategies to achieving objectives are tuned according with latest observations.

## 4. Discussion

We start with a literature review to describe and seize how the notion of resilience has been conceptualized and has informed fisheries management across the North. Only 7% of the articles had a low relevance score, which indicated that the literature review was effective in targeting research at the interface of fisheries management and resilience. We found that peer-reviewed literature on resilience in northern fisheries was unevenly huddled geographically, with Canada and the United States dominating this emergent field. This may reflect a stronger move towards integrating resilience in fisheries management of these countries but may also be influenced by higher research effort. Four themes arose as fundamental to building the resilience of northern fisheries through management: understanding drivers of change that shape the fishery social-ecological system; using learning as a central mechanism to navigate change; understanding enablers and barriers to building resilience specific to the fishery system; and including different knowledge systems and fostering knowledge co-production. Most of these themes are widely documented in peer-reviewed literature as well as i major regional and Pan-Arctic assessments, such as the Arctic Resilience Report (Arctic Council 2016), thus offering guidance for their incorporation into adaptive co-management. However, efforts to understand enablers of, and barriers to, resilience are relatively limited in the context of Arctic fisheries management compared to southern settings, which highlights the importance of advancing research at this frontier. We further stress the importance of assessing resilience enablers and barriers through place-based lens and approaches, as some system's features can be both enabler and barrier depending on the context. For example, technology can be an enabler enhancing adaptive capacity of fishers by helping them navigate difficult environmental conditions, but also a barrier through the risk it poses to oral tradition or the repair difficulties it generates (Tejsner and Veldhuis 2018). Critically, the inclusion of diverse knowledge systems plays a central role in building the resilience of Arctic fisheries as reflected by the 44 studies (out of 72, thus 61%) we found documenting the application of ILK in fisheries management. The themes that emerged from the narrative review in turn informed our conceptual amplification of the steps originally proposed to implement adaptive co-management.

### 4.1. Novel steps to build resilience and interweave knowledges

Through a narrative review of peer-reviewed literature from the natural and social sciences and an assessment of foundational scholarship on adaptive co-management and resilience, we conceptually revisited the steps that Kristofferson and Berkes (2005) introduced some years ago to implement adaptive co-management of Arctic Char fisheries. The original steps consisted in an 'outline' of an adaptive co-management process that initiated a reflection on how to approach uncertainty, complexity, and collaboration among multiple stakeholders and their different knowledge systems. Thus, there was already room to expand the steps back then. In recent years, calls for new ways to manage Arctic resources in the face of rapid environmental change (e.g. Arctic Council 2016, Meredith *et al* 2019), the emergence of novel guidelines for evaluating and building resilience (e.g. Biggs *et al* 2012, 2015), and calls for reconciliation through research and management (e.g. Reid *et al* 2021), have all further expanded the room for improving the initial guideline. Therefore, we push forward steps that propose novel ideas for how adaptive co-management can support knowledge plurality and co-production, with the common goal of building resilience in fishery social-ecological systems. Our steps encourage paradigm shifts that promote a better fit between management, ecological dynamics, and social dynamics, deeper interweaving of knowledges, as well as concrete ways to foster more resilient fisheries through management.

Given the pace of change in the Anthropocene, shifts away from conventional approaches to management that maintain top-down dynamics as well as a mechanistic view of uncertainty—seen as something to quantify through models and to minimize—are needed (e.g. Arctic Council 2016). While modelling is essential to guiding management, uncertainty is, and will be, inherent to rapidly changing Arctic systems. Rather than viewing it as daunting, adaptive co-management embraces uncertainty through an experimental process of fostering transdisciplinary learning and collaboration among co-managers and stakeholders (e.g. Plummer *et al* 2012). For example, co-managers of the Cambridge Bay fishery regularly meet to discuss and assess fish stocks' status in light of jointly defined goals, including sustainability and shared stewardship (DFO 2014). In this discussion space, new management actions can be defined for the next iteration. Adaptive co-management thus seeks to gather as much information as possible on the system through regular monitoring via both Western science and ILK. It also experiments with new management actions (the revisited step 3 propose that actions are jointly identified by co-managers as actions to foster resilience) as part of an iterative process acknowledging uncertainty as inherent to complex systems.

While the original steps proposed to test alternative management options, there was no explicit focus on resilience in defining management actions, merely to 'analyze management actions in relation to outcomes predicted by *ecological theory*' (Kristofferson and Berkes 2005, p 265). We suggest moving beyond ecological theory which, although relevant to assess ecosystems and fisheries, can miss social-ecological feedbacks and cascading effects that are hardly captured by quantitative models focused on the ecological system (e.g. Kutz and Tomaselli 2019, Falardeau and Bennett 2020). Rather, we bring forward, under revisited step 4 (Collaborative monitoring), that management outcomes are assessed via collaborative, transdisciplinary approaches (such as Two-Eyed Seeing) that embrace a resilience thinking lens, better suited to unravel the wider social-ecological implications of management actions.

Indeed, our proposed steps prompt a shift towards participatory decision-making and bottom-up approaches where local fishing communities have the lead role in monitoring and managing their fisheries. In these participatory, bottom-up processes, learning-by-doing and knowledge co-production are instrumental (Armitage *et al* 2011, Berkes 2018, Conway *et al* 2019, Schatz *et al* 2019). Given that most

Arctic fisheries are placed within Indigenous Territories, adaptive and participatory approaches together with Two-Eyed Seeing—a framework to interweave Indigenous Knowledge and Western science (Reid *et al* 2021)—are more appropriate than conventional fisheries management. In these post-colonial contexts, ethical considerations prompt the inclusion of ILK and Indigenous methodologies to move away from the mould of top-down science and management. Community-based participatory approaches can also generate outcomes beyond research and management, such as capacity building and community healing (Drawson *et al* 2017, Bernauer 2022).

There are additional practical considerations in shifting towards participatory, bottom-up approaches, including the co-production of more integrative and usable knowledge for management (e.g. Ford *et al* 2013, Tengö *et al* 2017), and a better understanding of problems through improving the spatial and temporal scale of knowledge (e.g. Kutz and Tomaselli 2019). The original steps were at the forefront by proposing to 'document Inuit knowledge' and 'incorporate traditional ecological knowledge' in a time where management was largely driven by Western science. But the revisited steps build on major progress and novel propositions made to foster reconciliation through research and management (e.g. Pederson *et al* 2020, Reid *et al* 2021), by proposing to interweave knowledges in ways that maintains their integrity, and by encouraging the use of Indigenous methodologies (table S8).

Importantly, our proposed adaptive co-management steps have the explicit goal of fostering resilience within Arctic Char and other small-scale fisheries in the Arctic and more widely. The original steps did not articulate how the adaptive co-management process can contribute to resilience-building. However, as Plummer *et al* (2012) highlighted, a clear purpose is critical for assessing and evaluating the outcomes from adaptive co-management. This expansion to deeper and more explicit considerations for resilience building is timely, given the pace of Arctic climate change (e.g. IPCC 2019), the increasing demand for fisheries products at local (e.g. GN 2016) and global levels (e.g. Niiranen *et al* 2018, Naylor *et al* 2021), and thus the urgent need for management to cope, adapt, and transform in ways that ensure sustainable access to fish. As such, we revised each of the original steps with a resilience thinking lens. For instance, the action item of 'understanding resilience barriers and enabling factors' was included under step 3 (Design of resilience-building management actions). This was meant to ensure that, when developing new management actions, co-managers first aim to understand barriers to, and enablers of, resilience within their system so that the chosen actions do not unintentionally increase vulnerability. Opportunities for building resilience could also be jointly identified by co-managers during this step, by using the seven principles for building resilience (Biggs *et al* 2012, 2015). This could include, for example, monitoring and managing the diversity, redundancy, and connectivity that underpins productive fisheries. The original step 'design of alternative management actions' did not bring up the importance of considering the resilience implications of different management options, thus missing a critical dimension that could create risk in the system.

Finally, to prompt management improvements and inspire co-managers regarding the practice of adaptive co-management, we propose action items associated with the steps and based on examples from the literature review (table S8). The action items provide initial guidance for those involved in fishery co-management processes; they are intentionally broad so that they can adapt to local contexts. For instance, community-based monitoring efforts could investigate a range of social-ecological indicators, as well as the drivers affecting them and resilience factors that can mitigate these drivers (e.g. see Burgass *et al* 2019 for a good example of such social-ecological indicators). Participatory monitoring could examine barriers to, and enablers of, resilience. Along these lines, Whitney and Ban (2019) feature a concrete example of how stimulating participatory monitoring efforts can improve social-ecological resilience and adaptation to climate change in coastal British Columbia.

### 4.2. How is adaptive co-management applied in Nunavut?

Overall, Cambridge Bay and Pangnirtung in Nunavut are two examples of adaptive co-management of small-scale Arctic fisheries that provide important reference points for other Arctic fisheries to move towards adaptive co-management. Records of adaptive co-management were being featured in the Cambridge Bay Arctic Char fishery up to three decades ago (McDonald 1988, Kristofferson and Berkes 2005), and management is continuously progressing towards more adaptive and ILK-based approaches. This highlights how adaptive co-management of Arctic small-scale fisheries is a long-term journey requiring mutual trust, respect, joint effort, and co-learning among co-managers and resource users—a journey that will likely involve challenges and compromises. This journey also requires long-term commitment from all the actors involved, which is fundamental to building trust as well as strong, long-lasting relationships needed to jointly navigate adaptive co-management.

Indeed, while the two fisheries already featured some adaptive co-management steps and many resilience-building practices, assessing these cases also provided an opportunity to examine means of further improvement. For instance, the Ikaarvik youth recently developed the SciQ concept along with 45 recommendations for researchers to achieve more meaningful engagement with Inuit communities and IQ (Pedersen *et al* 2020). This stresses that improvements are required regarding how science interacts with IQ. Moreover, resilience building has yet to become a formal goal of adaptive co-management in these regions. For instance, while the Cambridge Bay fishery does feature resilience-building practices, the IFMP does not mention resilience explicitly (DFO 2014). Featuring resilience-building as an explicit goal of management would be important to formalize discussions and learnings on resilience barriers and enablers specific to that fishery and foster concrete actions to act upon them. For instance, deeper collaborations with IQ for monitoring and management would correspond to a resilience-building action, as knowledge plurality arose among the four resilience-building themes we identified.

### 4.3. Adaptive co-management suited to the multifaceted Arctic and beyond

Adaptive co-management is recognized as a multipurpose, flexible approach (Plummer *et al* 2012). Thus, we argue that it can be easily connected to, or merged with, different ways of conceptualizing social-ecological systems, resilience, and other management approaches. This is especially relevant in the multifaceted Arctic (e.g. Larsen and Fondahl 2015, Arctic Council 2016), where multiple socio-cultural contexts, knowledges, and management dynamics coexist and interact (e.g. management of other wildlife has implications for Arctic Char fisheries if people turn to more fishing in response to changes in other wildlife). For instance, we approached resilience through an overarching definition of social-ecological resilience including other ways of conceptualizing resilience, such as resilience of hunting skills and practice (Berkes and Jolly 2001), livelihood resilience (Nuttall 2007), and Indigenous resilience. The latter encapsulates how cultural factors such as knowledge and learning, along with the broader political ecology, determine how Indigenous Peoples understand, deal with, and adapt to environmental change (Ford *et al* 2020, Berkes *et al* 2021).

Furthermore, adaptive co-management can function in collaboration with other management approaches. Our proposed adaptive co-management steps build on and echo other guiding principles to improve resource management processes in the face of human-driven perturbations of ecosystems and natural resources, including the eight design principles for commons management (Ostrom 1990), the ‘ten commandments’ for ecosystem-based management (Francis *et al* 2007), and community-based monitoring (Danielsen *et al* 2020). Thus, while our resilience-based steps for adaptive co-management bring unique elements for managing resilient fisheries, they can easily function in synergy with other management schemes. For instance, adaptive co-management of Arctic Char fisheries could be connected to existing ecosystem-based management (Thrush and Dayton 2010, McLeod and Leslie 2009) such as the Integrated Ocean Management Plan for the Beaufort Sea (Beaufort Sea Planning Office 2009). Moreover, adaptive co-management is part of a continuum and can accommodate Indigenous communities whose ultimate aim is self-management, that is, communities having jurisdiction over the management of their resources in a process whereby power shifts from top-down to bottom-up and local stakeholders jointly learn how to fully take on research, monitoring and management tasks.

Adaptive co-management is thus adaptable to multiple contexts, making it especially appropriate to the multifaceted Arctic and beyond. However, flexibility also presents the risk of lack of clarity in goals, and thus difficulty in evaluating whether specific outcomes are attained, which can be a setback in adaptive co-management (Plummer and Armitage 2007). We thus propose a guideline for implementing adaptive co-management with the specific goal of building resilience—resilience being proposed as a unifying concept to orient and assess adaptive co-management outcomes (Plummer and Armitage 2007). While we conceptually developed the steps for guiding the management of small-scale Arctic fisheries in ways that build their resilience, we believe the steps could be applied to any co-management context in which drivers of change such as climate change and overfishing put fisheries at risk, and where different knowledge systems coexist.

## 5. Conclusion

The Arctic is undergoing major and rapid transformations, posing risks to small-scale fisheries that are crucial to Arctic Indigenous communities. Fostering resilience of fishery social-ecological systems through management, in ways that embrace complexity and uncertainty, will be fundamental to sustainability. Here, we first describe, through a literature review, how the notion of resilience has been used in Arctic fisheries management. Then, we propose steps to implement adaptive co-management with the explicit goal of building resilience in fishery social-ecological systems. Our expanded steps can guide co-managers, scientists, and stakeholders in their effort to monitor and sustainably manage fisheries in times of complex Arctic changes.

## Data availability statement

The supplementary material includes most information and data relevant to this paper. More information can be obtained from the corresponding author on reasonable request.


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