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Ten years of climate change adaptation in Greenlandic fisheries: key observations from local ecological knowledge

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ABSTRACT: This article reviews and examines the most significant climate-change-related impacts and adaptation from the perspective of stakeholders in Greenlandic fisheries. The study was constructed as a comprehensive, multi-site, bottom-up case study around Greenlandic fisheries (south–north/offshore–inshore), where interviews and workshops with Greenlandic fishers and stakeholders have communicated their observations of fishery changes associated with changes in the marine environment within the last decade. Key observations include: changes in sea ice cover; increased abundance of known species in North Greenland; fish species relocation and periodic absences in coastal systems; a northward movement of the shrimp fishery; new and unprecedented bycatch issues; and new fisheries. Stakeholder knowledge acknowledges the capacity of both offshore and coastal fisheries to adapt to changing seasonality and distribution. Factory capacity and decision-making as well as bycatch legislation have been identified as the most critical bottlenecks for (re)diversifying fisheries and increasing the value of the locally available resources.

KEY WORDS: Arctic fisheries · Adaptation capacity · Livelihood adaptation · Local ecological knowledge · Inuit knowledge

1. INTRODUCTION

1.1. Climate change impacts on Arctic fisheries

The Arctic marine environment is under rapid change, and Arctic fisheries are exposed to changes in temperature, sea ice loss and changes in ocean productivity (SWIPA 2017). Since 2006, NOAA's Arctic Report Card has annually provided information on the current state of different components of the Arctic environmental system. The 2022 Report Card reports that Greenland's continental shelf has experienced rising ocean temperatures, which in turn contributes to melting glaciers along the ice sheet's margins and resultant ice loss (Druckenmiller et al. 2022). Noting further alarm, it states: 'The Greenland Ice Sheet experienced its 25th consecutive year of ice loss. In September 2022, unprecedented late-season warming created surface melt conditions over 36% of the ice sheet' (Druckenmiller et al. 2022, p. 1). Connecting these climatic and oceanographic changes to societal impact, the authors underscore: 'People experience the consequences of a rapidly changing Arctic as the combined effects of physical conditions, responses of biological resources, impacts on infrastructure, decisions influencing adaptive capacities, and environmental and international influences on economics

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and well-being' (Druckenmiller et al. 2022, p. 4). It is within this domain of climate research that we situate our contribution to understanding the adaptations among Greenlandic fisheries actors as they adapt to climate-driven changes in marine species distributions and infrastructure conditions.

1.2. Adaptation capacity of Arctic communities

Food security has been a consistent theme, and the resilience of Arctic food systems is known to include such factors as sharing mechanisms, hunting flexibility — including decisions to travel longer distances or shift to hunting by boat — and restoration of food access (Ford et al. 2012, Ford & Goldhar 2012). A recent case among Inuit fishers in Pangnirtung, Canada, identified 3 community-level adaptive strategies, which are diversification, technology use and fisheries governance that employs a co-management approach. Further, this work recognized 4 place-specific attributes that can shape community adaptations: Inuit worldviews, Inuit-owned institutions, a culture of sharing and collaborating, and indigenous and local knowledge systems (Galappaththi et al. 2019). This body of anthropological literature has also highlighted the flexibility inherent in Inuit ontology, its customary sharing practices, as well as the presence of alternative livelihood options and the mixed economy, which are fundamental for food security, well-being and livelihoods.

The importance of the mixed economy and access to financial resources and monetary income to pay for hunting equipment and fuel has been highlighted (Poppel 2002, Ford et al. 2012). In fishery- and hunting-dependent Arctic communities, the availability of alternative sources of income and willingness to alter livelihood are equally important when hunting opportunities fail or harvesting becomes too dangerous (Ford & Goldhar 2012). An early analysis of the previous paradigmatic shift from Atlantic cod *Gadus morhua* to shrimp (*Pandalus borealis*) in Greenland's commercial fisheries also concluded that different human and social capital within individual communities (Sisimiut and Paamiut) would influence adaptation capacity and adaptation outcomes (Rasmussen 2005).

Key stressors to the adaptive capacity of the Inuit have been identified to include rising costs of commodities and fuel, increased privatization of fish quota, constrained access and delayed responses to environmental changes in quota management regimes (Ford & Goldhar 2012, Tejsner 2012, Hendriksen & Jørgensen 2015). In general, it has been emphasized that climate change is only one of several change processes impacting Arctic societies, and that climate change should be perceived as an 'amplifier' of other changes (Crate & Nuttall 2009) as multiple change processes were observed to interact, e.g. in relation to fishery governance as well as the wider context of increased accessibility to the Arctic as a resource frontier not just within fisheries, but also extractive industries and shipping (Nuttall 2012). Although vulnerability and risk continues to frame adaptation discussions, an increased recognition of new opportunities and agency for Arctic communities has also been emerging (Ford et al. 2012, Government of Greenland 2012). In the process, resilience as a concept has been revisited to include creative processes of subject formation to recover, develop and challenge existing social systems and the way communities realize an alternative way of life (Hayashi & Walls 2019).

1.3. Climate change adaptation in the Greenlandic fishing and hunting sectors

Since the mid-2000s, there has been a surge of interest (e.g. analyses, assessments, scenarios) in climate-change related issues in Greenland. Early anthropological studies in northwest Greenland highlighted the inherently adaptive hunting and fishing practices and the resilience of the Inuit mindset (Nuttall 2009, Crate & Nuttall 2009, Tejsner 2012). These studies show that changing weather and environmental conditions are strongly embedded in Greenlanders' perception of 'Sila' (insufficiently translated as 'weather') and thus a resilience factor working at an ontological level and perceived as incremental changes. Nevertheless, the same studies are warning that climate change will present unprecedented changes. The loss and unpredictability of sea ice heavily impacts travel routes, animal migrations and hunting practices with severe risks to Inuit lives. The reliability and transmission of Inuit knowledge (IK) is challenged as ice-based practices and traditions become compromised. However, IK remains relevant and new educational initiatives are starting to develop, enhancing IK knowledge within the younger generations (Wilson et al. 2021).

Recently, the project Integrated Arctic Observation System (INTAROS, European Commission H2020) tentatively assessed key tendencies in the decadal changes for 33 species of demersal fish found in Greenland between 1993 and 2016 (Sejr et al. 2021), preliminarily concluding that Greenlandic fisheries are witnessing increased production. The study found

a 'substantial increase in average biomass combined with increases in average individual weight, average trophic level and composition of dominant species' (Sejr et al. 2021, p. 1). Measured against the baseline of previous studies, this finding is interpreted as a partial recovery of an over-exploited system and a sign that fish stocks are re-building from a low level. The likely causes are proposed to be large-scale climatic drivers, possibly combined with decreased trawling effort and bycatch mitigation: 'Climate change-related melting of sea ice and the Greenland Ice Sheet likely sustained increased primary production by increasing light and nutrient availability. Increases in temperature and salinity indicate increased inflow of Atlantic water, which increase connectivity to lower latitude systems. Finally, decreased trawling effort combined with mitigation measures to decrease bycatch may have decreased fish mortality. This suggests that a combination climate change and long-term hydrographic variability may have facilitated the recovery of fish stocks' (Sejr et al. 2021, p. 1).

Fisheries governance is expected to have significant influence on adaptation strategies shaping the operational conditions for the fisheries. In Greenland, the relationship between the large-scale seafood companies and the small-scale fishers has been characterized as one of 'pernicious harmony', including both symbiosis and competition (Snyder et al. 2017). In addition, there are different competing interpretations over 'what is to be sustained' in Greenlandic fisheries, pitching large- and small-scale fisheries against each other (Jacobsen 2018). Jacobsen & Raakjær (2012) found that coastal fishers have been successful in influencing short-term management decisions, whereas the public administration and the large-scale seafood companies have been controlling the policy reform arena (Jacobsen & Raakjær 2014). Furthermore, the Marine Stewardship Council (MSC), an independent and global, non-profit organization promoting sustainable fisheries based on consumer purchasing power, is influencing fisheries management in Greenland (Søbye 2019, Long & Jones 2020), as seen for more than the last decade (Jacobsen & Raakjær 2012).

Here, we used a bottom-up and qualitative approach to investigate how climate change adaptation has, in practice, manifested itself in Greenlandic fisheries over the last 10 yr. The present study was partly designed as a follow-up to previous, future-oriented and Greenland-focused assessment work conducted by the Greenland Self-Government and AMAP (Government of Greenland 2012, AACA 2017). We focused on what changes and adaptational actions fishers have actually identified and responded to during a roughly defined period of 'the last 10 yr'. This knowledge is communicated from a local ecological knowledge (LEK) and/or IK context and represented as knowledge in its own right (ICC 2021). We conclude by discussing possible ways to support fishery adaptation capacity even further.

2. METHODS

The analysis is based on qualitative data on changes and adaptation in Greenlandic fisheries, which was produced by a team of social and natural scientists in collaboration with a broad range of Greenlandic stakeholders representing fisheries and coastal community interests. The activities were conducted as part of the multidisciplinary project, Ecological Tipping cascades in the Arctic seas (ECOTIP). The knowledge creating activities included: (1) a stakeholder workshop conducted in Nuuk, 8 November 2021; (2) semi-structured interviews with 5 individual coastal fishers in Nuuk, 15–18 November 2021; (3) ethnographic fieldwork and semi-structured interviews in Nanortalik, including visits to Qaqortoq, 2–13 May 2022; and (4) ethnographic fieldwork and semi-structured interviews in Upernavik, including visits to Inarsuit and a telephone interview to Aappilattoq, 28 June–7 July 2022. Fig. 1 provides a map of Greenland and all of its communities.

2.1. Stakeholder workshop

The workshop focused on identifying the most significant environmental changes observed in the Greenlandic fisheries since 2010. The workshop served as an early follow-up to some of the first climate change assessments for fisheries in Greenland (Government of Greenland 2012, AMAP 2017), including a return to earlier stakeholder discussions of risk and opportunity in relation to perceptions of climate change related to Greenlandic fisheries. A total of 15 people contributed to the workshop, including: 3 skippers, 2 fish factory managers and 1 deputy director from Greenlandic seafood companies; 1 representative from the Greenlandic Ministry of Fisheries, Hunting and Agriculture; and 1 representative from the Fishermen and Hunters Association in Greenland. Six scientists from across social, economic, oceanographic and biological science disciplines participated.

The workshop was organized as a 3 h group conversation among the participating stakeholders

around open-ended questions related to the following themes: (1) observed changes in the marine environment and fish resources by industry, fishery managers and researchers; (2) observed/implemented adaptation in the offshore and coastal fisheries; and (3) identification of future risk, opportunities and/or knowledge gaps by stakeholders.

The workshop dialogue took place in Danish and was audio-recorded, transcribed, analyzed using NVivo software (QSR International) (see Section 2.4 for further details). A summary report including quotations was then distributed to the participating stakeholders with opportunity for feedback and corrections. The key changes and adaptations identified in this workshop and subsequent interviews with coastal fishers are now presented in the subsequent sub-sections.

2.2. Interviews with coastal fishers in Nuuk

Subsequently to the workshop, a series of semi-structured interviews with coastal fishers in Nuuk (n = 5) was conducted, covering similar questions of recent changes and adaptation, but only with respect to the coastal fishery in the Nuuk area. The interview guide covered the same 3 themes as the workshop described above. Furthermore, many of the interview questions were formulated as follow-up questions to a previous study of the Nuuk cod fishery, conducted by the same interviewer team in 2014 (Hedeholm et al. 2016). The interview series included 2 of the same (still active) commercial fishers together with 3 'new' fishers. Interviews were conducted in Danish or in Greenlandic with *in situ* interpretation by a Greenlandic- and Danish-speaking research assistant.

2.3. Ethnographic fieldwork in southwest and northwest Greenlandic communities

Fieldwork including LEK interviews was subsequently planned and conducted in 2 Greenlandic communities representing 'Northwest Greenland' and 'South Greenland'. Nanortalik, located at the very southernmost tip of Greenland, is administratively part of the South Greenlandic region. It is a region where transport, fishing and hunting is defined by the physical attributes of the offshore currents originating from the east coast of Greenland and curving around the tip of South Greenland. Additionally, participants at the workshop indicated that it is a region where fishers were likely to be able to talk about 'new/rare' species from the south. Fieldwork in Nanortalik was supplemented with a 2 d visit to Qaqortoq, focusing on new species at the local fish market and the consumption of local foods. Previously unpublished interview material with the then-chairperson of the local fisher organization in Narsaq in South Greenland has also been included to supplement the analysis.

Upernavik and the surrounding villages is part of the 3 Greenland halibut *Reinhardtius hippoglossoides* management districts together with the Disco Bay and Uummaanaq in Northwest Greenland. Since the 1980s, the commercial Greenland halibut fishery (originally conducted from the sea ice) has been the primary commercial fishery in northwest Greenland, where the mixed economy is particularly strong and includes various ice- and sea-based hunting activities (Delaney et al. 2012). At the stakeholder workshop, participants informed researchers that the ice-scape hunting and fishing areas had undergone changes due to the diminishment of sea ice and recently, a gillnet cod fishery had also started to take off, indicating a diversification and a general increase in fishing opportunities.

Interviews with Greenlandic- and/or Danish-speaking fishers, hunters, fish factory managers and fish market salespersons were conducted by Danish-speaking researchers in cooperation with Greenlandic- and Danish-speaking research assistants. In addition, the visiting research team engaged in more semi-structured interviews and informal conversations with a broad range of community members, local businesses, politicians and municipal managers to gain contextual local knowledge about the communities and current socio-economic changes.

All data were eventually recorded in Danish only, and all quotes presented in this manuscript have been translated from Danish to English by the authors.

2.4. Analytical strategy

Transcribed workshop dialogues, semi-structured interviews and field notes of informal conversations have been coded using NVivo software (QSR International). Thematic analysis or qualitative coding helps identify recurring and relevant topics across multiple qualitative data sources (notes and transcribed recordings from workshop and interviews), which significantly contributes to thorough and rigorous analysis when handling a large amount of qualitative data. This allows for a grounded theory approach (Glaser &

Strauss 1967) based on contextualized accounts provided by the local knowledge holders.

The coding process had a dual focus. One coding focused on a typology of adaptation needs and identified all empirical examples of changes and circumstances that fishers have been responding to. Besides an over-arching category of 'environmental changes', this coding also included the categories of 'operation costs', 'other fishers', 'crew and community', 'management and regulation', 'local buyers' and 'local market'. The over-arching category of 'environmental changes' was coded into various subthemes to specify the types of challenge and associated species as seen from a fishing perspective. The subcategories included: 'migration of x', 'emergence of x', abundance of x', re-location of x', absence of x', 'seasonality change', 'obstacles in net/long line' and 'need to travel longer distances'. A second coding focused on a typology of adaptation strategies and resulted in 7 sub-categories: 'political leverage', 'mobility', 'volume as strategy', 'downsizing as strategy', 'technological innovation', 'financialization' and 'the body toll/working harder'.

This coding was instrumental in understanding and keeping sight of the diversity of empirically relevant themes when seeking to understand climate change adaptation in a socio-economic fishery context. The final structuration of the article's Analysis and Discussion sections is a result of various qualitative iterations by the authors. Abundance, relocation, northward migration, by-catch and new fisheries eventually emerged as meaningful and inclusive headlines for the analysis. In addition, the analysis responds to a thematic that was raised repeatedly by small-scale fishers throughout the dataset: the constraining and facilitating condition of marketing options in the coastal fishery.

The Discussion seeks to assess the adaptation capacity of Greenlandic fisheries and provide LEK-informed perspectives on how to possibly enhance it even further.

3. ANALYSIS

3.1. The climatic drivers of water masses and sea-ice cover

During the workshop, fishery stakeholders and scientists cooperated around establishing an overall idea of marine climate change dynamics. Bearers of oceanographic science knowledge and LEK interacted and formed a consensus regarding the underlying dynamic of the marine ecosystem on the west coast of Greenland: to understand changes, one must understand the movement and distribution of different water masses with each of their characteristics in terms of temperature and salinity.

The participating oceanographer gave an introductory presentation in which he drew attention to competing ocean currents as the overall driver of change (see also Mortensen et al. 2022): 'All changes can be explained by 3 water masses competing for space — the Baffin Bay Polar Water from the north, the warmer Atlantic water flowing in from Cape Farewell to the south, and the coastal water'. He stated that polar water was recently sampled at Fyllas Bank off Nuuk, indicating that perhaps the polar front has been moving southwards. Yet, there are many different dynamics occurring at local scales in West Greenland. The offshore shrimp trawler skippers agreed that abrupt changes in temperature can be observed from one place to another. 'We recognize this from fishing after prawn on the fishing banks, that there is large difference between the water masses. The ships and the skippers seek certain temperatures. And it doesn't take a lot before it changes completely. It is within half a degree Celsius or 0.2 degrees, then there is already a large difference' (Trawler skipper).

Inside the West Greenlandic fjords, coastal fishers also experience the yearly/seasonal changes resulting from shifts in temperature and/or increased melt from glaciers. A shrimp trawler skipper described the dynamic of different water masses and animal distribution using a metaphor of the fjords in West Greenland as 'accordions': 'In wintertime it is dark, and the inland ice does not melt. At this time, it is possible for warm water from the northbound sea current to come close to the shore and all the way into the fjords. When summer arrives and the sun is up around the clock, there is a large melting of ice, and this water flows out into the sea and affects marine fauna in coastal areas. It almost acts as an accordion, where a significant amount of shrimp and other animals are pushed westwards during the summer, and we don't see them again until next summer. By that time, these shrimp and other animals have come closer to land' (Trawler skipper). This 'accordion' movement corresponds well to the fishing cycles in the Nuuk fjord described by Nuuk fishers in a 2014 interview study (Hedeholm et al. 2014). The cod fishery begins as longline fishery in the 'bottom and depth' of the fjord in wintertime and then shifts to gillnet in the summertime when the cod moves 'outwards and upwards' towards the beach and the coast.

Fig. 1. Greenland. Red dots show all the Greenlandic settlements (size is proportional to the formal Greenlandic clasiffication of 'town' and 'villages')

The arrival of capelin (*Mallotus villosus*) and its predators in the fjord is also observed in spring.

The subject of water masses dynamics served as an underlying reference for many of the subsequent discussions. In addition, LEK holders highlighted the significance of diminishing sea ice coverage early on in the workshop process. The decrease in sea ice in North Greenland was soon highlighted by the industry as a major driver of change within 'at least the past 10 yr or more': 'We may have to go further back than 10 yr, but the sea ice cover is definitely decreasing. I don't think anyone questions that. In Disco Bay, Uummaannaq and Upernavik we see shorter and shorter periods of sea ice cover. Sometimes there is no sea ice at all' (Factory Manager, RG company). Although the decrease in sea ice can be considered to have happened over a relatively short period when we speak of climate change in general, it is noteworthy that fishers in North Greenland have seemingly had 'sufficient' time to adapt their modes of transportation and fishing equipment: 'It [the decrease in sea ice] is something that has not happened very quickly and thus the fishers have been good at adapting, but it is a fact that this change has occurred. There is not as much dog sledge and snow mobile driving anymore and there is more sailing' (factory manager).

On the other hand, decreased sea ice in North Greenland can mean better logistics: 'We see that Royal Arctic Line has a schedule that says they don't sail in winter. But as we are then approaching the winter period, they go: 'all right, we can also sail the next 2 times'. So you can say that this gives some increased possibilities around logistics — that you can get supplies in, but of course also the products out. In that way, in my job, I don't see anything where things have gone all wrong. To the contrary, I experience that it [the decrease in sea ice cover] has provided more opportunities than 25 years ago' (Factory manager).

Respondents in the Upernavik district commented on the changes in sea ice and their implications for the mode of fishing in winter, as well as related changes in distributions of marine mammals, such as narwhal *Monodon monoceros*, and mobility in the villages and Upernavik. One fisher interviewed was less concerned because he was fine to adapt to winter fishing via boat as opposed to snowmobile or dogsled. However, others were less at ease with the change. Those respondents pointed to the time of year when the ice solidifies (from October or November to presently in January) and the ice's instability as its thickness was not sufficient to withstand breakage in the waves. Thus, safety is one of the concerns, but also the ability to move more freely between the island villages and its implications for winter mobility and isolation.

Although not referred to as such, the change from dog sledding to snowmobile is notable in connection to cultural heritage, especially in terms of intangible cultural heritage and tacit, local knowledge. Although sledges and dogs are still visible in the yards of Upernavik residences, many interview participants underscored how much this had changed over time. A man working at one of the Upernavik fish factories explained that with the smaller period of ice and its uncertain timing and conditions, there was now insufficient time to train dogs for the sled and thus there is a move toward the snowmobile. A man in one of the island villages lamented the loss of routes that he would take with his father to key fishing and hunting grounds that simply could no longer be used because of the lack of ice. A recent LEK study by Schiøtt et al. (2022) reported similar challenges from Qasigiannguit in the Disco Bay region. The explanations for the shift away from dog sledge are likely to be manifold and dependent on geographical and socio-economic context.

3.2. Increased abundance of well-known species in North Greenland

All previous climate change assessments operate with the possibility of increased abundance of fishery resources and a northward migration of key species in the current fisheries. This has certainly been the case in North Greenland (see also Hansen 2018), where it has now become possible to engage in a greater variety of fisheries. Whereas the community was previously landing Greenland halibut and crabs (*Chionoecetes opilio*) to 'trading ships', 2 fish factories are now established in Upernavik and fish factories and/or storage facilities have increased in the villages as well. The competition between 2 fish factories has had a positive impact on fish prices. At one of the factories in Upernavik, one of the overarching points made was that the halibut fishery in this area was relatively 'new' (about 30 yr), especially in comparison to further south in Uummaanaq (a '70 yr' fishery) and Ilullissat (a '100 yr' fishery), with positive implications for the average size of the individual fish caught.

Fishers and factories in Northwest Greenland have primarily been targeting Greenland halibut, but an expansion to crab fisheries and gillnet fishing for

Atlantic cod is now taking place: 'In North Greenland there is a positive effect because it is possible to fish for different species: cod, Greenland halibut and, now, crabs in Upernavik. In Uummaanaq area they have just started gillnetting for cod; previously, that was impossible' (Factory manager). In Upernavik, a shift from Greenlandic cod, also named 'uvak' (*Cadus ogac*), to Atlantic cod over the last 20–25 yr has been observed by long-term residents. In Upernavik, interviewed fishers said that they are catching cod, wolffish and crabs, but that they are not sold to the factory either because prices are too low (Atlantic cod) or the factory does not process the particular species (wolffish). The fish is then used for personal consumption (e.g. dried cod) and for local sale to neighbors.

The coastal fishery has become more efficient, with larger motors and an increased automatization of the deck equipment onboard the fishing vessels, which has significantly increased the efficiency of the fishers compared to 10–15 yr ago. Technological innovations include automatized long lines and net haulers. Otherwise, the application of catch equipment used for different fisheries is stipulated by the conservation regulations, which have not changed considerably.

3.3. Fish relocation and periodic absences

The interviewed fishers and stakeholders have observed some increases in coastal fishing opportunities as species have moved northward. However, they have also been experiencing periods with absence and 'relocation' of key species from the coastal areas and the individual fjord systems. Significant examples are capelin, Atlantic cod and Greenland halibut.

Capelin *Mallotus villosus* is a key species in the food web, affecting the seasonal migration of various predator species in the fjord, including cod and whales. Fishers and landing facilities have observed that capelin has not been present on the usual coastal fishing grounds in the past 2–3 yr. This has been the case in South Greenland, Nuuk and Qeqertarsuaq: 'It is important to look at the food chain. There is very little capelin coming south in September/October. There are many whales that stay further out because they don't have anything to eat' (Fisher from Narsaq in 2018, translated from Greenlandic). This point was also brought forth at the Nuuk workshop:

'For some reason it has become more difficult to find the capelin here in the Nuuk fjord. It stays in the fjord for a shorter period, or in deeper water. That is what fishers have observed for the last 2 yr. In earlier times the capelin could be fished for a longer period. This is no longer the case. Perhaps there is way too much [fresh] water on the surface' (Coastal fisher representative).

'It is the same in Qeqertarsuaq. Two years ago, capelin was landed to the fish factory. But the last 2 yr nothing has been landed in Qeqertarsuaq because there wasn't any to be fished' (Seafood company).

'I was also in Qeqertarsuaq in June and they said that there used to be a shoal of capelin arriving out at the beach. It hasn't arrived the last 2–3 yr' (Fishery manager).

Coastal fishers have observed that the meltwater from glaciers in West Greenlandic fjords have recently become more 'muddy' or 'slimy' during summer. This phenomenon impacts gillnet cod fishers as it makes the cod go to deeper waters, where they cannot be 'reached' by the gillnets: 'When the surface water, the muddy water, when it comes — then the cod stays in deeper water' (Coastal fisher representative). This phenomenon started in South Greenland around 5–6 yr ago, and within the last 2–3 yr it has also been observed in Baffin Bay as well. However, South Greenland may now be 'normalizing' again according to coastal fishers: the water is becoming 'clear' again and cod are returning to the fishing grounds where they used to be. It is unclear what the 'mud' or 'slime' is constituted of, but many of the fishery stakeholders suggested that it must be connected to an increased melt from the fjord glaciers, e.g. they had previously discussed with scientists that it might be related to silicon run-off. (A recent study by Schiøtt et al. 2022 also mentions the observations by fishers of a 'slimy' substance in Ilulissat Ice Fjord in connection with a lake draining event [Lake Tiningnilik]. Schiøtt herself hypothesizes that 'This upwelling of nutrients from the sediments may potentially stimulate an algal bloom of colonial *Phaeocystis* that creates a gelatinous structure that is odorous'.)

As a form of adaptation, some gillnet cod fishers are experimenting with their fishing seasons. Some fishers reported shortening their cod fishing season, while it was suggested that other fishers may have expanded their gillnet season in an attempt to increase the income from the cod fishery (starting their fishery as early as March–April or ending as late as November).

Adaptations to periods of 'absence' of the usual fish resources such as cod in the fjord system is not apparent from our study. Instead, 'normalization' and

'return' was a theme emerging from the interviews. After a 4 to 5 yr period of poor fisheries in South Greenland, fishers and the factory in Nanortalik were now seeing a return of fish to the coastal areas, including cod as well as wolffish and salmon. In Nanortalik, gillnet fishing for cod had simply been put on halt for a period.

To coastal fishers, it is relevant to understand changes in the fjord systems better, including phenomenon like 'muddiness' and 'sliminess', which impact the fisheries: 'The fjord systems means a lot for the sea temperature. As was being said, polar water masses are coming from [the] north. But the coastal fishers always talk about the melting of the inland ice. A lot has been happening there the last 5 yr because of climate change. We need more knowledge about this when we are to adapt in one way or the other' (Coastal fisher representative). With regard to the 'muddiness', the coastal fisher representative elaborated: 'So what about what we have observed the last 5–6 yr in South Greenland? The fishers explain that the water there is much more mixed. And it is more slimy. And now when the water is clear again, then the fish are more inside the fiords (…) and the last 2–3 years it has come to the northern part during summertime, for example in the Baffin Bay area' (Coastal fisher representative).

In Upernavik, a lot of discussions were had about the lack of ice in the autumn during narwhal migrations. The narwhals seasonally migrate from the north toward the south, but there is now a tendency of these marine mammals to remain in the Upernavik area for a longer period. Fishers and those working in the fishing industry explained that the presence of narwhals in the area affects the Greenlandic halibut's position within the water column, driving the Greenland halibut away from long-line fishing areas. In turn, this affects fish catches.

3.4. Northward movement of the shrimp fishery

The relationship and potential shifts between cod and shrimp was a key thematic in the first Greenlandic climate change assessment (Government of Greenland 2012). However, at the workshop, it was the shifting location of shrimp biomass that emerged as the key theme. Skippers and seafood companies alike agreed that over the last 20 yr, the shrimp biomass has moved further north. A stakeholder from the offshore fishery summarized the change like this: 'Over the last 20 yr, the [offshore shrimp fishery] has maybe moved a little further northwards, in general. In a period, they fished further west and then they only fished in the eastern side, close to land. And then they moved north'. This movement of the shrimp biomass was also confirmed by a Greenland Institute of Natural Resources (GINR) scientist: 'It is correct that in the late 1990s there was a larger share of the biomass south of 66° N. But in the middle of the 2000s it shifted, and since then 80% of the shrimp biomass has been north of 66° N. And there has been a tendency for it to move more eastwards'. A shrimp trawler skipper explained the tendency as such, 'Although the shrimp biomass may be the same, the fishery has experienced a loss of fish territory from southwest. In the late 1990s there was a larger share of the biomass south of 66° N.

An experienced shrimp trawl skipper was able to add some more historical perspective to the shrimp migrations. He noted that back in the late 1970s to early 1980s there was hardly any shrimp south of Maniitsoq. He cannot explain why, but he thinks that some went in towards the coast while others migrated to deeper water. In the meantime, there was always shrimp in South and East Greenland independent of these changes — sometimes they were to be found on the flat seafloor and other times at 'the edges'. For all that he knows, 'Greenland has a shrimp population all the way from East Greenland and all the way up to Qaanaaq' (Shrimp trawler skipper).

The incremental relocation of the shrimp biomass over the last 20 yr has not proved to be a challenge for the trawling fleet in terms of adaptation. The fleet has been able to shift the fishing grounds, following the biomass northwards. Furthermore, the decrease in ice cover and bad weather off the east coast of Greenland has even increased the physical access to shrimp on the east coast, providing a 'good fishery of large and fine shrimp'. The main adaptation theme from the workshop is therefore further exploration and exploitation of shrimp north of 73° N – this interest in the 'hidden' or 'new' opportunities in the more northern waters was in fact also expressed back in 2014. Currently, the issue seems to be the distance and operation costs. It is not profitable enough for the fleet to explore this area systematically due to the distance: 'It is very difficult to make ends meet because the distance is so great and the fishery per day is not. But there is a great value in these big fine shrimp, and Greenland only misses out if there is no fishing in the area'. To make ends meet, the same skipper suggests an additional total allowable catch (TAC) share for the fishery north of 73° N as a way to make the exploration more profitable: 'It is a shame

that there is no extra quota for the areas north of 73° N in addition to our TAC. Then we could adapt our fishery and not, like now, only fish sporadically as it may fit within a fishing trip'.

Another adaptation thematic concerned a more accurate understanding of shrimp migration in connection with the shrimp's life cycle. The shell and meat quality, and hence the market value of the shrimp product, varies seasonally depending on its life cycle. The shrimp is particularly valuable when it has produced and carries roe in the head (orange head). Once the head has been emptied, the shrimp are sorted as a lower-value product. Therefore, it would be of interest to the shrimp trawlers to catch the right shrimp in the right time and place: 'The interesting thing is, that all this (the different stages in the shrimp's life cycle) does not occur at the same time all over the West Coast. If we could learn where these cycles are — e.g. it seems as if everything begins in the south and then moves up the coast — then the fishery could plan and go for the good quality and expensive products instead of the opposite' (trawler skipper).

3.5. New bycatches in the offshore fisheries

Bycatch has emerged as an important adaptation issue — perhaps even more than what was expected by the earlier climate change assessments. This may also reflect the fact that bycatch regulation has increasingly managed to define the fishery governance agenda in connection with the MSC certification of Greenlandic fisheries. In 2020 and 2021, the offshore fishery experienced a sudden inflow of small redfish (1-yr-old redfish at approximately 6–9 cm) on some of the shrimp fishing grounds. The fishers expect that this fish fry was transported with sea currents (as opposed to redfish spawning and growing up in the area). The fishery is curious as to the causes for this phenomenon, and GINR currently leans towards the hypothesis that it may be caused by changing environmental conditions and/or changes in abundance for the redfish cohorts. According to the trawl fleet, the small redfish appear in greater volume from 67°N to 68°N and from 56°W and westwards. The Canadian shrimp fishery on Flemish Cap and scientific surveys from 2020 confirm the observation. The small redfish are caught as bycatch and constitute an issue because bycatch regulation demands that the fishery changes location when bycatch exceeds 5% of a given haul; thus, the bycatch of small redfish cannot be exploited for commercial purposes.

Bycatch of polar cod *Boreogadus saida* has also emerged as an issue. A trawler skipper stated that the polar cod is already adapting to changing environment and temperatures, and is observed to have moved further north. Thirty to 35 yr ago, many polar cod were observed at the east–west edge at approximately 67° N at depths ranging from 300 to 500 m and near the Canadian Exclusive Economic Zone (EEZ). In those areas, polar cod are now less abundant, and have moved north of 73° N. The offshore fishery has observed polar cod as a bycatch in the fishery.

Currently, polar cod bycatch is not exploited due to the formulation of the bycatch regulations. If these regulations could be changed, polar cod could be used for bait in the coastal fishery and thus diminish the large and pricy import of bait from abroad. It was suggested to arrange a meeting with the participation of fishery managers, industry representatives and scientists, where the goal is to discuss how to solve this problem and possibilities of changing the current bycatch regulations.

3.6. New fisheries

The mackerel fishery in East Greenland has emerged as a new fishery and was a major theme in previous climate change assessments. Since 2012, when the mackerel fishery took off, it relatively quickly became an important and profitable fishery, where Greenlandic companies made substantial investments in new pelagic vessels to pursue this new offshore possibility. However, for the last 2–3 yr, mackerel has not been present in the EEZ. Presently, the mackerel fishery is limited to explorative and scientific fishing for monitoring purposes, and no commercial fishery for mackerel is conducted.

The coastal fisheries and fish factories have not started to include any fish species that were not already known and being fished and sold to fish factories in Greenland. It is still the same species that are being fished and processed, although sometimes in other places and/or in different volumes. As one factory manager states, 'We don't suddenly see a lot of some species that we haven't seen before. It is still the common species — Greenland halibut, redfish, catfish, and then of course some capelin when in season. And some roe and so on. It is the common species we see. We don't have others. At least so it seems'.

From interviews with fishers and local market vendors in Qaqortoq, we learned that some 'rare' species are sometimes caught and put on sale on the local market. There is little sale, however, because only

the older generation will know how to use it. According to interviews in Narsaq in 2018, the national culinary college Inuili had experimented with various preparations (e.g. salted, smoked, etc.) from the following species, often caught as bycatch: eel, shark, wolffish and shorthorn sculpin. We also learned about a fisher in Nanortalik who was planning to fish for eel in 2022.

Importantly, we learned that fishers point to many known species that have been traded previously but which are not landed and produced by the factories today. In Nanortalik, Arctic char *Salvelinus alpinus* was mentioned. In Nuuk, it was shrimp in the fjord. In the coastal fisheries, it is a recurrently stated fact that fishing strategies are determined by the actual marketing options, which are, in turn, decided by the fish factories.

3.7. Adaptation within the limits of the local marketing options

The sections above show how fishers have adapted to the changing seasonality and distribution of resources. But they also show that most adaptations are essentiality facilitated or complicated by marketing options. In this last section, we want to show how adaptation to low market prices and limited marketing options is a key thematic in many of the interviews with coastal fishers. For example, 'He says that the fishers and hunters go mostly for what pays off. He says that they don't catch a lot of herring. They are more focused on what they can sell' (Fisher from Nanortalik, translated from Greenlandic).

'The factory in Qaqortoq also owns this factory in Nanortalik. But in the lumpfish (*Cyclopterus lumpus*) season, only Qaqortoq buys lumpfish. But they cannot buy it here in Nanortalik because the factory is different. That is why they catch seals here in Nanortalik now, to sell sealskin, even though it is lumpfish season. So, what we are lacking is good management. When there is lumpfish season there should also be [opportunities to sell it], because the factories have the same owner' (Fisher from Nanortalik, translated from Greenlandic).

'[…] and the price for cod was so low at that time, like now, the prices just dropped. His cutter has a harpoon and so he was catching a lot of whales at that time. Otherwise, he would probably have given up the profession' (Fisher from Nuuk, translated from Greenlandic).

As shown in the quotations above, oftentimes fishers can maneuver different species and trading options to increase profit or simply, stay afloat with their business. Economic hardship hits in terms of low prices for cod. For example, there are sometimes no other obvious strategies for the fishers than to work harder, to sail longer or to increase the working days to secure or increase the volume: 'The price we receive for cod is much lower compared to other countries. You must work very hard to make it go around. For example, you have to fish a lot in a dinghy or a cutter to fill them up. You have to fill them up in order for the fishery to go round. And it is hard work. It wears you down. There are sort of high seasons where you work almost around the clock to fill up the boat. So it is hard and physically exhausting' (Fisher from Nuuk).

This current adaptation strategy where volume compensates for low price is taking a toll on the human capital of the fishers, very concretely in terms of the body. Fisher interviews touched upon this theme of hard physical labor many times, and it is common for fishers and their colleagues to have to cope with serious and untreated injuries, and to have left the fisheries due to health issues. The fishers see a solution in higher fish prices, which they also perceive as a barrier for development and innovation: 'I don't think there's any optimism in the city [Nuuk] […] it's so cheap in this city with the cod, you don't really go for, how do you say it, you don't really experiment. Everything is so expensive! Diesel is expensive, the crew has to live, so we need to catch a lot. But when the cod is so cheap, it's difficult, right? If you start to catch well, the factories just lower the prices' (Fisher from Nuuk).

In South Greenland, there is a persistent call to make more out of the available resources. A previous interview with a fisher from Narsaq, South Greenland, pointed to the same issue: 'In Iceland last year they use 100% of what they fish. But here in Greenland we only use 3 species: Greenland halibut, redfish and cod. The fishery goes well at our neighbors — but everything else is discarded in Greenland. He has asked the municipality and the Self-Rule to make better use of the resources to the benefit of the fishers' (Fisher from Narsaq, translated from Greenlandic).

4. DISCUSSION

From interviews with Greenlandic fishers and stakeholders, this study has identified 6 major categories of biodiversity changes to which the Greenlandic fisheries have been adapting within the past 10 yr. They all relate to distributional shifts and

include: an overall appreciation of water masses and sea ice distribution as key drivers of change; increased abundance of known species in North Greenland; relocation and periodic absences of fish in the water column and/or in and out the fjord system; a northward movement of the shrimp stock; new and unprecedented bycatch issues in the offshore fisheries; and new fishing opportunities.

Fisher interviews also point to a range of ecological changes in the coastal ecosystems, the extent and impact of which are unclear and could be investigated further. In Disco Bay, Nuuk fjord and South Greenland, there have been years when capelin did not arrive or stay for as long as it used to. Capelin is fished for food and for bait, while also being a key species in the coastal food web, but there are no clear conclusions regarding the causes or impacts of such incidents, should they become more prevalent. Increased run-off from glaciers and increased algae is suggested by some fishermen in Nuuk (but not others) to compromise the effectiveness of the gillnets and to make fishery operations more cumbersome. This phenomenon and its impacts could also be explored further.

In assessing the adaptation of the offshore fishery, we note that the offshore fishery itself expresses contentment with the situation and that it has generally been able to adapt to the environmental changes. They have been able to make the desired technological investments to pursue new pelagic fisheries, and they have been observant and mobile enough to 'follow' incremental shifts in the location of the shrimp biomass. Furthermore, the seafood companies express satisfaction with the structural infrastructure, including the economic adaptation that has occurred in the offshore fishery: the offshore vessels have become fewer, larger and more efficient, and the fishery is considered attractive in terms of working conditions, salary level and company profits. Overall, they consider the offshore fisheries to be 'stable for the moment'.

Meanwhile, changes and adaptation in the coastal fishery varies along the west coast of Greenland. The coastal fishery in North Greenland is assessed to have adapted well overall to decreasing sea ice and greater abundance of various species. The Greenland halibut fishery remains an attractive fishery, and cod and crab stocks are observed to be increasing. New factories have opened, while others have expanded storage and processing capacity during the last decade. South Greenland has not experienced similar positive developments in the form of increased fishing opportunities. Also, the cod fishery saw a decline for a period of 4 to 5 yr but has now started to 'normalize' again, as suggested by fishery stakeholders and the fish factory. New fisheries have not emerged, and fishers lament low cod prices and local lack of marketing options for more of the well-known local species.

Fishers and stakeholders agree that the offshore and the coastal fishers and hunters have demonstrated a high degree of capability and willingness to change strategies when they have been faced with environmental changes, regulations and diminishing market opportunities, which could otherwise have reduced their fishing possibilities. When adaptation has been successful, it has been associated with successful experimention with fishing seasons and fishing grounds. Meanwhile, fishers and stakeholders identified factory capacity and/or decision-making as an important bottleneck for benefitting from known and new fishing opportunities in the coastal fishery: new or increased factory production forms part of the 'positive stories' of adaptation in North Greenland, while low cod prices and a lack of landing opportunities cause frustration in South Greenland.

When the nearest fishing sites, landing possibilities and/or fish prices are poor, fishers find ways to cope in the short term. Then, the primary adaptive strategy in the coastal fishery has been to focus on quantity (to catch more), work harder and travel longer to land the fish. Health risks resulting from repetitive and heavy lifting have been somewhat reduced with recent advancements in deck technology, which has made fishing operations lighter and more efficient. But increased distances and new fishing grounds remain costly in terms of fuel and destroyed fishing gear (when applied to new fishing grounds), and the longer travel times can be physically exhausting.

The economic, as well as the geographical, maneuverability of coastal fishers could be enhanced by addressing the structural conditions for marketing a greater diversity of catches at a fair price. The structure of the land-based processing industry is the gateway to international markets for the coastal fishery. Only a handful of 'traditional' species are currently of interest to factories and can thus be landed by fishers. If more diverse species were allowed to be sold, there would be an increased interest in fishing for more diverse species. One can imagine this would alleviate pressures on some of the coastal species that are currently fished beyond ecological and biological advice, including coastal cod and Greenland halibut in the Disco Bay area. Should ecological changes eventually bring more new species from the

south, promoting diversity and changes in landings would allow for easier adaptation to changing ecosystems. For now, however, fishers also tend to focus on well-known species in their area rather than articulating observations of and interest in 'new' species.

Fishers — be they offshore or coastal — are used to monitoring the dynamic and constantly changing ecosystems in which they operate. They change fishing strategies and techniques within a season (e.g. cod gillnetting in Nuuk), over a few years (shifting to open-water fisheries in the north) or gradually over a decade (the offshore trawling fleet following shrimp distribution northward). Overall, adaptation has so far appeared managable. But Greenlandic glaciers are still retreating from the fiords and the layering and mixing of water masses of the region are still changing, with likely impacts on nutrient flows and fish distributions. Creating scenarios for the way in which future environmental changes may impact marine food chains and distribution of fish resources could help fisheries anticipate risks associated with less incremental changes in the future (e.g. the retreat of sea-terminating glaciers). Such scenarios could be developed on local scales, as coastal fisher representatives express particular interest in understanding the dynamics of their local fjord systems. Still, 'predictions' of future ecological changes did not transpire as the most pertinent knowledge or policy gap considering the adaptative capacity of the fisheries. Echoing the concerns of many of the interviewed fishers, this study has included an increased focus on marketing and infrastructure restrictions, on food and market innovation, and on policy and technological responses to bycatch issues. Focusing on increasing the diversity and value of commercial catches and finding ways to make sustainable use of and/or avoid bycatch could very well broaden the maneuverability of fisheries, while also easing the pressure on the few selected species in Greenlandic fisheries.

Due to its geographical location and scattered settlement structure, Greenland is representative of many coastal and rural communities situated in the periphery of infrastructural networks (Ounanian 2016, 2019). Enhancing the structural conditions and first-hand prices for small-scale fishers in peripheral areas should, in our opinion, constitute a primary adaptation strategy within policymaking and climate change planning. The goal should be to facilitate the necessary diversity, flexibility and maneuverability of all fisheries while also protecting small-scale coastal producers from exhausting their personal capital (i.e. health, safety and time) as private and family-run businesses (Søbye 2019, Højrup 2021), not to mention the natural capital of their local marine ecosystems. In short, long-term adaptation strategies should serve to make coastal fishers less reliant on short-term coping strategies of working harder, travelling longer or fishing more intensively on a very narrow selection of species. Emerging initiatives within seafood innovation and bycatch exploitation transpire as promising potential adaptations in this regard, and could be supported further through research, investment and policy.

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