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Adapting to climate change in small-scale fisheries: Insights from Indigenous communities in the global north and south

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Abstract

Climate change is having a significant influence on global fish production as well as on small-scale fishers' livelihoods, nutrition, and food security. We compared two climate-sensitive small-scale fisheries (SSFs) – an Inuit community in the Canadian Arctic and the Coastal-Vedda in Sri Lanka – to broaden our understanding of how fisheries-dependent Indigenous communities respond and adapt to climate change impacts. We used three steps to achieve this comparative study. To do this, we developed a resilience-based conceptual framework to empirically assess adaptations in two SSF communities, based on a literature review. Using the proposed framework and collecting qualitative field data over three years (2016-2019) to investigate how different remote SSFs experience and respond to climate change, we assessed Inuit and Coastal-Vedda case studies. The framework provided the structure for data analysis and conceptual guidance for two empirical assessments and the comparative analysis. Finally, we carried out the comparative analysis across the case studies using content analysis, identifying adaptive strategies, sources of resilience, and characteristics of successful adaptation. Additionally, we used discourse analysis to develop sources of resilience and characteristics of successful adaptation. Two key adaptive strategies emerged in common across the two communities – diversification and adaptive co-management. Eight sources of resilience that underpin adaptive capacity: i) use of diverse kinds of knowledge; ii) practice of different ways of learning; iii) use of community-based institutions; iv) efforts to improve human agency; v) unique worldviews; vi) specific cultural attributes that keep up with adaptation; vii) effective social networks; and viii) a high level of flexibility.

Definitive characteristics that need to promote successful community adaptation: continuous learning through knowledge co-production; capacity-building to improve human agency; a place-specific nature (rootedness); collective action and partnerships through community-based institutions; and flexibility.

Keywords: Climate change, Inuit, Coastal-Vedda, Adaptation, Resilience, Adaptive capacity, Indigenous peoples

1. Introduction

Small-scale fisheries (SSFs) are mainstays of livelihoods and food systems in diverse regions globally. Adapting to rapidly changing conditions is a key challenge in fostering the sustainability of global SSF systems (d'Armengol et al., 2018, Chuenpagdee and Jentoft, 2019, Jentoft, 2019). Climate change is one of the most critical challenges that increase stress, randomness, uncertainty, and disorder in SSFs (Keys et al., 2019, Galappaththi et al., 2019a). The recent IPCC special report on the impacts of the 1.5°C global warming highlights the need for more policy attention on climate adaptation, particularly in fisheries and aquaculture (de Coninck et al., 2018, Galappaththi et al., 2020a). The report identifies the associated impacts of climate change that result in drastic changes in coastal resources and that reduce the productivity of aquatic systems. Beyond fishing, these changing SSF communities are meaningful 'places' to fishers, whose identities are shaped by an intimate relationship with nature as a means of earning a livelihood, shaping culture, and underpinning food security (Tschakert et al., 2019, Cunsolo-Willox and Ellis, 2018, Ford et al., 2020). In this context, adaptation efforts must focus on sustainable SSFs while addressing impending shocks and stressors and their undesirable consequences.

Successful adaptation to changing conditions requires a comprehensive understanding of the unique characteristics of communities and SSF systems (Osbahr et al., 2010, Adger et al., 2005). Adger et al. (2005) argued that adaptation operates at various spatial and societal scales, and that its success or sustainability depends on the capacity to adapt and on the distribution of the capacity within a society. Later, Osbahr et al. (2010) defined 'success' as those actions which promote system resilience and legitimate institutional change, and, hence, generate and sustain collective action in the context of evaluating livelihood adaptation to climate variability. More recently, Piggott-McKellar et al. (2019) identified the most common barriers to successful community-based adaptation to be cognitive and behavioral; government structure and governance; communication and language; inequality, power, and marginalisation; resources (finances, time, human resources, access to information and technology, infrastructure); and physical systems and processes. From this perspective, opportunities for successful adaptation and policy development in a broader SSF context warrant an advanced understanding of how different disadvantaged communities experience climate change and the ways in which they respond to it, across scales (Conway et al., 2019, Ford et al., 2018b). Given that aquatic food dependence among coastal Indigenous peoples worldwide is much higher than it is among non-Indigenous peoples (Cisneros-Montemayor et al., 2016), a broader understanding of climate adaptations among Indigenous populations is particularly important.

Our aim in this paper is to uncover a broader understanding of vulnerability and resilience processes with respect to climate adaptation in SSF at a community level to inform adaptation efforts. We refer to climate adaptation broadly as being about opportunities for building resilience in SSF and what ways make the community adaptation a reality (i.e., successful). To do so, this paper conducts a comparative analysis of the vulnerabilities and adaptive responses of two SSF communities (Sri Lankan and Canadian Arctic case studies). Comparative studies are a cornerstones of social science research yet have not been widely used in a climate adaptation or SSF context (Salas et al., 2018, Maru et al., 2014, Conway et al., 2019). The first two objectives of the paper are: (1) to compare and contrast the ways in which Inuit and Coastal-Vedda SSF systems experience and respond to change; and (2) to examine opportunities that can nurture successful adaptation in a SSF context. The next section illustrates how the comparative study took place, including the conceptual approach and the two case studies we used. The following section compares and contrasts the two case studies to understand how these identified changes experienced and adaptive responses of Indigenous fishers differ (or are similar) in the Canadian Arctic and Eastern Sri Lanka. Finally, the paper discusses sources of resilience, adaptive strategies, and the definitive characteristics of a successful adaptation process aimed at SSF.

2. Comparing global north and south communities in terms of adaptation opportunities

Comparative studies are used to test theoretical frameworks, refine concepts, and discover new relationships while contributing additional insights to individual cases studies (Lesnikowski, 2019). Individual case studies are key for developing theory and obtaining a deeper understanding of particular areas unique to individual cases (Ford et al., 2010). However, empirical case study comparisons are also important for examining how relationships change under different conditions, helping develop broader understanding (Dasgupta et al., 2007, Ford et al., 2018b, Maru et al., 2014). To date, in the growing adaptation literature, most comparative studies have focused on communities within one country (e.g., (Schmitt et al., 2013, Hung et al., 2018, Oviedo et al., 2016)). In this context, the broader applicability of the findings (i.e., scaling up) is unclear/unknown, which constrains efforts to develop resilience and adaptation in communities (Conway et al., 2019, Leite et al., 2019). In this comparative analysis, we examine the broader applicability of findings by assessing what is either different from or similar to other SSFs and by bringing more insights about adaptation across spatial (the Canadian Arctic vs. Eastern Sri Lanka) and temporal (over 30 years) dimensions (Maru et al., 2014).

To accomplish this comparative analysis, we used three steps. First, we proposed a resilience-based conceptual framework to assess place-based community adaptations to change in Indigenous fisheries systems (Galappaththi et al., 2019a). We used this framework throughout the knowledge production process to maintain conceptual consistency, maintain a place-specific focus, and provide guidance for the data analysis. Second, using the proposed conceptual framework, we examined two case studies based on fieldwork conducted between 2016-2019 in the Canadian Arctic (Galappaththi et al., 2019b) and Eastern Sri Lanka (Galappaththi et al., 2020b). Third, we carried out a comparative analysis across the case studies using manifest and latent content analysis supplemented with discourse analysis (definitions: table S1). The next section describes the conceptual framework used following the methods of two case studies and comparative analysis.

2.1 Conceptual framework

A place-specific resilience-based conceptual framework was developed, based on a literature review, to assess fisheries community adaptations (Galappaththi et al., 2019a). The framework conceptualises resilience as a function of coping, adapting, and transformative capacities, and its place-based nature is designed to be applied in diverse SSFs globally. The characteristics of the framework by which community adaptation is assessed, are: place, human agency, collective action and collaboration, institutions, Indigenous and local knowledge (ILK) systems, and learning (table 1). These framework characteristics provided the structure for data analysis and conceptual guidance for two empirical assessments as well as the comparative analysis; this helped maintain the focus on the community adaptation process rather than stability-oriented assumptions (figure 1). This framework was used to develop community adaptive strategies, the sources of resilience, and the characteristics of successful adaptation. Moreover, throughout the study, we adopt a social-ecological systems (SES) approach to recognise the integrated human and environment subsystems as a unit of study for this paper (Berkes et al., 2003, Berkes et al., 1998). This SES analytical construct was used to capture the complex and uncertain nature of SSF systems.

Table 1: Definitions of characteristics of the resilience-based framework ((Galappaththi et al., 2019a)).

Characteristic	Definition
Place	Social and physical space that has attachments to people and social processes. Attachment to place is understood as the bonding that occurs between people and their meaningful environments (for example, livelihoods, culture, and wellbeing).
Human agency	Human (individual or collective) capacity to act independently in making their own decisions as part of the process of their way of life.
Collective action and collaboration	Action taken together (or shared) by a group of two or more people to meet a common desired objective.
Institutions	Local organizations that facilitate collective action meeting a local goal (for example, co-managed institutions).
ILK systems	Co-evolving cumulative body of knowledge (including observations, experience, lessons, and skills) belonging to a specific group of people and their resource management systems (or a place) and handed down through generations by cultural transmission; reflects the cultural identity.
Learning	Social learning, which itself refers to collective action and reflection that occurs among specific group of people as they work to improve the management of human-environment interactions.

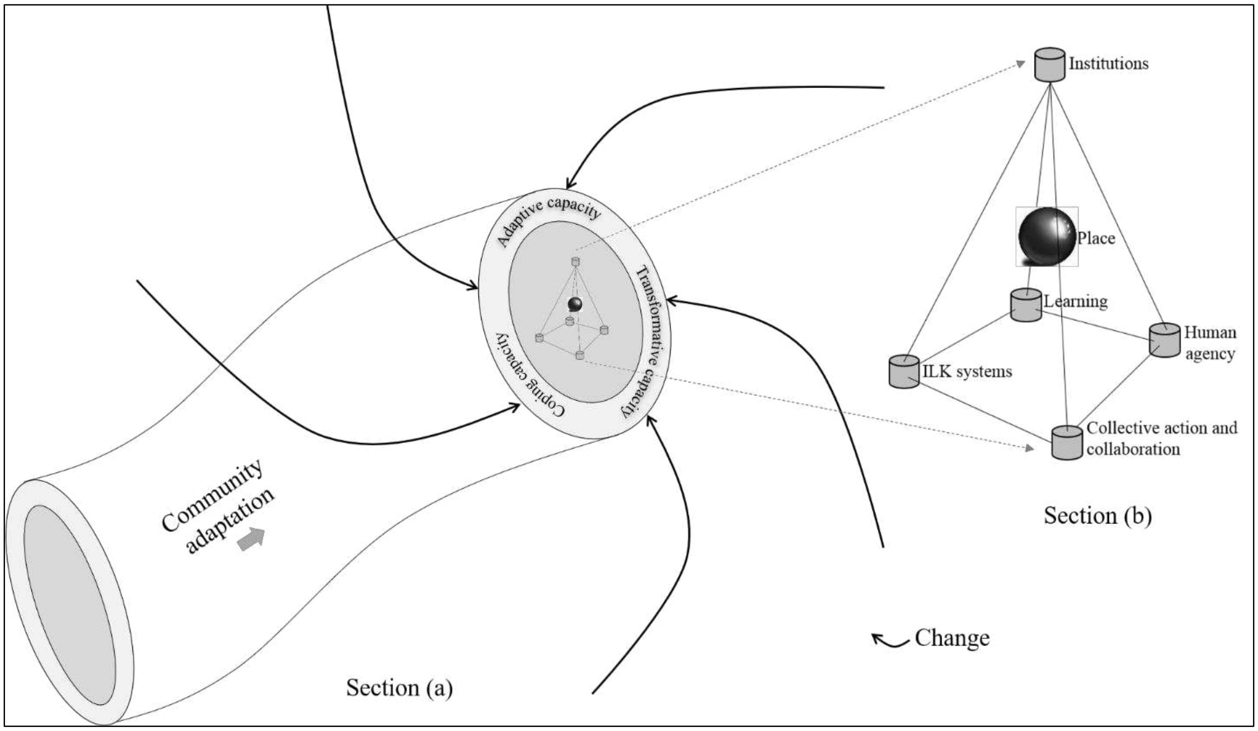


Figure 1: Conceptual framework for comparative analysis (building on (Galappaththi et al., 2019a)).

Section (a) shows the white tube-shaped object that represents the community adaptation process over time. The curved arrows pointing at the community, illustrate the specific changes (internal or external) that affect the community. The outer layer of the community adaptation process represents the resilience capacities (coping, adapting, and transforming). The core of the adaptation process is a pyramid-shaped network of place-based elements (or framework characteristics as in table 1), which is enlarged in section (b).

2.2 Assessing community adaptations in the Canadian Arctic and Eastern Sri Lanka

The same conceptual and methodological framework guided both case studies. Two regions (the Arctic and tropics) were chosen to investigate how different remote SSFs experience and respond to climate change (figure 2). Two Indigenous communities were strategically chosen considering the high level of fisheries activities in which they engaged and the feasibility of data collection. Fieldwork was conducted over three years in the communities of Pangnirtung (Canadian Arctic) and Kunjankalkulam (eastern Sri Lanka), using multiple data collection methods supplemented with a community-based participatory approach (Magee, 2013). First, we used participant observations to examine the Indigenous way of life, which included spending an extensive amount of time interacting with Inuit (over 14 weeks) and Coastal Vedda (over 24 weeks) fishers (for example, attending community events, meetings with local institutions, and going on fishing trips).

Second, semi-structured interviews were conducted with Inuit fishers (n=62) and Coastal-Vedda fishers (n=74) to document the changes being observed in the region, and to identify and characterize the response to them. The semi-structured questioning focused on “change” in general so as not to insert bias into the interview and to keep interviews open-ended, focusing on the issues and changes that Indigenous fishers viewed as most important. All the interview questions related to ‘change’ referred to “about 30 years back” in fishers’ lives in the geographical area of the particular region. Third, key informant interviews were conducted with individuals related to Inuit fisheries (n=25) as well as Coastal-Vedda culture-based fisheries (n=38), to examine areas of specific knowledge that were not accessible via fishers (for example, fisheries market information, government subsidy programs, non-government programs, fisheries co-management). Finally, focus group discussions were carried out in the Arctic (n=6) and in Sri Lanka (n=17) to build thematic areas related to changes that fishers experience and to the key ways in which fishers respond to such changes. The data from both case studies were analysed using ‘manifest’ and ‘latent’ content analysis supplemented with ‘discourse’ analysis to develop themes and patterns related to the ways in which Indigenous fishers experience and respond to change. Full methodological details are provided in the published articles focusing on each case study (Galappaththi et al., 2019b, Galappaththi et al., 2020b).

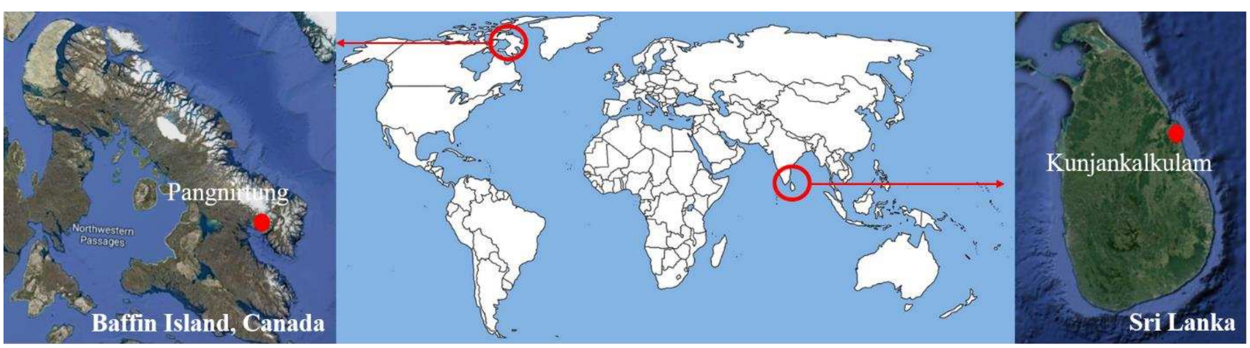


Figure 2: Two case study regions: Pangnirtung Inuit community (Canadian Arctic) and Kunjankalkulam Coastal-Vedda community (Eastern Sri Lanka).

Pangnirtung (population: 1,481) is one of the few communities in Nunavut territory that has significant commercial and subsistence fishing activities. The Inuit-owned fish processing plant (Pang Fisheries Ltd.) is located in the community and facilitates key fisheries, which are on Arctic char (*Salvelinus alpinus*) and turbot (*Reinhardtius hippoglossoides*). They co-exist with subsistence fisheries. About 90% of turbot products are exported to eastern Asia, including South Korea, Japan, Taiwan, Vietnam, and China. This Inuit fisheries system is undergoing rapid change related to: sea-ice conditions, the people themselves, the landscape and seascape, fish including Arctic char, turbot, and capelin (*Mallotus villosus*), the weather conditions, and fish selling prices and markets. We examined how Pangnirtung Inuit respond to identified changes; for example, the use of advanced technology, food sharing culture, use different kinds of knowledge systems, Inuit owned local institutions, learning opportunities (Galappaththi et al., 2019b) (section S1).

Kunjankalkulam Coastal-Vedda is one of the few groups in the region that has a higher level of fisheries activities while maintaining its identity (less integrated with the majority Tamil and Muslim populations). Coastal-Vedda use a village tank (reservoir) to rear fish (i.e., culture-based fisheries--CBF[1]) as a primary year-round livelihood activity. With the support of the government, fisheries and aquaculture institutions, and NGOs, an annual stock of various fish fingerlings (for example, tilapia, carp, endemic fish species, and freshwater prawn) grows in a natural reservoir system without the need for artificial feed. This CBF consists of two types of fishing activities: during the day, fisherwomen walk into the water using fishing rods for subsistence fishing; and in the early morning (2-3 am), fishermen go fishing in deep areas of the reservoir, using canoes and gill nets, and selling to fish buyers every morning. Key changes identified in this fisheries system were related to: Sri Lankan civil war, extreme weather, natural disasters, human-elephant conflicts, unpredictable nature of weather patterns, and social pressure from modernization. The responses of Coastal-Vedda respond to identified changes include, livelihood diversification, practice collective action through multi-level institutional structures for fisheries co-management, and use different kinds of knowledge systems (Galappaththi et al., 2020b).

2.3 Comparative analysis

For the comparative analysis, we used content analysis to assess the qualitative data of both case studies (Berg, 2016). The key techniques we used were ‘manifest’ and ‘latent’ content analysis (Krippendorff, 2018) supplemented with discourse analysis (Fairclough, 2013) to develop common themes, patterns, and correlations related to the ways in which fishers experience and

[1] CBF are essentially a form of extensive aquaculture, or a farming practice, conducted in small water bodies (generally less than 100 ha).

respond to change. We used coded data and fishers' quotes (from individual case study analysis) to compare resulting changes (shocks and stressors) and adaptive responses in the two different SSF systems throughout three decades. We also freshly coded the adaptive-strategies-related data (obtained during previous steps) to understand the most common and generalizable adaptive strategies in SSF. We compared and contrasted the coded information and themes from two case studies using various tables and institutional diagrams to identify the patterns, causes and effects, and linkages related to community adaptation that builds resilience and reduces vulnerabilities to change. The calibration of coded information was supplemented with feedback from the community representatives in the Canadian Arctic and Sri Lanka (i.e., member checking). This knowledge co-production was the result of a complex iterative process between the researcher and the partner communities. The comparison was guided under each of the characteristics of the resilience-based framework (place, human agency, collective action and collaboration, institutions, knowledge systems, and learning) to create an understanding of the relevance of such characteristics to resilience building and adaptation. The eight key sources of resilience, two adaptive strategies, and five definitive characteristics of a successful adaptation process were derived through iterative inductive reasoning (Rihoux, 2006, Vaismoradi et al., 2016) to generate knowledge that supports successful adaptation in SSF communities and effective policy development.

To develop the eight sources of resilience, we brought up three different forms of analysis, combining: theory, coded data, and field evidence (figure S1). The first form of analysis is the characteristics of the conceptual framework (i.e., place, human agency, collective action, institutions, knowledge systems, and learning) (Galappaththi et al., 2019a) and specific resilience literature that can guide the analysis (e.g., (Folke et al., 2003, Galappaththi et al., 2019c)). The second form of analysis is the coded materials of comparative analysis that represent both Inuit and Coastal-Vedda data. We started further examining, reorganizing, combining, breaking down, and summarising the coded material (Strauss, 1987, Strauss and Corbin, 1990). Two fundamental questions that guided this process were: 1) How do fishers minimize vulnerability, and 2) How do fishers build resilience? From this analysis, we developed various themes related to the conceptual framework and specific sources of resilience literature (i.e., the first form of analysis) and the third form of analysis. The third form of analysis was the field data from each case study (e.g., interview transcripts, quotes, photos, videos, voice recordings, and the field diary). Bringing together these three forms of analysis and their interpretations, we came up with the eight sources of resilience. We achieved member checking with the community representatives of both the Canadian Arctic and Sri Lanka.

To identify the five definitive characteristics of the successful adaptation, we used an approach similar to that used to develop the sources of resilience. We combined three different forms of analysis, i.e., theory, coded data, and field evidence (figure S1). For the first form of analysis, we used the conceptual framework and specific literature about the successful community adaptation (e.g., (Adger et al., 2005, Osbahr et al., 2010, Piggott-McKellar et al., 2019)). Based on the literature, we argued that successful adaptation should: bring equitable benefits and opportunities to Indigenous fisher communities, and build resilience in the areas of food security, nutrition, and sustainable livelihoods. For the second form of analysis, we further examined, reorganized, combined, and summarized the coding material related to the eight sources of resilience (Strauss, 1987, Strauss and Corbin, 1990). The key question guiding this analysis is what successful adaptation means for Indigenous fishers. To examine this key question, we used three steps: 1) identification of the characteristics that make the community more resilient (when the features are present or practice), 2) identification of characteristics that weaken community resilience (or increase vulnerability) with the absence, and 3) identification of the overlapping features of steps 1 and 2. From this analysis, we developed themes related to the field evidence from both Indigenous communities. This third form of analysis included the field data, such as the interview transcripts, quotes, photos, videos, voice recordings, and field diary. Bringing together all three analyses and their interpretations, we developed various definitive characteristics of successful adaptation. These characteristics were member checked by both the Inuit and Coastal-Vedda communities. As a result of this iterative process, five characteristics were selected.

3. Results: Comparative analysis

This section illustrates a comparison of the Inuit and Coastal-Vedda fisheries systems, examining how these identified changes experienced and adaptive responses of Indigenous fishers differ (or are similar) in the Canadian Arctic and Eastern Sri Lanka. The next section compares the changing fisheries systems following the adaptive responses. Finally, this section identifies and compares the adaptive strategies and place-specific attributes.

3.1 Changing SSF systems

The Canadian Arctic and eastern Sri Lanka are specifically different SSF systems (geographically, climatically, and socio-economically). Inuit experience climate change impacts as a way of changing biophysical (sea-ice conditions, landscape, fish) and socioeconomic environments (Inuit, fish markets/price). Coastal-Vedda are affected mainly by sociopolitical changes (war and social modernization) and climate extremes (tropical storms, droughts). The Arctic capture fishery functions within the limits of climatic-seasonality (winter, spring, summer, and fall), whereas Sri Lankan aquaculture is subject to unexpected extreme events driven by monsoons and the dry conditions of the region (Bay of Bengal). Climate change is very relevant with respect to changes in Inuit SSF given the magnitude of the climate change signal in northern Canada (Ford et al., 2018a), whereas climate change is not as prominent at present for the Coastal-Vedda SSF. For example, most of the stressors that Inuit experience are due to global warming impacts that create internal changes within Arctic SSF systems (sea-ice conditions, landscape and seascape, fish species—char, weather conditions). The stressors of Coastal-Vedda are due mainly to external drivers such as civil war, natural disasters and climate extremes, wild elephant attacks, and social modernization. Yet, the nature of the implications (how stressors affect fishers' way of life) is common to both SSF systems. For example, shorter fishing seasons, impediments to fish growth, safety concerns, damages to infrastructure, and limited access to travelling (including to fishing areas) are changing the fishing way of life (table 2).

Table 2: Comparison of implications of change affecting Indigenous fisher populations in different SSF systems.

Drivers behind change	Nature of change related to	Implications of change	
		Inuit	Coastal-Vedda
Climate-change-related impacts	Weather (temperature, winds, storms, droughts)	-Shorter fishing seasons -Safety concerns while traveling on ice -Constrained access to fishing areas -Affected fish aging process and seasonality -Damaged infrastructure including housing, trails, roads	-Shorter aquaculture season -Limited fish growth -Decrease in fishing days due to extreme weather -Constrained access (eroded gravel roads)

	Natural environment (animals, forest, snow and ice, glaciers)	-Lessening aesthetic value of the community -Inuit perceptions about reducing char fish population	-Unsafe and high-risk living environment due to wild elephants and lack of drinking water and infrastructure -Damaged infrastructure including housing
Modernisation and globalisation	People	-Weaker bonding among family members -Lessening of workdays as their health does not allow them to engage in fishing activities	-Adoption of new lifestyle (cash economy, aquaculture, cement housing); locals positioned between 'traditional' and 'modern'—middle of social transformation
Global change and modern-day colonialism	Socio-economic and political	-Shrinking Arctic char market portfolio in fish plant	-Loss of livelihoods (chena cultivation, cattle, hunting) -Loss of lives (during the war)

3.2 Adaptive responses of SSF systems

We compare and contrast the adaptive responses to change of Inuit and Coastal-Vedda SSF systems, using the characteristics of the resilience-based framework. These characteristics are place, human agency, collective action and collaboration, institutions, knowledge systems, and learning (table 3).

Table 3: Comparison of adaptive responses using characteristics of the framework.

Characteristics	Areas of adaptive responses	Responses to systems change	
		Inuit	Coastal-Vedda
Place	Fishery	Two co-existing (wild capture fisheries)	Reservoir aquaculture (culture-based fishery)
	Types of fisheries	Subsistence and commercial	Subsistence and commercial
	No. of fish species	Two	Eight
	Food diversity (protein supply—number of edible animals accessible throughout the year)	n=20	n=9

Human agency	Use of advanced technology	GPS, VHF radios, advanced rifles (84%)	Not observed and couldn't measure
	Livelihood diversity (number of livelihood activities involved—occupational multiplicity)	n= 6	n=11
	Access to number of assets needed for fishing activities	x= 3.8, s=1.1 (relatively high)	x= 2.3, s=0.9 (relatively low)
	Fishing gear diversity (access to number of different fishing gear)	x= 4.0, s=0.9 (relatively high)	x= 3.2, s=1.8 (relatively low)
	Access to loans	Via Fish Plant and Nunavut government	Via informal money lenders
Collective action and collaboration	Sharing fish	Observed in subsistence fishery	Observed in subsistence fishery
	Sharing fishing gear	Observed	Observed
	Sharing of weather information	Through internet and social media	Internet not available
	Sharing of information related to fishing operations	Observed in commercial fishery	Observed in commercial fishery
	Social networks	Through internet-based social media and community radio	Face-to-face small-group informal discussions
	Level of use of collective action for problem-solving	Observed	Often use (for example, local institutions)
Institutions	Fishery management approach	Co-management	Co-management
	Key local institution	HTA	RFO
	Structure	Multi-level	Multi-level
	Way of functioning	Mostly top-down	Mostly bottom-up
	Adaptive nature in functionality	Flexibility observed	Flexibility observed
ILK systems	Identified knowledge areas	Arctic char, turbot, fishing techniques, fish processing, local environment knowledge	Reservoir fishing spots, aquaculture, weather predictions, collective action, climate adaptation, disaster/ emergency situations, wild elephants
	Level of application of ILK	Some aspects of ILK identified are not used anymore	Used all ILK identified (loss of some traditional knowledge)

	Weakening of knowledge systems	Observed	Observed
	What bridges the weakening knowledge gap	Advanced technology	Knowledge of aquaculture and climate adaptation
Learning	Level of diversity of learning opportunities	Relatively less diverse opportunities	More diverse learning opportunities
	Key ways of learning (top three)	From elders/parents/extended family members (84%), learning-by-doing (13%), via internet, via school education	Learning-by-doing (65%), via local institutions (53%), via stakeholder institutions (32%), from parents and elders (28%)

3.2.1.1 Place

Inuit have co-existing wild capture fisheries of arctic char and turbot in the Arctic, whereas Coastal-Vedda engage in reservoir aquaculture (culture-based fishery). Both fisheries systems incorporate subsistence and commercial fisheries. This co-existence with commercial fisheries provides an opportunity for fishers to increase their adaptive capacity by improving their earning potential and food security to cope with the SSF systems' randomness. The process of maintaining co-existing fisheries could be considered an adaptive response to change, as it requires intentional and substantial human effort. For example, the co-existing fisheries are essential for Inuit food security—now more than ever after the caribou out-migration.

Also, in terms of food security, Inuit have access to more than 20 Arctic animal species including char and turbot, while Coastal-Vedda have access to about nine edible species including seven aquaculture species. In this context, Inuit and Coastal-Vedda have close, meaningful relationships to their 'place' or natural environment (for example, forest, mountains, coast, sea, lagoon, and reservoir); place attachment, the associated Indigenous culture, and their worldviews substantially influence ideas about adapting to change and staying within the community while dealing with challenges.

3.2.1.2 Human agency

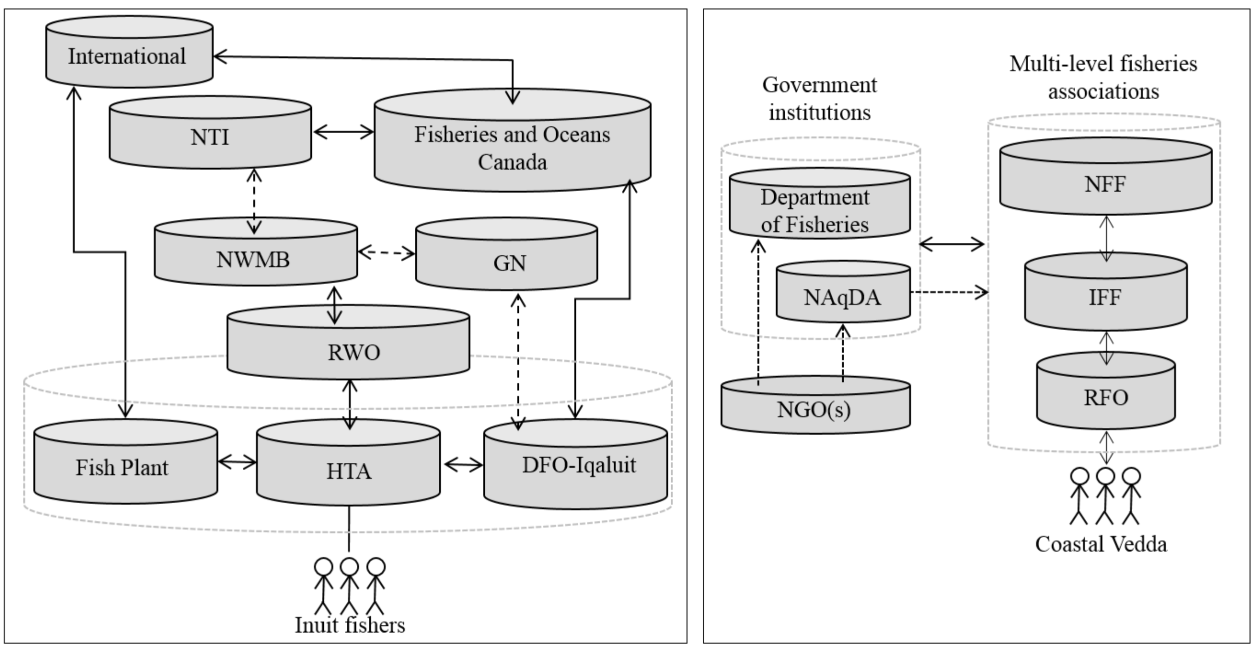
Our case studies possess different levels of human agency, yet both Indigenous populations are adapting to specific changing conditions in their SSF systems or 'place'. A key distinction we identified is the Inuit adoption of new technologies for their SSF; however, we did not observe a considerable use of technology in Coastal-Vedda aquaculture. A majority of Inuit fishers use GPSs, VHS radios, and advanced rifles in their fishing and hunting operations to overcome daily challenges such as unexpected weather and navigational challenges as well as to stay connected to the community for safety and operational purposes. Based on the measure of occupational multiplicity, however, Coastal-Vedda show higher livelihood diversity (for example, home gardening, animal rearing, and collecting wild honey and fruit), which improves their food/income options for survival. In terms of fishing activities, Inuit show higher fishing gear diversity and access to assets required for fishing operations. Moreover, both fishing populations have access to loans and financing mechanisms that support their fishing activities through government programs (Inuit and Coastal-Vedda), fish plant (Inuit), NGO programs (Coastal-Vedda), and informal money lenders (Coastal-Vedda).

3.2.1.3 Collective action and collaboration

Collective action and collaboration are common phenomena among both SSF. For instance, in Indigenous subsistence fisheries, both communities widely share fish for food purposes. The sharing of fishing gear is observed at different levels within the commercial as well as subsistence fisheries in both SSF. In commercial fisheries, both Inuit and Coastal-Vedda share specific information that is required for fishing operations. The use of the internet and community radio to share weather-related information and for social networking is a distinguishing characteristic of Inuit capture fisheries. Coastal-Vedda do not have access to the internet; nonetheless, social networking and the sharing of specific fisheries information takes place through face-to-face informal gatherings in specific places within the community. These kinds of informal gatherings are also observed among Inuit. For example, just before Inuit leave for turbot fishing, they meet and do some planning and information sharing in specific places. Overall, collaboration is a common practice in both SSF systems, whereas collective action is widely practiced by Coastal-Vedda to deal with common challenges in their Indigenous way of life.

3.2.1.4 Institutions

Inuit and Coastal-Vedda SSFs use institutions with multi-level structures for fisheries co-management (figure 3). Both settlements each have a key community-level institution that is the focus of attention: the HTA (Hunters and Trappers Association) for Inuit and the RFO (Regional Fisheries Organization) for Coastal-Vedda. These multi-level institution structures consist of mixed institutions; for example, the Inuit structure represents government, private, and communal institutions whereas the Coastal-Vedda structure consists of government, NGO, and communal institutions. Also, these multi-level structures have specific institutions/leadership that lead the co-management process (Gutiérrez et al., 2011)—for example, the combination of HTA, DFO, and NWMB in Arctic char fisheries and RFO, NAqDA, and NGO(s) in Sri Lankan reservoir aquaculture add on adaptive capacity to their SSFs. In terms of the nature of operations and decision-making related information flow, the Arctic institutional structure mostly works top-down while the Sri Lankan structure has a bottom-up approach. Yet, both co-management institutions show flexibility in terms of adapting to challenges and uncertainties produced by shocks and stressors, such as climate change impacts. Table 4 offers a detailed comparison of the two fisheries governance approaches.



(a) Co-management structure for Pangnirtung Arctic char and turbot fisheries

(b) Co-management structure for Kunjankalkulam reservoir aquaculture

Figure 3: Comparison of Inuit and Coastal-Vedda fisheries governance structures (building on Galappaththi et al., 2019b and Galappaththi et al., 2020b)

HTA (Hunters and Trappers Association); DFO (Department of Fisheries and Oceans); RWO (Regional Wildlife Organization); NWMB (Nunavut Wildlife Management Board); GN (Government of Nunavut); NTI (Nunavut Tunngavik Incorporated); RFO (Rural Fisheries Organisation); IFF (Inland Fisheries Federation); NFF (National

Fisheries Federation); NAqDA (National Aquaculture Development Authority); NGO (non-governmental organisations). Solid-line arrows represent the inter-institutional links for fisheries and aquaculture management-related aspects and dotted-line arrows represent the links for financing-related aspects.

Table 4: Comparison of characteristics in fisheries governance context.

Area	Features of fisheries governance system	
	Inuit	Coastal-Vedda
Approach	(Adaptive) Co-management of Arctic char and turbot fisheries	(Adaptive) co-management of reservoir aquaculture
Partnerships	DFO, HTA, and NWMB directly co-manage Arctic char and turbot fisheries, while NTI, GN, and RWO are also partners in the decision-making process. An Inuit-owned private-entity fish plant informally has a large influence on the co-management process.	NAqDA and RFO directly co-manage reservoir aquaculture, while multiple NGOs and other government (Department of Fisheries) and aquaculture industry associations (IFF and NFF) are also influential in the process.
Mixed regime	Government, private, communal	Government, NGO, communal
Vertical and horizontal linkages	Both vertical and horizontal linkages are active within the mixed regime. For example, the federal government (DFO) and community organisations (HTA), with the support of private sector industry organisations (fish plant), horizontally connect for fisheries management while provincial government (GN/NWMB/RWO) entities vertically connect to support decision-making.	Both vertical and horizontal linkages are active within the mixed regime. For example, government institutions (NAqDA, Department of Fisheries), NGOs, and aquaculture industry associations (RFO) connect horizontally for community aquaculture management while aquaculture industry associations connect vertically for aquaculture development.
Sharing of responsibility, authority, and power	The community organization HTA is the co-management licence holder for Arctic char and turbot fishing. For example, the HTA uses a lottery system to make decisions about issuing licences for commercial char fishing.	Government, NGOs, and the RFO together share the responsibility for funding reservoir aquaculture. Administrative power is shared among government institutions (operating license through NAqDA and canoe registration through the Department of Fisheries) and RFOs (landing-site management).
Learning-by-doing	Considering the size of fish populations and migratory patterns, the fish quota will be reviewed annually based on the best available	Particularly at the RFO level Coastal-Vedda continuously research fishing spots, the time of fingerling stocking, locations for the pen

	science and Indigenous and local knowledge. Community fishers are part of the fish population monitoring program.	culture, and setting nets for commercial fishery, and learn from trial and error while dealing with change.

3.2.1.5 Indigenous and local knowledge systems (ILK)

Inuit and Coastal-Vedda possess diverse ILK systems. For example, Inuit hold ILK related to Arctic char, turbot, fishing techniques, fish processing, and local environment knowledge, whereas Coastal-Vedda' practice ILK related to reservoir fishing spots, aquaculture, weather predictions, collective action, climate adaptation, disaster emergency situations, and wild elephants. Both SSF systems have experienced a weakening of their ILK systems while adapting to change over the last three decades (Galappaththi et al., 2019b, Galappaththi et al., 2020b). In terms of application, some aspects of Inuit ILK are no longer used but knowledge still exists among Inuit. Coastal-Vedda believe that they have already lost some traditional practices (capture fishery/hunting and equipment such as the bow and arrow). However, Coastal-Vedda are currently practicing all the components of ILK identified in the Sri Lankan study. The new knowledge of advanced technology (particularly among young Inuit) could bridge the knowledge gaps resulting from a weakening of Inuit ILK systems. Knowledge of aquaculture and climate adaptation in the Coastal-Vedda setting could bridge SSF knowledge gaps due to a loss of old hunting/fishing knowledge. A combination of different kinds of knowledge systems (that evolve over the generations) is essential to the fishing and hunting lifestyle of both Indigenous groups. We recognised both ILK systems as sources of resilience for their SSF, and as a means of measuring the understanding of adaptation as they underpin adaptive capacity to deal with change (Folke et al., 2003).

3.2.1.6 Learning

We compare the learning opportunities to foster adaptation and resilience building, which are available and currently practiced in each fisheries system, as a means of dealing with the change. Key ways of learning for Inuit fishers are through elders/parents/extended family members, learning-by-doing, the internet, and school education. Coastal-Vedda possess more diverse learning opportunities in an aquaculture setting: learning-by-doing, local and stakeholder institutions, and parents and elders. Learning from elders, parents, and extended family members is the most common means of learning among Inuit, while learning-by-doing and learning through institutions are the most popular means of learning among Coastal-Vedda. Both SSF communities building resilience to adapt to changing conditions through learning as a part of knowledge (ILK) co-production process.

3.3 Adaptation strategies and place specific attributes

Overall, diversification is a common strategy among Inuit and Coastal-Vedda that allows them to increase the range of options available for dealing with change and building adaptive capacity. SSF systems-specific adaptive strategies use advanced technology (Inuit) and aquaculture (Coastal-Vedda). Also, a multi-level institutional structure that facilitates collective action, co-learning, and knowledge sharing is another strategy in Sri Lanka. Co-management is a common approach practiced by Inuit and Coastal-Vedda; however, it is a particularly well-established adaptation strategy in the Inuit SSF setting for use in managing changes in capture fisheries. In addition to adaptive strategies, we compare place-specific attributes that shape the community adaptation process. Inuit and Coastal Vedda possess unique worldviews and ILK systems that support adaptation (table 5). Inuit owned institutions (fish plant) and culture (sharing and collaboration) are other attributes of Inuit fishers that improve their systems' resilience. The co-management approach for aquaculture and Coastal-Vedda's flexibility in switching between different adaptive responses are attributes that advance adaptation in the Sri Lankan culture-based fisheries system.

Table 5: Adaptation strategies and place specific attributes.

Response type	Inuit	Coastal-Vedda
Adaptation strategies	Diversification	Diversification
	Advanced technology	Aquaculture
	Co-management	Multi-level institutional structure
Place-specific attributes	Unique worldviews	Unique worldviews
	Indigenous and local knowledge systems	Indigenous and local knowledge systems
	Inuit-owned institutions	Flexibility in switching between different adaptive responses
	Culture (sharing and collaboration)	Co-management approach

4. Discussion

Using a common framework, we carried out a comparative analysis of two case studies (Inuit of Canadian Arctic and Coastal-Vedda of Sri Lanka) to examine the changes (shocks and stressors) they experience, and their adaptive responses, to develop an understanding of opportunities for climate adaptation in SSFs. This idea of the comparison of case studies can be found in other climate-sensitive resource systems around the world (e.g., Maru et al. (2014). Conway et al. (2019)). It is essential to deepen the understanding of the characteristic features of the ways in which people experience climate change (i.e., vulnerabilities) and possible responses (i.e., adaptations) in remote SSFs in particular. In the discussion we examine how these responses serve to broaden understanding of successful adaptation at the community level, and can build resilience at a much broader scale.

Both the Arctic and Sri Lankan cases show parallels in the way in which SSFs experience change. We identified four characteristics of the nature of climate change impacts in SSFs: i) SSF systems are undergoing multiple stressors simultaneously (integrative vulnerability) (Debortoli et al., 2019); ii) The implications of climate impacts affect people in mixed/interrelated ways combined with other non-climatic changes—intertwined nature (e.g., sea-ice conditions, markets and fish price changes in the Canadian Arctic); iii) People themselves are changing (e.g., culture, economy, lifestyle) over time with the changes in SSF systems; and iv) Changes associated with rural SSF are linked to other distant systems including markets and economies (e.g., Asian fish market for Arctic turbot). These characteristics reconfirm the documented climate impacts in other resource systems in both Arctic and tropical settings (Ford et al., 2019, Arctic Council, 2016, Chen and Mueller, 2018).

We also identified two major contextual differences associated with the nature of climate impacts in SSFs. First, climate change is one of the many drivers of changing SSFs. Climate change creates more vulnerabilities in Arctic SSFs and it has received much attention from Inuit and researchers worldwide (Ford et al., 2016, Pearce et al., 2015, Overland et al., 2014). Meanwhile, the Coastal-Vedda, because they have been concerned with civil war and natural disasters (e.g., tsunami), have focused relatively little attention on climate change in an aquaculture context. Second, Indigenous SSFs regularly experience climate change impacts but locals do not always perceive climate change as a key vulnerability depending on the context. Many of the changes related to climate change are clearly noticeable in Arctic fisheries due to evident changes in a physical environment (e.g., sea-ice) (Ford et al., 2019, Nichols et al., 2004). However, in some tropical SSFs, including in the Sri Lanka case study, it is not clearly visible until perhaps the fish harvesting stage. There is a risk of hidden vulnerabilities (e.g., ocean acidification) (Speers et al., 2016, Lam et al., 2016).

After examination of adaptive responses across case studies, we identified eight sources of resilience that minimise vulnerability and build adaptive capacity to climate change impacts (table 6). These are: i) use of diverse kinds of knowledge; ii) practice of different ways of learning ; iii) use of community-based institutions; iv) efforts to improve human agency; v) possession of unique worldviews; vi) holding of specific cultural attributes to keep up with adaptation; vii) effective social networks; and viii) a high level of flexibility. These proposed sources nearly overlap with the principles introduced by other scholars to improve the resilience of changing social-ecological systems (Folke et al., 2003, Huitric et al., 2016, Biggs et al., 2015). For example, the use of diverse knowledge bodies for learning is one of the key ways of building resilience in major assessments such as the Arctic Resilience Report (Arctic Council, 2016).

These eight sources of resilience can be recognised as distinct but interrelated ways of supporting adaptation to the impacts of climate change in SSFs. Yet, we are not arguing that Inuit and Coastal-Vedda communities are utterly sustainable. Factors including an inequitable distribution of benefits among fishers/families, power imbalances, and irreducible uncertainties can affect the resilience of SSF systems (Nolan, 2019, Klain et al., 2014). Rural SSF systems are relying on specific-distance economic and market systems to maintain local fisheries activities, which may involve uncertainty and indicate that they are not completely self-sustaining (Bennett et al., 2020). For instance, the Arctic turbot fishery relies mostly on the Asian export market, whereas Coastal-Vedda reservoir aquaculture relies partially on NGO funding support for reservoir aquaculture. However, the combined result of identified sources of resilience could greatly nurture community adaptations to climate change in SSF and Indigenous settings.

Table 6: Sources of resilience in changing SSFs in an Indigenous context.

Source of resilience	Description and examples	References

Use of diverse kinds of knowledge systems for daily fishing activities	Inuit use knowledge about fishing spots, turbot fishing techniques, fish processing knowledge, marketing knowledge, and local environmental knowledge. Coastal-Vedda use knowledge about reservoir aquaculture operations, weather predictions, collective action, and climate adaptation actions. Both fisher populations in a group setting work together and combine and co-produce new knowledge.	(Armitage et al., 2011, Folke et al., 2003, Galappaththi et al., 2019c)
Practice of different ways of learning opportunities to foster adaptive learning	Key ways of Inuit learning are: elders, parents, and extended family members; learning-by-doing; the internet; and school education. Coastal-Vedda learn mainly from learning-by-doing, via local/stakeholder institutions, parents, and elders. Both communities are co-learning.	(Tschakert et al., 2014, Armitage et al., 2011, Berkes and Turner, 2006)
Use of community-based institutions to cope with common challenges and fisheries management	The purpose of local institutions is to successfully confront common challenges and resource management. Coastal-Vedda use fisheries organisations to attract resources for continuing reservoir aquaculture operation and regular aquaculture management. Inuit possess fisheries management units (Hunters and Trappers Association) as well as Inuit-owned entities (Fish Plant) to maintain their co-existing char and turbot fisheries.	(Fidelman et al., 2017, Berkes and Armitage, 2010, Ostrom, 1990)
Efforts to improve human agency to build adaptive capacity	Building capacity through livelihood diversification (Coastal-Vedda) and the use of advanced technology for fisheries activities (Inuit) is evident. Both Indigenous groups build adaptive capacity through local institutions by collective action and collaboration.	(Brown, 2016, Brown and Westaway, 2011, Galappaththi et al., 2019a)
Unique worldviews that encourage living with the changing conditions and adapting	Both Indigenous fishers learn to live with change and uncertainty rather than try to migrate or quit. Both Inuit and Coastal-Vedda have strong attachments to place and people. These worldviews allow them to deal with change over time and to cope with, adapt to, and sometimes transform (Coastal-Vedda) certain aspects of their SSF.	(Adger, 2016, Amundsen, 2015, Kaján, 2014)
Specific cultural attributes such as	Collaboration, sharing, and collective action are specific attributes of Indigenous people’s culture. These aspects will improve social equality and cohesion through the sharing and transferring of adaptive	(Ostrom, 2014, Adger,

sharing, collective action, and collaboration	capacity within the community. An example is the sharing of a fish harvest with Inuit/Coastal-Vedda elders who are incapable of hunting/fishing.	2003, Galappaththi and Berkes, 2015a)
Effective social networks that lubricate specific information-sharing processes that are mandatory for fishing activities	Indigenous fishers use various forms of networking that improve effective fisheries-related information sharing. For instance, Inuit use internet-based social media for weather and fishing spot updates. Further, both Inuit and Coastal-Vedda rely on informal social gatherings to share information including fish prices and warnings about animals (polar bears in the Arctic/wild elephants in Sri Lanka).	(Orchard et al., 2015, Alexander et al., 2015, Galappaththi et al., 2016)
Flexibility with which SSF systems can switch between different adaptive responses or engage in multiple responses as appropriate to adapt to changing SSF conditions	Both Inuit and Coastal-Vedda SSF systems have the flexibility to engage in multiple adaptive responses or switch between different responses. For instance, most Inuit are involved in Arctic char and/or turbot fisheries. Further, most Coastal-Vedda switch between multiple income activities as livelihood options and have a range of aquaculture options (subsistence, commercial, or pen culture).	(Cinner et al., 2018, Cinner et al., 2015)

We identified two adaptation responses that are common to the two cases. These responses are: diversification strategies and an adaptive co-management approach. First, diversification is a widely applicable strategy in the areas of livelihoods, fisheries, knowledge systems, learning opportunities, and institutions. In the broader resilience literature, diversification has been identified as a source of resilience and a means of adaptation in the context of climate change (Leu, 2019, Asfaw et al., 2018, Cline et al., 2017). For instance, Leu (2019) identified tourism in the SSF context as a diversification strategy among Sámi Indigenous people in northern Sweden. Nurturing diversity in changing social-ecological systems can increase creativity and adaptive capacity, as well as setting the system for reorganization and renewal (Folke, 2016, Nayak and Armitage, 2018). Second, the adaptive co-management approach is widely used in natural resource management, including SSF in both developed and developing regions (Fidelman et al., 2017, Dale and Armitage, 2011). For example, Plummer and Bird (2013) reveal key considerations for using adaptive co-management for climate adaptation in the Barents Euro-Arctic region.

What does successful adaptation look like in the context of SSF (Adger et al., 2005, Osbahr et al., 2010, Piggott-McKellar et al., 2019)? We argue that successful adaptation must bring equity benefits and opportunities to marginalised vulnerable communities, ensuring good nutrition, food security, and sustainable livelihoods through a bottom-up participatory resilience-building approach (Leite et al., 2019). Building on recognized sources of resilience, we identified five definitive characteristics of a successful adaptation process in SSF. They are: i) Continuous learning through knowledge co-production (learning new knowledge and updating existing knowledge) (Armitage et al., 2011, Dale and Armitage, 2011); ii) Capacity-building to improve human agency (transferring existing capacities and building new capacities) (Cinner et al., 2018); iii) Place-specific nature (rootedness), which recognizes the situated nature of resilience and the importance of culture and place, including the focus on identity, worldviews, and attachment (Brown, 2016); iv) Collective action and partnerships through community-based institutions to effectively co-manage (fisheries) resources (Conway et al., 2019, Schipper et al., 2014); and v) Flexibility in terms of switching between adaptive responses (Cinner et al., 2018). These characteristics are important in judging success (section S2), but the relative weight allocated to each criterion is not given; rather, it emerges from a societal process of consent and action (Adger et al., 2005, Osbahr et al., 2010). Cultivation of these characteristics has the potential to address some of the barriers to effective community-based adaptation as identified by Piggott-McKellar et al. (2019).

The identified characteristics of Inuit and Coastal-Vedda governance regimes in table 4 (e.g., partnerships, mixed regimes, vertical/horizontal linkages, learning-by-doing, and the sharing of power, responsibility, and authority) are well-documented and recognised in the co-management literature in various resource systems (Fidelman et al., 2017, Alexander et al., 2015, Galappaththi and Berkes, 2015b). Adaptive co-management in SSF and Indigenous contexts draws on their collective capacity to use accessible resources at the right time and in the right way to harness resources and human capital together. Brown (2016) identified and termed this attribute ‘resourcefulness.’ It reflects human agency and capabilities, innovation, and opportunities.

5. Conclusions

We compared two empirical case studies of remote Indigenous communities from two very different geographic regions to articulate an understanding of how SSF communities can build resilience and minimise vulnerability in the face of climate change and other stressors. We also identified what successful adaptation looks like in the context of remote marginalized Indigenous populations. We argue that successful adaptation, particularly in a disadvantaged community setting, should focus on bottom-up resilience-building approaches that offer equity benefits and opportunities in the areas of nutrition, food security, and livelihoods. The community adaptation process could offer support through commonly used strategies (e.g., diversification and adaptive co-management) and various community resilience-building approaches. We proposed eight sources of resilience, which are: i) the use of diverse kinds of knowledge; ii) the practice of different ways of learning; iii) the use of community-based institutions; iv) efforts to improve human agency; v) the possession of unique worldviews; vi) the holding of specific cultural attributes to keep up with adaptation; vii) effective social networks; and viii) a high level of flexibility. These sources of resilience could guide the adaptation process with identified definitive characteristics (continuous learning; capacity building; rootedness; collective action; and flexibility). These opportunities could be used to guide and formulate the community adaptation process and help with policy development, particularly in the domains of climate change adaptation and sustainable SSF. The findings provide policy insights to broaden the understanding of what successful adaptation looks like in remote disadvantaged communities.

Appendix A. Supplementary data

Supplementary material associated with this article can be found, in the online version.

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