12 Marine fisheries and aquaculture in the Arctic

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Introduction

Arctic peoples and economies have long been linked with reliance upon living marine resources. Fisheries livelihoods center on both capture fisheries and its related industries (fish processing, gear manufacturing, harbor operations, etc.), and subsistence fisheries that contribute to local mixed economies (Vilhjálmsson et al., 2005; SADA Report, 2014; Zeller, Booth, Pakhomov, Swartz, & Pauly, 2011). The rich, productive waters of the Arctic supply over 10% of the world's marine fish catches (CAFF, 2013) and delete for culturally important traditional fisheries to the over 40 ethnic groups of the Arctic (Fondahl, Filippova, & Mack, 2015). Further, although aquaculture production for all of the Arctic hasn't changed much since 2014, it remains an important economic sector and has opportunities for growth (FAO, 2020). The Arctic marine socio-ecological ecosystem is experiencing continuous, rapid change, including shifts in the range of fisheries, decreasing sea ice coverage, increased risk of pollution, and varying forms of economic development and governance changes that can have both positive and negative impacts (Lam, Cheung, & Sumaila, 2014; Burgass et al., 2019; Kaiser, Pahl, & Horbel, 2018). As interest in the Arctic marine space increases, it is ever more important for research and policy to address specific challenges at local, regional, national, Arctic, and global levels. For example, as areas of the Arctic are becoming more and more accessible due to melting sea ice, there is increasing interest in developing new fisheries in the northern seas (Lam et al., 2014). Even though these fisheries would generate a positive economic benefit for the Arctic, developing the area bears a potential ecological risk (Lam et al., 2014). Another example is that of access to local fisheries, whether commercial or subsistence, where access rights to specific resources are governed without the interests of small-scale actors in mind (Briant, 2018; Chambers, Einarsson, & Karlsdóttir, 2020). This creates systems of inequity that can impact the well-being and self-actualisation goals of sustainable development. While fisheries and aquaculture can provide continued and perhaps expanded opportunities for

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renewable Arctic economies, barriers and uncertainties related to climate change, socio-economic change, environmental impacts, and institutional and political obstacles can create challenges.

Information reviewed in this chapter will provide background information and identify opportunities and constraints related to fisheries and aquaculture to increase our understanding of renewable economies in the Arctic. The specific objective of this chapter is to use the best available data to contribute to scholarship, policy and future development by identifying opportunities and threats for current and fisheries and aquaculture activities in the Arctic. The chapter is organised as follows. Section 2 reviews the best available knowledge related to fisheries and aquaculture in the Arctic from an interdisciplinary perspective, including the impacts of climate change. To narrow the scope, this chapter does not cover other living marine resources such as marine mammals or seabirds. Next, Section 3 identifies opportunities and threats related to renewable economies based on fisheries and aquaculture in the Arctic related to governance challenges. Section 4 then identifies knowledge gaps relevant for the research community by highlighting areas for future research under the framework of the United Nation Sustainable Development Goals (UN SDGs). The chapter concludes by offering key considerations for Arctic communities and decision-makers interested in renewable economies that include fisheries and aquaculture.

Background

There is a wealth of scholarship on Arctic fisheries and aquaculture (see, for example, Zeller et al., 2011; Kourantidou et al., 2021). Rather than extensively reviewing the literature, this section highlights the current state of knowledge of Arctic marine socio-ecological systems, which will then be used to highlight specific focus areas under the SDGs in Section 3. The PAME (Protection of the Arctic Marine Ecosystems) Working Group of the Arctic Council identifies 18 LME's (Large Marine Ecosystems) of the Arctic. Not all waters of Arctic nations are in the 18 Arctic LME's, and non-Arctic nations may fish in Arctic waters. Therefore, the information presented below denotes the best available data based on either Arctic LME's, sub-Arctic waters, or Arctic nations.

Fisheries

Subsistence fisheries

The Arctic has a long history of Indigenous fisheries, heavily relying on marine resources such as fish and mammals (AHDR, 2004; CAFF, 2013). Various traditionally harvested food sources are an important part of the diet in Arctic Indigenous communities such as in the Canadian and Alaskan Arctic with whitefishes (*Coregonis* sp.), salmon (*Onchorchynchus* sp.), char (*S. alpinus*) and trout (*Salvelinus* sp.) representing the most frequently consumed fish species (Kuhnlein & Receveur, 2007). In Greenland, the

population largely consists of Indigenous inhabitants, making up approximately 90% in 2019 (Statistics Greenland, 2019). Up until today, small-scale commercial fisheries and hunting are an important economic aspect in the eastern, southern, and northern parts of Greenland (Pálsson, n.d.).

Commercial fisheries and processing

According to the United Nations Food and Agriculture Organization (FAO), the Arctic can be divided into the Fisheries Statistical Area 18 and 27 (Zeller et al., 2011). Area 18 can be subdivided into the 8 Large Marine Ecosystems (LME) of the Kara Sea, Laptev Sea, East Siberian Sea, Chukchi Sea, Beaufort Sea, Arctic Archipelago, Baffin Bay, and Arctic Ocean (Zeller et al., 2011). Using the PAME designation of the 18 Arctic LME's, the commercial fishery catch in 2014 is outlined below in [Table 12.1](#), using Sea Around Us data (searoundus.org).

Table 12.1 Commercial fishery catch in Arctic large marine ecosystems (LME) in 2014

LME	2014 catch (1000 tonnes)
1-Faroe Plateau	413.27
2-Iceland Shelf and Sea	914.71
3-Greenland Sea-East Greenland	172.97
4-Norwegian Sea	1108.23
5-Barents Sea	1355.5
6-Kara Sea	1.64
7-Laptev Sea	2.17
8-East Siberian Sea	1.18
9-East Bering Sea	1001.59
10-Aleutian Islands	725.73
11-West Bering Sea	804.75
12-Northern Bering-Chukchi Sea	377.32
13-Central Arctic Ocean	0
14-Beaufort Sea	.24
15-Canadian High Arctic-North Greenland	0
16-Canadian Eastern Arctic-West Greenland	194.99
17-Hudson Bay Complex	1.47
18-Labrador-Newfoundland	487.15

While some of the most productive fishing grounds are located in the sub-Arctic region, such as the Barents and Bering Sea, with 633 fish species occurring of which 58 are considered commercial, the Arctic basin is comparably deserted with only 3 commercial species out of 63 (Meltote, 2013; SADA report, 2014). These productive fisheries are usually characterised by only one or two species, with the Bering Sea being dominated by Pollock and the Barents Sea by a cod-capelin system (SADA report, 2014).

The Russian area of the Arctic consists of the Kara Sea, the Laptev Sea and the East Siberian Sea as well as the Chukchi Sea, which is also bordered by the United States (Zeller et al., 2011). In accordance to the overall low fishery production of the Arctic waters, the Russian Arctic areas sustain a low number of fish species (Pauly and Swartz, 2007; Zeller et al., 2011). There were significant increases in the population of Siberia during the Soviet regime, and the current expanding industrialisation of the Russian Arctic between the 1960s and today has further expanded the population of the region. The implications of potentially increasing capture fisheries targeting such limited fish populations in adjacent Arctic waters is uncertain, but reported estimates of current fisheries production from this region may not accurately reflect its potential in this regard (Zeller et al., 2011).

Commercial fishing in the Kara Sea is dominated by six species of white fish, making up about 80% of the landings (Zeller et al., 2011). In the Laptev and East Siberian Seas, there are no commercial fisheries being operated and instead just small-scale fisheries (Newell, 2004). The East Siberian Sea does have populations of pink salmon (*Oncorhynchus gorbuscha*) and Dolly Varden (*Salvelinus malma*) that could sustain commercial harvesting on the grounds of size, but these populations are facing the risk of overfishing (Newell, 2004). In the area of the Chukchi Sea, the human population has been steadily decreasing with about 1,000 people remaining in coastal areas where they rely heavily on marine food sources (Newell, 2004; Zeller et al., 2011).

In 2009, under the United States Magnuson-Stevens Fishery Conservation and Management Act, an Arctic management area was implemented north of Alaska, reaching from the Seward Peninsula to the Canadian border and therefore covering parts of the Chukchi and Beaufort Sea (NPFMC, n.d.). In this area, all commercial fishing for finfish, crustaceans, and other animals except for marine mammals and birds, is prohibited to protect the sensitive ecosystem from potentially destructive fishing activities (NPFMC, n.d.). However, fisheries in the sub-Arctic waters of Alaska accounted for 2.67 M tons of catch or \$1.872 billion 2010 USD in 2014 (searounds.org) and are a vital economic activity in coastal communities.

Aquaculture

In the Arctic, harvesting fish from aquaculture is limited, however, there is room for growth in the sector for mainly finfish aquaculture (SADA report, 2014; Barbier & Burgess, 2017). There is also a small but growing niche

production of seaweeds and shellfish (Allison, Badjeck, & Meinhold, 2011). Norway, by far, dominates aquaculture production in the Arctic, mainly through salmon farms, followed by the USA and Canada (AP, 2012; SADA report, 2014). Norway's production of Atlantic salmon (*Salmo salar*) was valued at 2.2 billion EUR in 2010 (Norwegian Directorate of Fisheries, 2020). In Alaska, finfish aquaculture is prohibited (ADF&G, n.d.) but the aquaculture sector produces shellfish, such as Pacific oyster (*Magallana gigas*) and blue mussels (*Mytilus trossulus*), and kelp, which generated 1.53 million USD in 2017 (Pring-Ham, 2018). Meanwhile in Canada, as in Alaska, no measurable aquaculture currently takes place in Arctic waters, but in the sub-Arctic Pacific waters of British Columbia, 88,834 tons of finfish were produced in 2018, generating a value of 791 million CAD (Fisheries and Oceans Canada, 2020). In the Canadian Atlantic, Newfoundland, New Brunswick, and Newfoundland combine to produce 51,634 tons in 2018 for a value of 480 million CAD (Fisheries and Oceans Canada, 2020). Salmon pen aquaculture is rapidly expanding in Iceland, with backing from Norwegian companies. In 2018, 19,000 tons were produced, consisting mostly of salmon and Arctic char for an export value of 13.1 billion ISK in 2018 (Statistics Iceland, 2020). In Russia, there are cultivation rights for 30 salmon and trout sites in the Murmansk and Karelia regions, with the strategic goal of increasing by 16–18 farms in 2025 to produce up to 25–30,000 tons of salmonids. This growth coincides with the steady demand for and consumption of salmonids in Russia during the last decade along with the identification of aquaculture as a top priority in the agri-food section by the country's authorities.

Impacts of climate change

Based on model predictions, the effects of climate change will be most acute in the Arctic, with sea surface temperatures expected to rise more than in temperate latitudes (Team, Pachauri, & Meyer, 2014). The rate of climate change is considered to be two times faster in the Arctic than in other regions, and it is projected that the rate of ocean warming might be up to seven times faster than projected changes in terrestrial landscapes (Burrows et al., 2011). As an example, with 1.5°C of ocean warming, mobile species, such as plankton and fishes, might be driven to relocate at higher latitudes. Those species that cannot move, such as kelps and corals, would undergo high mortality, causing damage to dependent ecosystems (Hoegh-Guldberg et al., 2018). With either the mortality of sessile species or the range expansion of mobile species, the marine ecosystem complexes may experience great change. In the Arctic, change has already shown some impacts on the environment, both the abiotic and biotic components (Wassmann et al., 2011; Hoegh-Guldberg et al., 2018, AMAP, 2018). Other chemical changes occur due to the absorption of anthropogenic carbon dioxide have already been observed in the Beaufort Sea and in Alaska's coastal waters (Sumaila, 2015), resulting in ocean acidification that can affect the growth and development

of organisms that build shells. This in turn impacts a wide range of marine species further down the food web that depend on shelled organisms for food (AMAP, 2018). However, documenting particular changes is not easy due to a lack of reliable baseline data, which is needed for a comparison to the current situation (Wassmann et al., 2011).

Expected changes in the Arctic include more than just warming air and water temperatures; for example, the observed mean annual spatial extent of sea ice has been decreasing 3.5–4.1% per decade and precipitation is expected to increase between 30 and 50% (Team, Pachauri, & Meyer, 2014). The reduction in the duration of shore-fast sea ice will likely yield greater coastal erosion due to more impactful winter storms, with coastlines in many locations of the Beaufort Sea expected to undergo high rates of erosion (Gibbs & Richmond, 2015; Jones et al., 2009). Increased coastal erosion in the central Beaufort Sea has amplified the suspension of sediment load, thereby reducing benthic and water column primary production (Bonsell & Dunton, 2018). Such large-scale changes in environmental conditions in the nearshore region of the Arctic have significant implications for the ecological responses of local fishes as well as other marine organisms.

Physical impacts on marine ecosystems

All fishes are impacted by variability in their surrounding environment (Fechhelm, Fitzgerald, Bryan, & Gallaway, 1993). Water temperature and salinity are perhaps most influential, and deviations from “normal” conditions can lead to significant energetic costs through increased temperature regulation, metabolism, and osmoregulation (Bøuf & Payan, 2001; Edsall, 1999). Fish species that are forced to inhabit environments with conditions outside their optimal requirements can experience reductions in growth and recruitment and/or higher mortality (Arnesen, Jørgensen, & Jobling, 1993; Dutil, Lambert, & Boucher, 1997). To optimise growth and survival, fish may seek environments which provide conditions to optimise growth and survival (Monaghan, 2008); to locate such conditions may include shifts in geographic distribution (Hansen & Closs, 2009; Křivan, 2003). As a result, the magnitude, duration, and variability of environmental factors all play a significant role in determining the fish species composition, abundance, and rate-dynamic parameters, especially in dynamic environments such as the Arctic.

Despite the variable environment, nearshore Arctic waters support a variety of fishes. Whitefishes, such as Arctic Cisco *Coregonus autumnalis*, Broad Whitefish *C. nasus*, Least Cisco *C. sardinella*, and Humpback Whitefish *C. pidschian*, are amphidromous species that are tolerant of moderate levels of salinity and often undergo long-range migrations (de March, 1989; Fechhelm et al., 1993). For example, Arctic Cisco in Alaskan waters of the Beaufort Sea originate in the Mackenzie River, Northwest Territories, Canada, and are transported as juveniles >500 km along the shore via

easterly wind-driven surface currents (Fechhelm & Fissel, 1988; Fechhelm & Griffiths, 1990). However, other coregonids (for example, Broad Whitefish, Humpback Whitefish, and Least Cisco) spawn in rivers throughout northern Alaska and Canada (Craig, 1984, Craig, 1989; Fechhelm, Bryan, & Griffiths, 1994). Regardless of species, juvenile whitefishes spend the short growing season (late June into September) feeding in coastal estuaries and deltas of the Beaufort Sea and overwinter in freshwater pools or upwelling areas in coastal tributaries (Craig, Griffiths, Haldorson, & McElderry, 1985; Fechhelm, Martin, & Gallaway, 1999; Seigle & Gottschalk, 2013). The gadids Arctic Cod (*Boreogadus saida*) and Saffron Cod (*Eliginis gracilis*) are also ecologically important and support the Arctic marine ecosystem with their high abundance and energetic content (Elliott & Gaston, 2008; Harter, Elliott, Divoky, & Davoren, 2013; Thorsteinson & Love, 2016). These species serve as a key link between lower trophic levels (for example, calanoid copepods and amphipods) and higher trophic organisms (for example, seabirds and marine mammals; Harter et al., 2013). Pacific salmon *Oncorhynchus* spp. have been documented in the Arctic at increasing frequency in recent years, with a natal population in the Mackenzie River in Canada and potentially other rivers of the central Beaufort Sea in Alaska (Gatt, Hamman, Priest, & Sutton, 2019; Irvine, Macdonald, & Brown, 2009).

Impacts to coastal communities: Food security, economic opportunity, and local infrastructure

In addition to their key role in the ecology and food-web structure of coastal marine ecosystems, nearshore fishes also provide important subsistence food resource for local Indigenous communities (Fechhelm, Streever, & Gallaway, 2007; Thorsteinson & Love, 2016). As a consequence, the effects of climate change could significantly impact fishing activities of Indigenous peoples (Galappaththi, Ford, Bennett, & Berkes, 2019). As higher levels of acidity are already documented for the Beaufort Sea (Zhang, Yamamoto-Kawai, & Williams, 2020) and Alaska's waters (Monacci, Cross, Hurst, Long, & Rossin, 2019), Indigenous communities might eventually not have enough nearshore marine resources available to harvest as fish stocks will be decreasing due to lower prey availability (Sumaila, 2015). As a result, climate change has the potential to disrupt food security for humans. While there are no commercial fisheries in federal waters of Arctic Alaska, subsistence fisheries in nearshore areas are important socio-cultural and nutritional contributions to local Inupiaq communities (Fechhelm et al., 2007; NPFMC, 2009). Communities along the Chukchi and Beaufort Sea coastline, such as Utqiagvik, Nuiqsut and Kaktovik, are dependent on the subsistence harvest of marine organisms, including abundant whitefishes found in the river deltas and nearshore coastal waters (Craig, 1987; Braund et al., 2012). Although the economic impact of these fisheries is limited, ecological changes in the Arctic would have substantial ramifications for both

food-web structure and dynamics as well as human communities (Moerlein & Carothers, 2012). As a result, the importance of Arctic fishes to coastal communities necessitates the examination of potential effects of climate change prior to understanding how ecosystems and food security may be impacted in the future (Reist et al., 2006).

There is also uncertainty involved in projecting fisheries catches for commercial stocks under climate change (Cheung et al., 2016) and how the fishing industry might change. While it can be assumed that fisheries-dependent communities could adapt to fluctuating fish stocks or might even profit in the short term, their overall adaptive capacity is limited due to the threatened infrastructure and other socio-economic factors (Alvarez, Yumashev, & Whiteman, 2020; Ford, McDowell, & Pearce, 2015). The adaptive capacity of Arctic fishing communities can be defined as the ability to cope with external stresses, such as climate change, and the ability to modify or change (Kokorsch & Benediksson, 2018). It is an integral part of community resilience which describes “[...] the ability of a community to cope and adjust to stresses caused by social, political, and environmental change and to engage community resources to overcome adversity and take advantage of opportunities in response to change” (Amundsen, 2012, p. 1). However, the adaptive capacity and community resources are somewhat limited and dependent on economic factors, decision making power and resource access that are usually not part of the local agency (Landauer & Juhola, 2019; Ford et al., 2015). Relevant locational factors include infrastructures for the communities in general and the fishing industry in particular. Especially fisheries dependent communities with a monotonous local or regional economy are predicted to face difficulties due to climate change. Community infrastructure, local agency and a diversified economy are, however, key parameters for resilience building and the preparedness for transformative shocks (drastic shifts or sudden changes) or structural changes (slow and gradual processes) (Kokorsch, 2018).

Arctic coastal communities are not only dependent on the infrastructure at the shoreline, but also the hinterland and transportation systems onshore are of relevance. Thus, climate change related threats to renewable fisheries economies are not limited to melting sea ice and rising sea levels, but include coastal erosion, thawing permafrost, extensive precipitation, flooding and severe weather (Landauer & Juhola, 2019; Moon et al., 2019; Melvin et al., 2017). Hence, some communities, for example in coastal Nunavut or Alaska, will face multiple threats and socio-economic burdens (Alvarez et al., 2020; Melvin et al., 2017; Walker & Peirce, 2015). It can be expected that climate change will lead to significantly higher costs for maintenance, restructuring or new construction of critical infrastructure (Larsen et al., 2008; Pahl & Kaiser, 2018; Streletskiy, Suter, Shiklomanov, Porfiriev, & Eliseev, 2019; Suter, Streletskiy, & Shiklomanov, 2019). While rising costs for infrastructure are not a problem per se, in the Arctic it hits communities and industries that are commonly investment-intensive and

face small profit margins (Stephen, 2018; Suter et al., 2019). Recommended proactive investments in adaptation and infrastructure preparedness are subject to debate regarding their financing and responsibility (Landauer & Juhola, 2019; Melvin et al., 2017). From this perspective, it is debatable to what extent renewable economies can be sustained, in a setting in which critical infrastructure is vulnerable. In other terms, the economic fundamentals (literally and figuratively) might not be renewable but need to be constantly renewed.

Apart from the impact on infrastructure and local economies, several socio-cultural and demographic consequences for coastal communities due to climate change can be identified: cultural heritage loss, health disparities and worsening food and water security (Alvarez et al., 2020; Fritz, Vonk, & Lantuit, 2017; Irrgang, Lantuit, Gordon, Piskor, & Manson, 2019; Stephen, 2018). The combination of these factors might lead to intensified out-migration or the relocation of some communities, thereby impacting the workforce for economic activities. The attractiveness of the fishing sector (capture fisheries and subsistence fisheries) on and offshore will be negatively affected by the threats outlined above; fisheries are a business sector that can be characterised as unstable and climate change is an additional hindrance for new entrants to the industry in the long run. Aquaculture might be an alternative business strategy for Arctic coastal communities and an opportunity to respond to the changes and threats.

Impacts to aquaculture

Aquaculture is likely not as affected by climate driven change in the environment as the commercial fisheries, since location, population density and resource availability are controlled factors (SADA report, 2014). Significant environmental changes might change the distribution of the aquaculture industry throughout the Arctic (SADA report, 2014), but overall aquaculture in the Arctic will likely see positive effects from warming water temperatures (Hermansen & Troell, 2012). For example, the climate-induced temperature rise on the Norwegian coasts is likely to range between 0.5 and 2.5°C and will play out differently during different seasons. Despite large uncertainties, and just a few detailed studies that specifically target climate change impacts on Arctic aquaculture, the direct effects of temperature change on the aquaculture industry can be modelled with fairly good accuracy, including effects on fish growth and impacts on the whole industry. Present optimal conditions for open sea cage salmon farming in Norway lie between 62 and 64° North latitude. Further south, summer temperatures are higher than optimum, and further north, temperatures are too low throughout the year. Increased sea temperatures will generally move this optimal zone further north. For fish farms in colder locations than optimal, production can increase with 11–15% per degree increase in temperature (Lorentzen, 2008). For farms at optimum or higher temperatures,

production will decrease. Salmon farms in the Arctic generally experience lower than optimum temperatures and will therefore likely experience improved productivity. Species like cod and halibut have narrower temperature ranges and should respond in a similar way (Troell et al 2017). As a buffer against uncertain climatic impacts of sea-pen aquaculture, employing recirculating aquaculture system (RAS) technologies is seen as a means of reducing exposure to climatic extremes. The RAS are expensive in terms of both capital and operational costs and require high levels of technical expertise (Murray, Bostock, & Fletcher, 2014). The long-term reliability of RAS still needs to be demonstrated. Aquaponics, the production of fish and plants in an integrated system, is proposed as a means of producing food in areas where freshwater is limited (Somerville, Cohen, Pantanella, Stankus, & Lovatelli, 2014).

Opportunities and threats related to governance systems

The management of the Arctic areas of those nations adjacent to the Arctic Circle lies within each country's national governance (Burgass et al., 2019). Under the 1982 United Nations Convention on the Law of the Sea (UNCLOS), each country is obliged to prevent overfishing by national fisheries within the EEZ (Pinsky et al., 2017). However, some issues reach beyond just one jurisdiction and therefore require nations to work together and develop joint management strategies (Pinsky et al, 2017; Van Pelt, Huntington, Romanenko, & Mueter, 2017). Therefore creating new, more legally binding cooperative fisheries governance mechanisms and strengthening existing agreements, has been identified as a pressing need (Molenaar, 2012; Molenaar, 2013).

The Arctic Council was created to provide a forum for enhancing and expanding international collaboration in the Arctic, but any focus on fostering such collaboration with regard to sustainably managing fisheries in this region has largely been “off the table” (Molenaar, 2013). As reported by Schatz et al. (2020), “the Arctic Council decided in 2007 that fisheries issues should be considered ‘within the context of existing mechanisms’.” However, Molenaar (2012) has observed that “there is no juridical obstacle” for the Arctic Council to take a more active role, and it has engaged in some broader international fishery management-related discussions through its standing committees. While the Arctic Council has not “explicitly reversed” its formal position with regard to governance and international coordination and management of fisheries in the region, it could, and perhaps should, take a more active role (Molenaar, 2013).

As extensively reviewed and summarised by Molenaar (2012, 2013), the existing governance framework for fisheries in the Arctic encompasses global, regional and bilateral fora and instruments, as well as limited Indigenous co-management arrangements (Ayles, Porta, & McV Clarke, 2016). However, all of these arrangements, instruments and fora are

constrained by lack of sufficient data, inadequate domestic regulation, gaps in important Arctic Coastal State fora and instruments, and gaps in high seas coverage with Regional Fishery Management Organizations (RFMOs) and other arrangements (Molenaar, 2013). This last identified shortcoming was more recently addressed in 2018 by the signing and ratification of the “Agreement to Prevent Unregulated High Seas Fisheries in the Central Arctic Ocean” (2020). This agreement was signed in Ilulissat, Greenland, by the five Arctic states of Norway, Denmark (for the Faroe Islands and Greenland), Canada, the United States, and Russia as well as by Iceland, Japan, Korea, and China (European Commission, 2018; Harvey, 2018; NOAA Fisheries, 2018). Such broader participation in creating new, and enhancing existing, Arctic fisheries management instruments and agreements continues to be a significant challenge and needs to be actively pursued (Molenaar, 2012) as it was for this agreement.

This CAO agreement has been represented as the first preventive, international agreement of such magnitude (Harvey, 2018; Rayfuse, 2018; NOAA Fisheries, 2018). Currently there is no fishing activity actively occurring in the CAO, but exploratory fisheries have been conducted in that area in the past (Harvey, 2018). The agreement provides for some limited continuation of this exploratory fishing activity under requirements to be developed within three years of the agreement's ratification. For a period of 16 years following ratification, commercial fishing is limited, “pursuant to conservation and management measures for the sustainable management of fish stocks adopted by one or more regional or sub-regional fisheries management organizations or arrangements” (Article 3,1a), and any “conservation and management measures that may be established” by the parties (Article 3,1b). Encompassing an area of approximately 2.8 million km², commercial fishing will only be allowed after this 16-year period if international management strategies are developed and implemented to manage such fisheries (NOAA Fisheries, 2018). Furthermore, the agreement also requires (Article 4,2) the establishment of a “Joint Program of Scientific Research and Monitoring” to better understand the ecosystem and potential impacts of fisheries as well as create a baseline needed to document future development (Harvey, 2018; NOAA Fisheries, 2018). This joint program also explicitly includes the integration of “Indigenous and local knowledge” (Article 4,4). By largely prohibiting commercial fishing activity for the period the agreement is in force and effect, not only are fish populations present in the CAO protected from overexploitation, but potential pollution and damage caused by the vessels will be very limited (Harvey, 2018). However, before the agreement comes into force, all nations that have signed the agreement must ratify their commitment which, as of August 2019, has only been done by Canada, the EU, Russia, and the United States (US Dept of State, 2020). Some analyses of the agreement have predicted that closing the high seas could eventually benefit coastal fisheries as the high seas would become recovery areas from which a spill-over effect

could replenish harvested fish stocks in coastal areas (Sumaila et al., 2015). However, the agreement has also been the subject of some criticism. Schatz et al. (2019) provides a comprehensive and exhaustive legal analysis of the agreement that identifies potential conflicts and ambiguities, concluding that “the success of the newly concluded CAOFA Agreement cannot be assessed from a purely legal standpoint, but largely depends on the political will of its parties to implement the rights and obligations codified therein in an effective, lawful and legitimate manner.”

Arctic Coastal States and non-Arctic countries have participated in both unilateral National actions to address fishery management in their Arctic waters and have engaged in international collaborations. The United States was the first nation to set an example on protecting their Arctic waters by adopting, in 2009, a Fishery Management Plan for their Arctic management area that bans commercial fishing activity (NPFMC, n.d.). China has not only shown interest in the development of the Arctic but has been involved in Arctic politics over the past decades, such as its involvement as an observer in the Arctic Council (Pan and Huntington, 2016; Østhagen, 2019, Kuo, 2019). Particularly on Svalbard, China has established considerable infrastructure to conduct research on natural science as well as on opportunities to utilise Arctic resources to strengthen further the relationship to Arctic states (Pan & Huntington, 2016; Østhagen, 2019; Kuo, 2019). Besides their interest in possible Arctic sea routes, there are incentives for involvement in potential Arctic fisheries to ensure enough resources for China's growing population, recognising that local fish stocks are in decline (Østhagen, 2019, Kuo, 2019). The European Union lacks direct access to the Arctic Ocean, but the EU states of Finland, Sweden, and Denmark are geographically positioned close to the Arctic (Østhagen, 2019). Interest in being involved in the policy of developing the Arctic has been expressed by the EU (Østhagen, 2019). The EU's Arctic Policy as well as their Ocean Governance policy highlights various goals, including sound stewardship of the high seas, developing a responsible strategy to access the Arctic's resources, and at the same time respecting the rights of Indigenous communities in the Arctic (European Commission, 2018).

While it is clear that progress is being made towards creating and implementing a governance framework for fisheries in the Arctic, the challenges are significant. Many countries are involved that often have conflicting interests. It could be argued that the power, and much of the responsibility, lies with the Arctic Coastal States in achieving this goal, but many other countries have interests in the future of Arctic fisheries, and their perspectives must be heard. Most importantly, the Indigenous peoples of the North are very much affected by the outcome of these deliberations over fisheries resource allocations and conservation, and need to be at the table and share equally in the decision making. Many hard choices and trade-offs need to be made as this new and hopefully integrated and comprehensive

fisheries governance framework is crafted. As Jensen and Rottem (2010) have observed, “The Arctic region does not suffer under a state of virtual anarchy, despite outward appearances.”

The future of aquaculture in the Arctic

Recent international policy directives from the UN recommend replacing meat with seafood to limit global temperature rise to 1.5 degrees C, and that increasing food production in the ocean through aquaculture is a key strategy in reaching the climate goal set in the Paris Agreement. Other directives for growth, such as the EU Blue Economy Report, identify worldwide opportunities for aquaculture production, and Arctic nations are among those with strong potential due to the environmental changes discussed above. However, governance of aquaculture in the Arctic is in constant flux and this presents a challenge for communities planning for growth.

In the United States, the Advancing the Quality and Understanding of American Aquaculture Act was introduced in the US Senate in 2018 (S 3138 – 115th Congress) and the United States House of Representatives (HR6966 – 115th Congress) to encourage aquaculture to meet the global demand for seafood (Resneck, 2018; Bittenbender, 2019). As this new bill could impact the ban of finfish aquaculture in Alaska, the United States Rep. Don Young responded by filing the Keep Fin Fish Free Act to ensure the health of wild fish stocks (Bittenbender, 2019). While the 2018 bills did not progress, a 2020 version was introduced to the United States House of Representatives in March and is progressing through Committee reviews (HR 6191 – 116th Congress). More recently, the United States president has signed an executive order intended to expand United States aquaculture production rapidly due to pressures from the COVID-19 pandemic to increase domestic food production and reduce foreign trade (EO 13921, 85 Fed. Reg. 28,417 (May 12, 2020)).

In Russia, there is a clear example of how the growth of aquaculture is linked with political decisions that are not easily reversed. Sanctions introduced in August 2014 that prohibited imports of trout and salmon to Russia from Norway, the EU, United States, Canada, and Australia meant that Russian companies expanded to replace the near 200,000 tons of those products that previously came from outside Russia (Adamowski, 2017). While the growth in Russia is expected to continue, it is unclear how future governance decisions might impact the growth of aquaculture.

In Norway, aquaculture licensing and permitting processes can be a hindrance in an uncertain future. Legal requirements limit production sites because a license is granted for one region and cannot be transferred to any of the other four regions in place for aquaculture management. Model predictions show a significant improvement in productivity for the northern farms and vice versa for the farms furthest south and a corresponding northward shift in production if the restrictions are lifted (Hermansen & Heen, 2012).

Discussion: Renewable economies, SDGs, and knowledge gaps

Because renewable economies are so tightly linked with sustainable development, the authors chose to organise the discussion around the UN SDGs (UN 2020). The UN SDGs are a list of 17 priority goals that serve as a call to action for countries around the world, and provide a basis of comparison for tracking the progress of sustainable development (UN, 2020). All SDGs are relevant for Arctic nations; however, it has been noted that the SDGs were not created with the Arctic in mind and certain goals are difficult to scale down (Sköld, Baer, Scheepstra, Latola, & Biebow, 2018). Specifically, goals related to poverty, food, education, water, and sanitation are not often thought of as important topics in Arctic nations due to a dichotomy in the UN between developing and developed nations, but these issues can have high variance in the Arctic depending on country and region (Kroll et al 2019; Menezes & Chater, 2018). It has been suggested that the SDGs can be addressed through the development of indicators that are Arctic-specific (Sköld, Baer, Scheepstra, Latola, & Biebow, 2018). Following this line of thought, the authors of this chapter selected seven SDGs that have the most relevance in identifying knowledge gaps for Arctic fisheries and aquaculture. Based on the information provided in Sections 2 and 3, we identify below 2–3 priority points for each SDG that identify areas of future focus for researchers and decision-makers that will help track indicators and therefore the fulfillment of SDG targets. For ease of dissemination, the following section presents a series of graphics. With each SDG, bullet points are listed to provide recommendations by the authors for priority areas of research questions that would create relevant data to assess the goal under the lens of Arctic fisheries and aquaculture.

Figure 12.1 SDG 1 “No Poverty” and related research topics. (SDG image reproduced from <https://sdgs.un.org/goals>)

Figure 12.2 SDG 2 “Zero Hunger” and related research topics. (SDG image reproduced from <https://sdgs.un.org/goals>)

Figure 12.3 SDG 3 “Good Health and Well-being” and related research topics. (SDG image reproduced from <https://sdgs.un.org/goals>)

Figure 12.4 SDG 5 “Gender Equality” and related research topics. (SDG image reproduced from <https://sdgs.un.org/goals>)

Figure 12.5 SDG 8 “Decent Work and Economic Growth” and related research topics. (SDG image reproduced from <https://sdgs.un.org/goals>)

Figure 12.6 SDG 10 “Reduced Inequalities” and related research topics. (SDG image reproduced from <https://sdgs.un.org/goals>)

Figure 12.7 SDG 14 “Life Below Water” and related research topics. (SDG image reproduced from <https://sdgs.un.org/goals>)

Conclusion

As reviewed in this chapter, many reports produced for the Arctic Council, among others, have detailed the best available knowledge of Arctic fisheries and aquaculture. The goal of this chapter was to put that knowledge in the context of renewable economies and sustainable development to provide key considerations for Arctic communities and decision makers. The UN SDGs are not a perfect framework to guide policy concerning renewable economies in the Arctic, but instead provide a starting point to build effective future policy and research for renewable, sustainable Arctic fisheries and

aquaculture. This chapter has reviewed the prevailing social, economic, and climate-related challenges to Arctic fisheries and aquaculture, and provided a path forward by creating recommendations for future focus related to seven SDGs that are most closely related to fisheries and aquaculture: No Poverty (1), Zero Hunger (2), Good Health and Well-being (3), Gender Equality (5), Decent Work and Economic Growth (8), Reduced Inequalities (10), and Life Below Water (14). Through the focus on SDG's, this chapter highlights the need for Arctic-specific data collection and modeling that is not currently clearly visible through larger indicator data sets in fisheries and aquaculture. For example, poverty indicators, hunger elimination national objectives, job satisfaction and well-being data sets, and gender and technology aspects are not often considered with specific focus on fisheries and aquaculture. However, these industries and livelihoods, when practiced renewably and sustainably, may be key factors in fulfilling Arctic-specific SDGs. The path forward to renewable economies in the Arctic related to fisheries and aquaculture must start with better and more detailed Arctic-specific focus related to commercial and subsistence fisheries and aquaculture.

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