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Executive summary

The Workshop on Global Ecological and Economic Connections in Arctic and Sub-Arctic Crab Fisheries (WKCRABCON), chaired by Brooks Kaiser, Denmark, met at ICES HQ, Copenhagen, Denmark, 11–13 December 2017. The meeting was attended by 20 participants, one of whom provided input via WebEx facilities, representing 8 nations.

The purpose of the meeting was to review and consider recent research into the complex bio-economics of Arctic and Sub-Arctic commercial crabs as profitable fisheries resources and new ecosystem disruptors. The participants come from academic disciplines, industry activities, and nationalities involved in the demand and/or supply of these crabs.

Under the overarching consideration of the Barents Sea as a new entrant into the supply of commercial Red King and Snow Crabs, individuals in the group made presentations about the market and/or ecological conditions in their area of expertise.. The meeting consisted of individual presentations, group discussions, and break-out sessions. Sessions were mainly organized geographically, with presentations covering Alaskan, Norwegian, Russian, Canadian and Greenlandic supply of commercial crabs and economic and ecological research pertaining to these crabs, and Japanese and Korean economic research into demand and domestic and international supply of the crabs. The report summarizes these contributions to information sharing and develops a list of research interests and priorities that benefit from a global approach to understanding these changing fisheries. The absence of representation from the growing markets of China presented a limitation

Through the workshop, significant information sharing channels were introduced amongst ecologists, economists, and industry professionals. The participants identified key areas in which international and interdisciplinary research could provide gains to all parties. In particular, they find that both the inherently competitive interests of regional suppliers and the consumers who benefit from this competition could be made better off through improved cooperation in understanding the ecological-economic dynamics affecting each local community, and the steps that local communities have taken to respond to global shifts in markets and environmental conditions.

Focal points for cooperation include acknowledgement of how increased diversification strategies intended to smooth climate uncertainties might require international agreements and cooperation for global sustainability. Furthermore, these strategies might be executable through industry and scientific research in addition to policy channels, particularly with respect to information sharing. Valuable information sharing might include better exchange amongst crab producing environments facing different ecological challenges, ranging from invasion in the Barents, to failing recruitment in the Bering, to possible northward shifts and IUU fishing harming Japanese and Korean production.

Similarly, better information sharing about harvest quality can better connect sellers and buyers, including sustainability measures and efforts to reduce IUU. The question of whether sufficient consumers are willing to pay more for documentation of sustainable catches to make it worth the additional costs is an important one that remains unanswered.

The main recommendations are to continue sharing information amongst global participants in these markets and the scientists who support their continued productivity. This includes more translation from scientific understanding of the stock to the institutions that regulate the stock, and for more inclusion of economic considerations in stock assessments and regulation settings.

1 Opening of the meeting

The Chair, Brooks A. Kaiser (University of Southern Denmark) opened the meeting at ICES HQ, Copenhagen, Denmark. B. Kaiser welcomed the participants.

WebEx facilities and an ICES SharePoint were made available before and during the meeting to support online discussions and storage of key papers and minutes collected during discussions. These tools were useful to speed up the work, support discussions and support efficient exchanges of information. After a brief overview of the ToRs and our goals, the participants introduced themselves and gave a brief review of their background with regards to Arctic and sub-Arctic crab harvesting, research and advice. A total of 20 participants representing eleven nationalities and working in 8 countries (Denmark, Greenland, Finland, Japan, Korea, Norway, Russia, and the United States) participated during the meeting. Flight disruptions prevented one participant from arriving from the United Kingdom.

2 Adoption of the agenda

The agenda had been circulated and agreed to prior to the meeting. The organizational goals of the agenda were to:

a) Review and consider recent research into the complex bio-economics of Arctic and Sub-Arctic commercial crabs as profitable fisheries resources and new ecosystem disruptors;

b) Review and synthesize ongoing work across relevant disciplines to develop a more comprehensive understanding of potential risks and opportunities related to shifting global market conditions for these globally utilized Arctic and sub-Arctic crabs;

c) Generate insights concerning the big picture impacts of ecological shifts in marine productivity and/or economic transformations in fisheries markets that we expect due to climate change, technological developments, and shifts in consumer preferences for sustainability or other product qualities

3 Summary of the Presentations

3.1 Norwegian Barents Sea Perspectives

Overview of the existing biological and ecological knowledge on the invasive crustaceans of the Barents, the Red King Crab (*Paralithodes camtschaticus*) and the Snow Crab (*Chionoecetes opilio*) (Jan H. Sundet, Institute of Marine Research (IMR) Tromsø)

Crab fisheries management in Norway along with the long-term strategic goals within the country are complex and evolving due to the dual nature of profitable resource and biological invasion.

Early Norwegian perceptions for the Red King Crab (RKC), dating back to the Grey Zone Agreement with Russia that did not allow for commercial fishing activity, indicate mixed concerns over the potential of the invasion from the beginning. The reasoning behind this

first strategy is not well-documented on behalf of Norway. The prohibition aided the progression of the invasion, which gradually became problematic for the gillnet fishers in Finnmark. The experimental fishery in Norway started in 1994 and continued through to 2002, when the commercial fishery opened for the first time.

Changes in the Norwegian perceptions were manifested across time through the regulatory changes regarding the Total Allowable Catch (TAC), the carapace length size of the harvestable stock, the proportion of female to male crabs harvested as well as the seasonal limitations for commercial fishing. The management goals in place, since 2008, aim at maintaining a long-term population east of 26°E (quota-regulated fishery) and at the same time eliminating the spread of the invasion west of 26°E (open access fishery). Norwegian management goals notably refer to the RKC fishery as ''long-term'' rather than ''sustainable.'' IMR conducts annual stock surveys east of 26°E and uses a survey and population-dynamics model to provide stock estimates and provide recommendations on the annual TAC. The fishing mortality for RKC in the quota-regulated area is higher than in other fisheries. In recent years the TACs have been set even higher than the recommendations from IMR and this has created concerns for overfishing of the RKC stock. Conversely, the unregulated fishery appears efficient in minimizing the spread and is therefore seen as an effective measure that serves well the Norwegian management goals for curtailing the invasive crab.

The origins of the SC presence in the Barents are less certain than the well documented introduction of RKC by Russian scientists. Alternatives include natural range expansion or ballast water introduction. Regardless of the drivers behind the introduction and spread of the SC in the Barents, the growth and spread of the SC in the Barents display clear characteristics of an invasion.

Global landings for SC include the Northern Pacific, Atlantic Canada and Greenland. The Barents fishery has grown significantly within few years of commercial exploitation (since 2012), with high prices driving an increasing demand and therefore attracting increased harvest, particularly during the 2012–2015 high seas fishery in the Loophole.

The Norwegian authorities have issued more than 60 licenses for the SC fishery but the actual number of Norwegian vessels participating does not exceed 15. The IMR is currently building knowledge on the SC stock, using models from the fishery in Eastern Canada but also utilizing their experience on the RKC in the southern part of the Barents Sea. The management goal for the SC is to maximize long-term yield. The most dense concentration of SC is currently found in the Russian EEZ and the International waters of the Loophole. As shown from the annual ecosystem surveys and the ongoing commercial activity, the SC has gradually started expanding its range of distribution within the Svalbard Fisheries Protection Zone (FPZ). The SC is treated as a sedentary resource by the two countries that share the stock, Norway and Russia.

Following the 2015 designation of the SC as sedentary, commercial activity has been restricted by Russian authorities for the 85% of the Loophole that lies over the Russian Continental shelf. Norwegian vessels are thus limited to the smaller portion of the Norwegian continental shelf in the Loophole.

Vessels that are neither Russian nor Norwegian are increasingly targeted for exclusion from the Loophole and from the Svalbard Fisheries Protection Zone (SFPZ). The sedentary species designation renders the SFPZ management uncertain as Norway claims sov-

ereignty over the continental shelf but the Svalbard Treaty (1920) may require equal access for commercial activities under any flag. Norwegian authorities have entered into disputes with European fishing vessels that have been openly harvesting SC in the Loophole and the SFPZ. Multiple arrests of European SC vessels have progressed to trial through Norwegian courts and EU courts. J. Sundet has been called to offer his expertise on biological characteristics of the SC (e.g. its sedentary nature), indicating the use and need of scientific input to economic and political decision making.

Nofima and scientific interest in large Arctic crabs (Bjorg Helen Nøstvold, Nofima)

Nofima has several ongoing joint projects related to the Snow and King Crabs in the Barents Sea. These include SnowMap to optimize utilization and value throughout the value chain; Finnkrabbe, involving the processing industry; Live storage, also with industry; Exploitation of by-products; Bait optimization; crab welfare; market opportunities for live crab to Asia and the US; live storage and farming of RKC; and internal agency research.

70% of RKC in Norway is now destined for live markets. Snow Crab remains a frozen market; 100% of 2017 processing was sold as frozen clusters. The most important markets for Norwegian RKC are frozen exports to Japan and live exports to S. Korea and the US. The most important markets for Norwegian SC are frozen exports to the US, Japan and to a lesser extent, S. Korea.

S. Koreans eat 54 kg of seafood per capita per year, and the economy is growing. The country also serves as a transit hub for seafood; the effect this has on crab imports and exports remains unclear. The RKC is perceived as the highest quality/ greatest luxury crab, followed by domestic SC, imported SC, Korean swimming Crab, and lastly, Red Snow Crab. Norwegian crab faces competition from Russian crab delivered at lower cost from the North Pacific by vessel.

Japan also consumer about 54 kg/person/year and has a long tradition of eating crab. Crab imports have been declining. The frozen market dominates, with 86% of RKC frozen and 67% of SC frozen. In the hierarchy of Japanese preferences, RKC remains on top while Snow Crab is a mid-level produce and Red Snow Crab is low end. There is a large variety in retail options and preparations for crab. In Japan, 55% of the RKC imports go to retail with 45% going directly to food service, while in Korea, 10% go to retail and 90% go to food service. The percentages for SC are similar; for Japan, it is 50/50 between retail and food service, while for Korea it is 5% retail and 95% food service.

In all countries, quality conditions that matter are packaging, cleanliness and color of the crabs, high meat content (>70%), intact legs, and in Asia, lower salt content.

Economic uncertainties in the Barents Sea crab invasions and implications for management (M. Kourantidou, University of Southern Denmark)

The RKC and SC invasions/fisheries in the Barents are considered ''mixed-blessing invaders;'' they impose externalities on the ecosystem and its flow of services but at the same time can be productive assets of the economy. For the RKC, Norwegian authorities are trying to reconcile the goals of long-term crab fishery with minimizing the spread further west along the Norwegian coast. This is a hard-to-measure trade-off which becomes evident in the difficulties that the Ministry of Trade, Industry and Fisheries are facing in balancing the risk of spread with maintaining stability in the fisheries. Applying high fishing mortality seems to have limited the spread, but at the same time it reduces the stock. This reduction imposes visible costs on the socioeconomic welfare in coastal communities in Finnmark now profiting from the growing crab industry. These costs may or may not be higher than harder to measure ecological costs underway.

Despite the initial bycatch problems in other traditional fisheries, the RKC fishery has grown significantly over the last decade and this has permitted small fishing communities to grow. The initial purpose of the introduced RKC quota system was regarded as a compensation scheme that would allow small-scale fishers, who had previously suffered losses from bycatches, to grow. Norway has seen a decline in the number of people working in fisheries as well as in the number of vessels deployed. Finnmark has been no exception to this declining trend, but their percentage to the total number of active vessels in the county started increasing soon after the opening of the commercial fishery for the RKC (in 2002). The increasing participation of vessels signals the high profitability of the fishery as well as the ease of entry. The crab fishery in Finnmark displays characteristics of perfect competition and is also opening up new markets that involve significant ongoing export activity.

The RKC in Finnmark has given rise to a fishery that has revitalised small communities but requires new infrastructure and capital investments to sustain it. Traditional fisheries in Northern Norway are mostly codfish, whose infrastructure needs do not match those of live crab exporting. The recent increase in exports of live RKC to Asian markets calls for investments into new infrastructure that can support the upcoming industry. The increasing trend in RKC harvested quantities and world market prices, especially for live crab, supports increasing investment and a shift out in supply through entry.

The question of how to support the industry and empower coastal communities is directly dependent on the management of the fishery, which in turn depends upon perception of the losses from the invasion. Depending on how large the perceived invasion damages are, regulators may change their assessment of the fishery value and move to a lower stock with lower external damages.

Numerous uncertainties over socioeconomic and ecosystem benefits and costs complicate the management of the crab and determination of the optimal stock level. The biggest uncertainties are with respect to the ecosystem costs of the invasion, which are also debated in the literature. The big question is whether the crab fishery should continue to be treated as a compensation fishery or whether it should be considered a main occupational fishery. Is it optimal to move the 26°E degree line and expand the quota-regulated fishery, which would increase profitability of the fishery but create a bigger population in the west? In doing that, do we consider the obligations of Norway towards the Convention

for Biological Diversity and its adherence to the precautionary principle when it comes to management of invasive species?

The biggest risk with the spatially differentiated management goals in Norway is the fact that the cost of being wrong in our perception of the invasion losses is unknown. The fisher-centric optimal dynamic path for stock levels conflicts with a fully ecosystem-inclusive dynamic path of stock levels. This results in a need to identify the bioeconomic trade-off inherent in the fuller ecosystem dynamics. Until we have enough information to identify with accuracy this trade-off, how should we allocate our resources? Should we invest more into managing efficiently the commercial stock or learning more about ecosystem impacts of the invasion?

Yet another challenge is that Russian and Norway share the same population but only cooperate at the research front and have different management goals. There is some debate about whether the population is now two separate stocks.

The story may be repeating itself in the case of the newly introduced SC in the Barents. There are similar types of ecological uncertainties. The management complexities differ. They are mainly due to the uncertain property rights that are resulting in international conflict. Though the SC fishery is mainly offshore with on-board frozen processing, there may be some additional cost to coastal communities, such as for example in Batsfjord. There are useful lessons to be learned for the management of the SC from the RKC experience, in spite of the many differences. Careful understanding of these lessons also can inform Arctic fisheries management more broadly as more and more species displacements follow from climate changes.

Norwegian Red King Crab and Snow Crab (Benedicte Nielsen, Norges Råfisklag)

Infrastructure investments in RKC landing facilities are increasing. There are now 19 RKC buyers at 31 landing points in Finnmark. In 2016 there were 603 active vessels in the fishery. All but 3 of the buyers are located in the quota area to the east of 26 degrees E. The first hand price they pay must meet a minimum threshold that is adjusted monthly. The model weights live and frozen prices and the actual price received by the fisherman over the previous two weeks in calculating the minimum price. The price is graduated by size.

The fishery had very high catch in 2008–9 corresponding to new impetus to control populations to the west. Since 2013 the catch, average price, and overall value of the fishery has been climbing. Catches are mainly from the quota area; high catches in 2015 in the free fishing zone (855 tons) have not lasted.

The fishing season has been open year round for several years; there are reduced catches during molting season. August and September have had the highest catches. August has gained in market share vs. September since 2015 as fishers work to get ahead of the September season openings elsewhere.

Prices are high and rising. There is more effort to sort small or poor quality crabs onboard and get them back into the sea. This results in lower damages and better prices.

There are improving logistics and facilities at both Oslo-Gardermoen and Lakselv airports that facilitate live crab exports. Overnight express company DHL has doubled their

capacity for handling live crab, for example, and a "crab hotel" is used to store and refresh crabs in transit.

Live RKC exports are increasingly dominating, accounting for over half of all exports currently. The main market for live crab is S. Korea, with the US and Canada as distant seconds. Some live exports to Italy, Taiwan and Great Britain have happened in the past few years.

Frozen prices are slightly more volatile than live and appear to have more of a dip in the summer months. Markets for frozen RKC are more diversified. Japan dominates, but the US, S. Korea, France, Denmark, the Netherlands, Sweden and Spain all imported at least 50 tons in 2017.

The US market is relatively weak, though there are record prices in Alaska for local product. Alaskan quotas have fallen, pushing prices up. There have been quota increases in Russia, but Japan has reduced overall imports from Russia and the price has subsequently risen.

The small size of Norwegian Barents production capabilities has led to a high-end strategy for promoting Norwegian RKC. Crabs are going directly to the world's fanciest restaurants. There is a crab campaign at Olso-Gardermoen airport to increase awareness of the product amongst travellers.

SC production in the Barents grew rapidly from 2014 on. Canada, the dominant supplier, has been reducing output, particularly from Newfoundland-Labrador. Alaskan production is also down. There has been more entry by Norwegian vessels in 2017, but a reduced harvest volume after closure of the Loophole area on the Russian shelf. In 2015 total live weight was 16 ktons, which fell to 10 ktons in 2016 and was 2.8 ktons by December 2017. Of these tons, the share belonging to Norway has increased from 22% in 2015 (27% of value) to 99.9% in 2017 (100% of value). 95% of production is frozen at sea. There are 10 factory vessels in operation; two firms have on-shore production plants, and two ships deliver to those plants. Snow Crab prices have increased significantly from 2016 to 2017. Prices are at all time highs.

Main markets for Snow Crab are the US, Japan, the Netherlands, Denmark, S. Korea and Indonesia. The US market is mainly sourced from Canada and Russia, with Norway, Greenland and China also competing in small amounts. Frozen imports to Japan are down overall.

The TAC for 2018 is not yet determined. The first TAC was set in 2017.

3.2 Russian Perspectives

Stock Status and Russian Fisheries of Snow Crab (C. Opilio) and Red King Crab (P. Kamtchaticus) in the Barents Sea and Russian Far East (S. Bakanev, Polar Research Institute of Marine Fisheries and Oceanography (PINRO), Murmansk, Russia).

There are two main commercial crab species in the Russian Barents Sea, both new introductions. Red King Crab (RKC), purposefully introduced in the 1960s, had 6.3 ktons harvested in 2016, and Snow Crab (SC), introduced by uncertain vector in the 1990s, had 8.9 ktons harvested in 2016. Thse account for 43% and 32% of Russian catches of these spe-

cies respectively. The RKC invasion has proceeded more slowly than the SN invasion and overall biomass of the SC is expected to be much greater than that of the RKC.

Russian Far East fisheries also include 3 additional King Crabs, 3 additional Snow Crabs, and 2 additional crab species. SC is the greatest portion of Far East harvests, with Japanese Snow Crab (C. Japonicus) and RKC in 2nd and 3rd positions respectively.

Recorded RKC harvest in the Russian Far East (Sea of Okhotsk) dates back to the 1920s. Harvests have been cyclical with booms in the early-mid 1920s and mid-late 1930s, a mini-downturn in the early 1930s, followed by very little harvesting during WWII. Rising harvests from 1945 to the mid-1950s plateaued and then declined beginning in the late 1960s, plateauing at between 20–40 ktons in the mid-1970s, with further declines leading to harvests from 5–20 ktons in the most recent decade.

Illegal (IUU) fishing in the Russian Far East is estimated to have peaked in the mid-2000s. The main importer is identified as Japan, with the US second. Current imports remain above the official TAC and recorded crab catch, but the difference has shrunk significantly as increasing enforcement and new international agreements have come into play.

In the Barents, the newness of the invasions, particularly for SC, means that the species have likely not expanded to their full ranges. The RKC invasion is expanding west into Norwegian fjords and, more recently noted, east along the Russian coast.

RKC depth ranges are less than 100 m for small crabs; less than 300 m for adult males. The crabs need access to shallow coastal water for mating; the distance between coast line and feeding area is a maximum of 150 km.) Coastal substrate must be suitable for larval settling. The preferred temperature range is 1–9 degrees C. Food availability remains good for further expansion.

There is no coastal fishery in Russia; the harvest occurs offshore, and is mainly onboard frozen processing. Harvesting is monopolized by a single firm (Association of Crab Catchers of North [Moscow]) with multiple vessels (10 vessels approximately 50 m length). The fishery has just recently been MSC certified, albeit with some restrictions requiring increased reporting. (https://fisheries.msc.org/en/fisheries/russia-barents-sea-red-king-crab/@@assessments). The harvest control rule aims at preserving biomass and generating some stability in annual TAC levels. The resulting forecast for RKC is a stable overall population with harvests taken from shifting areas with expectation of 10–15 ktons/year, with low probability of further spatial expansion.

The SC is expanding west, northwest and north from Novaya Zemlya into international waters and/or towards Franz Josef Land (Russian), and south around the island into the Kara Sea. The probability of occurrence remains highest in Russian waters. The SC has a depth range of 0–500 m and a temperature range from 0 to 3 degrees C. It does best with mud/sandy mud sediment bottoms. Further SC expansion predictions depend heavily on assumptions of changing sea bottom temperatures.

Most SC harvest to date has been in the international Loophole. In 2016, Norway and Russia agreed that the SC is a sedentary species, effectively closing the Loophole by changing the internationally agreed boundaries from the EEZs to the continental shelf boundaries (Kaiser *et al.*, 2018). A Russian fishery with Russian quota is now open to the east of the Loophole.

The presentation included details of the fisheries, including:

- Use of traps only (Trapezoid and rectangular for RKC; Conical for SC;
- Baits (Herring, Squid, and Cod heads);
- Min commercial size: RKC 150 mm males; SC 100 mm males. Female harvest prohibited;
- Closed season for RKC Dec 16-Jan 1-Aug 15;
- Spatial closures (mainly inshore).

3.3 North American Perspectives

3.3.1 Alaskan Bering Sea Perspectives

Alaskan Crab Fisheries and Concerns for the Future (G. Eckert, University of Alaska Fairbanks)

The Alaskan crab fisheries encompass a much vaster physical space than those in the Barents Sea. The fisheries are well developed and are well known throughout the world due to the long running television series "The Deadliest Catch." In addition to the Red King Crab (RKC) and Snow Crab (SC) there are 2 other commercial King Crab species, another SC species, and Dungeness Crab that have commercial fisheries.

Management in the fisheries is governed by both state and federal regulations; Alaska manages areas 0–3 nm offshore while federal regulations cover 3–200 nm (to the EEZ limit). The management unit is the stock; there are multiple stocks in the Bering Sea, Aleutian Islands, and Gulf of Alaska. State management sets TACs below an estimated Acceptable Biological Catch (ABC) (federal) and a higher Overfishing Level (OFL). The fishery is only for males; sizes are based on size of the crab at maturity, and seasons are stock specific to avoid molting and mating seasons. Annual trawl surveys inform annual stock assessments that are mainly model-based. The fisheries were rationalized in 2006.

Data extend back to the 1970s EEZ designations, or in some cases earlier. Peak biomasses for most crabs and for total biomass were in the early 1990s. The SC harvests in particular peaked and crashed. Some stocks have not recovered as well as others. The Bristol Bay RKC biomass experienced a 93% decline in the early 1980s and has recovered to some extent; while the Pribilof Islands Blue King Crab experienced a 98% decline in the same period but has not recovered at all; the fishery has not re-opened. 6 of 9 RKC stocks in AK are closed to commercial fishing. Snow Crab has been more cyclical.

The failure of King Crabs to recover in the absence of fishing is under study. Explanations include recruitment limitation, threshold effects surpassed by earlier overfishing, climate driven fluctuations, and/or fish predation on juveniles. Increased understanding of the ecological drivers of the Barents Sea invasions could help address further understanding.

There is a partnership started in 2006 including academia, state and federal managers, industry participants, tribal interests and community groups to study the feasibility of king crab stock enhancement in Alaska (AKCRRAB Program). A key concern of the program is to identify if the problem is one where stock enhancement could or could not be effective in increasing stock biomass after the larval stage. If the losses are because habitat has changed or predators have increased, then enhancement may not be effective. On

the other hand, if there have been changes in oceanography or acidification so that larvae are being swept away by currents, or if a threshold has been reached due to earlier overfishing, then enhancement could help stocks after the larval stage.

The life cycle of the RKC is well understood; surveying of the Kodiak stock suggests recruitment limitation is the source of the problem as no larvae were found. Efforts to culture RKC at various densities, diets, temperatures and water condtions have been underway since 2007. The efforts have focused on both increasing survival and increasing growth. Identified continuing problems are juvenile cannibalism in the hatchery and fish predation in the wild. Several predators have been identified through experiments in the field. These have identified biological requirements for successful stock-enhancing releases; these are to release small, release into structure, and at the right season.

Trawl survey data is not ideal as there is less consistency than needed and there may be errors based on behaviour that is correlated with shifts in bottom temperatures.

Concerns at the Intersections of Science and Industry for the Crabs. (C. Siddon, AK Department of Fish and Game)

The AK Department of Fish and Game has a professional scientist charged with improving the interface between governmental decision-making based on scientific input and fishermen wishing to operate on their own knowledge of the fishery. Relations between regulators and fishers have been contentious in the crab fisheries for decades. Problem spots have been the RKC in Southeast AK and the Golden King Crab in the Aleutian Islands. The Tanner Crab in the Bering Sea is a growing concern. By looking critically at stock assessment of the RKC in southeastern AK and engaging fishermen from the commercial fleet in the process, industry-regulator relations have improved significantly.

The scientific project included comparing biomass estimates from existing survey methods and from a new mark-recapture study. The Southeast AK RKC population is surveyed in 9 areas accounting for about 70% of the commercial catch. The mature biomass in the region appeared to be in decline from the mid-1990s to the late 2000s, resulting in commercial closures in several years. The cause of the decline was uncertain; was it population decline or migration? Using a mark-recapture study done with fleet support in order to supplement the catch survey, abundance estimates were should to be much higher in several locations. The comparison shows that the current catch study analysis provides an underestimate as the CPUE is not proportional to the area population, as had been assumed. The large effort required collabouration with the fleet to have enough manpower and coverage. These surveys will be repeated periodically and communication with industry will continue to develop.

In the Aleutian Island Golden King Crab (GKC) fishery, the stock assessments used for setting catch limits has been based on average historical catches. There are physical limitations to trawl surveying so there is a triennial pot survey that can only cover a small area and is inconsistent in terms of costs and vessels chartered for use. There is potential bias in the population models due to fishery dependent data. The desire is a consistent and unbiased survey through cooperative effort. The fishing area is extensive (~233 800 sqkm). The habitat increases these costs as it is steep and deep (100–1000 m). Existing surveying covers only about 10% of the area; scaling up to cover the whole area would require 15 months and $4.5–6.5 million USD. These are prohibitive costs.

The only alternative is an index for abundance from fishery observer data. Observer data is fishery dependent and focuses on the fishing hotspots, rather than spatially independent. There may be variable gear, skippers, bait and so forth. Generating a standardized CPUE is difficult. The aim of the cooperative study is to ask fishermen to fish outside their normal preferences to increase the spatial extent, reduce potential for hyperstability, and provide consistent long term data in a cost-effective manner. The program has increased the spatial extent significantly and produced higher quality data. The scientific staff on board has worked well with the skippers and crew; the importance of this for both short and long run outcomes cannot be underestimated. Skippers are benefiting as they find new areas to be profitable. Refinements continue.

Conditions, questions and concerns for the Alaska Crab Industry. (E. Poulsen, Independent Fisher; VP, Bering Sea Fisheries Research Foundation)

The Alaska crab fishery has undergone significant change in the past decades. Rationalization has better aligned capital investment in the industry as well as labour to the size of crab populations while making the fisheries significantly safer. Before rationalization, crab stock declines meant financial ruin or worse (crew injuries and deaths) for many participants in the derby-style fishing. Labour is greying, with no clear turn-around in sight. There is some increasing separation of vessel management (captain) and ownership (corporate). However, there are also incentives for labour to become vested.

Remaining vessels are generally large operations between 100'-150' with 150–450 pots per boat, catching ~250 ktons of crab each. Single pots are fished during 2–3 week trips out to sea with crab held live in onboard tanks. Much of the processing, where crab is frozen into sections, occurs at Dutch Harbor in the Aleutian Islands and there is little opportunity for live export from the distant port. This has limited marketing innovation and there is a marginal American-made premium on Alaskan crab domestically or internationally.

Technology and investment decisions have feedback loops from regulatory decisions. Decisions to link catch and processing quota in order to support local communities through processing quota mean that there is little opportunity for harvesters to invest in marketing or the creation of new product forms such as live crab sales. Laws and regulations governing e.g. new vessel construction mean that the fleet is aging and there is little investment in what the crab boat of the future should be.

There is awareness of very low recruitment for the King Crabs in particular. The cause is unknown, and it has both short and long term consequences for fishermen. Diversification across crab species by the stakeholders may be sufficient to maintain a stable industry, or it may not. Partnership with scientists is needed to answer these questions.

In recent years, conflict between industry and regulation has subsided due to increased communication between key members of each community over such scientific research. Tensions might be expected to rise again if climate changes habitat conditions and crab stocks continue on a downward trend, which would limit cooperative research funds and effort. Solutions from regulators need to consider more than the myopic year-ahead population and quota regulations.

Increasing information over how industry and governance are playing out around the world can help smooth uncertainties and provide impetus for innovation. For example, in Norway where populations are low and growing, consideration is being given to how

to use every bit of the crab in profitable ways. Alaska has had the luxury through its high population levels and harvests to not worry about such costly innovation, but might be able to learn a lot about how to operate a more profitable and therefore sustained fishery from increased cooperation.

3.3.2 Canada Gulf of St. Lawrence Perspectives

A Spatiotemporal model for Snow Crab (*Chionoecetes opilio*) stock size in the southern Gulf of St. Lawrence (A. Nielsen, DTU)

Fisheries often exhibit declining catch rates throughout a fishing season. This is the case fo SC in the Gulf of St. Lawrence (GSL). In theory, total biomass can be estimated from this depletion. The intuition is that if catch has little impact on the catch rate, then stock is high and vice-versa. This modelling imposes strong assumptions about the catchability rate (Q) however.

For example, declines in the actual stock size may be masked in the data if there is spatial depletion of new areas over time. The problem should be approached both spatially and temporally to improve accuracy. There is evidence of this problem in the spatio-temporal data; over the weeks of the season the effort mover from east to west and back again.

There could also be a change in behaviour of the fishermen. Soak times might increase or decrease, so that measuring effort only as the number of pots is inaccurate. There is evidence of such behavioural shift with a cyclical soak time pattern over the season, where it rises then falls then rises rapidly at the end of the season.

The combination of these problems means that CPUE does not describe the biomass well. A better, spatially explicit depletion model for the data can be built based on high resolution (weekly, spatially explicit) catch and effort data to provide more precise estimates of snow crab biomass and population dynamics. This allows the incorporation of spatio-temporal changes into CPUE catchability estimates; the changes have been substantial. The expected trends shown in the new model are different than those provided by the standard snow crab survey; this should improve management advice.

3.3.3 Greenlandic Perspectives

Overview of the snow crab fishery and scientific effort in Greenland (A. Burmeister, Greenland Institute of Natural Resources)

The SC fishery in Greenland started in the mid-1990s. Catches peaked at approx. 15 000 t in 2001, and have since declined. Annual catches have for the past 8 years have been almost 2100 t. In the early years of the fishery, exploratory fisheries were conducted inshore and offshore with an aim of mapping the geographical distribution of snow crab, testing different trap types, handing and survival. From 1998, commercial inshore and offshore fisheries have been tried, along with surveys for gear type, handing and survival. In 2000, large onboard producing trawlers were allowed into the fishery. The number of active vessels declined sharply by 2008, and all large trawlers were out of the fishery by 2009; onshore plants also closed. In 2016/17, however, new production facilities have been added at Nuuk and Aasiaat.

Scientific support for the fisheries have included participation in the trial fisheries, networking with Canadian snow crab scientists, implementing annual monitoring programs in Disko Bay and Sisimiut (still continuing since 1997) and Nuuk and Paamiut (cancelled in mid-late 2000s). GINR provides annual assessment and advice. There are ongoing research projects to improve knowledge of the species. There are also stakeholder meetings with local and international governments, industry, and fishermen; networking and meetings with local fishermen aim to improve local knowledge.

Existing data include: export data (Greenland Statistic Office); landing statistics from 1996 on, though of varying quality; logbook data from 2003 on; and scientific surveys as mentioned.

Management regulations currently mandate fishing zones with limited access, a male minimum legal size of 100 mm CW, no female harvest, and a TAC. Prior to 2005 there was a quota system with permits, a smaller 90 mm CW legal size, and poor landings information. There are 6 distinct management areas in Western Greenland.

The biomass is estimated on a standardized index from survey data for spatially differentiated areas. Recruitment data are available for the areas, as is temperature data which shows volatility around the range SC requires.

The industry has five production facilities spread unevenly across the areas. The SC are landed alive and slaughtered by hand, after which they are cooked and quick frozen. The main products are SC clusters, cocktail claws, leg meat, and meat extractions from shoulder parts. The two main companies, Royal Greenland and Polar Seafood, are open to requests for additional products.

Snow crab are only a small portion of the value of exports for Greenland. There was a boom at the beginning of the 2000s, during which time SC exports exceeded cod exports in value. Since 2005 this trend has reversed. There are 98 permits in the fishery but only 48 active vessels. The number of permits was much higher in the early 2000s.

The primary markets are the US and Japan, with new market opportunities emerging in the EU. There is interest in growing the export market. Industry-science interactions are strong and it is easy to share information. There is consideration of becoming MSC certified.

3.4 Korean and Japanese Perspectives

3.4.1 Korean Perspectives

Crabs in Korea (H. P. Hong, Korea Maritime Institute)

It is important to keep in mind that Korea is both a producer and a consumer of SC. There are three main commercial crab species in Korean waters. They are Snow Crab (*C. opilio*), Red Snow Crab (*C. japonicus*), and the non-Arctic swimming crab. SC are caught either offshore in gill nets or with coastal traps in the East Sea; Red SC are caught offshore with traps in the East Sea.

SC have been caught in Korea since the mid-1990s. Highest catch was in 2007 (4.8 ktons). Catches have since declined to around 2 ktons or less. In 2016, SC catch was 1.5 ktons,

while Red SC catch was 36 ktons. Red SC appears to be a close substitute for SC though it is smaller and there is a price premium on SC.

Korea has set TAC regulations over Red SC since 1999 and over SC since 2002. There are regulations over catch capacity in the forms of vessel size limits, engine HP, etc. Net usage is also limited, as is mesh size (240 mm) and crab size (90 mm). The SC season is closed 1 June – 30 November. There is a closed area that neighbors a large reef (Kyungbook).

Market volume of SC was ~7.4 ktons in 2015, almost all of which was domestic consumption. Of this ¼ was covered by local catch and ¾ imported. Red SC on the other hand had market volume of 41 ktons, with 35 ktons of domestic consumption and 6 ktons of export (2015). Virtually all was supplied by local catch.

Import inspections indicate 64.4% of imports were live SC, 1.9% cold, 33.7% frozen (2015). These ratios are approximately equal to the annual averages over the decade. There has been some increase in frozen imports since 2007.

Imports of RKC have been much lower, generally about 10% of the SC imports. Prices for RKC have risen since 2013. SC prices have risen overall, but not steadily nor as much. Red SC prices have been lower and stable. In 2009–2010, Red SC and SC had about the same import price at ~$5/kg. in 2016 the price fo Red SC remained just over $5 while the price for SC had risen to over $15/kg. There is a shift in tastes and preferences occurring that may be reflecting increasing incomes or growing quality differences.

Potential Research Issues on Crab Markets in Korea (H. Park, Korea University)

Though RKC is relatively new to the market, there is a growing preference toward live RKC, shown in the price premium. The even newer introduction of Atlantic lobsters may reduce this premium. In the live markets, there is evidence of a failure of inventory control represented through an increase in price volatility.

Efforts have been made to introduce Koreans to frozen crab, including "how to" infomercials on the home shopping network. There are high markups in the frozen crab industry; import prices are less than ½ the retail price.

These factors combine so that economists ask how one might weigh social concerns vs. private concerns. The social problem can be defined as how to make a sustainable SC fishery in S. Korea. This requires stock assessments and information about seasonally concentrated harvests. A bioeconomic model with uncertainty over the price path over time and the stock of snow crab might serve as a starting point for increasing understanding. There is also data in the country's seafood traceability system that may help inform the model.

The private problem is profit maximization by agents in the import business. How might one determine the feasibility of investments in live vs. frozen imports and RKC vs. SC? A real options approach serves as the base model, because irreversibility and uncertainty are important components of the decision making. The expected difference in profits from one species or the other can be measured and the value of the real option assessed in expectation. The model enables one to find a value for the switching option between RKC and SC and the threshold price of live and/or frozen RKC relative to SC.

These investment decisions feedback in to supply decisions in other nations by affecting the development of markets. If RKC profitability is expected to continue to grow relative to SC, increased investment in RKC may increase pressure on RKC harvests more than SC harvests. To run the models, price data at relatively high frequency are needed, as is information pertaining to investment costs.

Infrastructure costs may be highly similar for RKC and SC, including holding tanks and/or freezer storage and access to customers/ auctions. The main investment decisions are expected to be in network development and securing of sufficiently high quality, reliable product, reducing the problems of inventory control. Such investments may have significant feedback effects into small Northern communities.

A big uncertainty is the role of China. Korea and China have a sustainable cooperative fishery management agreement, but at the same time S. Korea has had to use military vessels to intercept Chinese fishing boats in disputed areas.

3.4.2 Japanese Perspectives

Consumer preferences for food safety in Japanese markets (M. Yamamoto, University of Toyama)

Fisheries are vital to Japan. Per capita consumption of fish in Japan is about 50 kg/year, more than double that of the USA and EU-28 countries. China is closing the gap but remains at per-capita consumption of about 40 kg/year. The Japanese EEZ is very large (4.47m sq.miles). The majority of fishing firms are small sized with seemingly low productivity. There are still 153 000 vessels and 160 000 fishermen operating out of 2866 ports, producing 4.69 m tons of fish, but labour, vessel numbers, and catch in the industry have declined considerably since the 1950s. Aquaculture has captured some of the losses, while imports have also risen.

Quality perceptions are expected to be important determinants of price; the spatially and otherwise differentiated fish markets in Japan allow econometric examination of changes in quality perceptions to determine how significant these perceptions are to market outcomes. The 2011 Fukushima earthquake, tsunami, and resulting nuclear disaster provide a natural experiment.

Food safety tests are ubiquitous in Japan. There was a 15–20% rate of detection of nuclear markers in food tests of fish immediately following the accident. This was significantly higher than rates for fruit, vegetables or rice. Today, there remains only a small 0.06% detection rate, while for other foodstuffs the rate has fallen to zero. The Japanese Fishery Agency has reported that 15–20% of people surveyed are unwilling to buy fish from Fukushima, a rate that has been more or less constant from 2013 to 2017. Findings for agricultural markets indicate that a substantiated price gap has evolved for Fukushima vegetables. What can be said about fisheries?

A difference-in-differences approach to the data allows one to compare whether and how prices and/or quantities traded have changed differently according to different events, while eliminating common trend factors. Then identified changes can be attributed to the occurrence of the event rather than other factors. With respect to the crabs, can we identify any changes attributable to radiation fears?

Overall, crab is very popular in Japan, and the import of fish and crabs is becoming more critical since the self-sufficiency rate of fishing is down from 113% in 1964 to only 53% in 2016. In recent years, about 67% of the crab supply has been imports. Imports have tended to be larger and more expensive SC and RKC. Domestic production of Red SC remains high. The markets for the three crabs are interlinked; price elasticities (the responsiveness of a change in quantity demanded of one good from the change in price of another good) can describe these interlinkages and changes in them over time to identify whether there have been shifts in their relative desirability.

An Almost Ideal Demand Systems (AIDS) model is used to calculate both the Marshallian and Hicksian elasticities and compare relationships before and after the earthquake. The difference between these elasticities rests on whether or not the changes in prices are considered in the full context of changes in the purchasing power of one's income (Marshallian) or whether they assume that prices and utility from other goods remain constant in spite of the changes possible due to the price shifts (Hicksian). Using both together, one can interpret income effects of changes as well as price effects.

Data limitations on this preliminary work mean that the data used are for the imported crabs in the market; relations to domestic consumption must be inferred until better domestic data are available. The description here is less based on actual expected impacts from Fukushima than it is on exploring how the AIDS model might help inform on market segmentation and quality perception if domestic data can be included. It also highlights interesting tradeoffs and complementaries in the world markets for the crabs. It is not always the case that one nation's increases in exports must come at the cost of decreases in another's.

The AIDS model compares responses of similar products to the same stimuli to determine their responsiveness to each other; the similar products examined in this case are King Crabs imported from Russia, the US, or the Rest of the World (ROWKC), and Snow Crabs imported from Russia, Canada, or the Rest of the World (ROWSC). The groupings are chosen by identifying Russia and the US as the largest exporters of King Crabs to Japan, and Russia and Canada as the largest exporters of SC to Japan. Swimming crabs from China and Vietnam, and Horsehair Crabs from Russia and N. Korea, are included to scope the edges of the relevant market space.

King and Snow crab imports are highly seasonal, particularly for US King Crabs and Russian Snow Crabs. The seasonality is both demand and supply driven. Luxury crab purchases correspond to seasonal events, and limited crab fishing seasons affect, in particular, live crab supply. King crab imports from Russia have seen dramatic increases since 2014, at which time an agreement to limit IUU fishing came into force. The USA's trend is also upward but less dramatically so volumes remain small. Canadian and Russian Snow Crab imports have both risen, with seasonal fluctuations, since a low in 2010.

Elasticities for King Crab before and after the Fukushima event are relatively unchanged. There is some indication of increased responsiveness to prices for supply from the non-dominant countries, but these results are not statistically significant. US crabs have higher elasticities signalling that they are considered more luxury goods than other suppliers.

Elasticities for Snow Crab before and after the Fukushima event are more affected, though overall statistical significance is lower, suggesting greater volatility and uncertainty of the results. In particular, Russian and Canadian SC become considerably more

complementary goods rather than substitutes. This is likely due to the overall increasing price trend indicating a shortage of quantity supplied that can be satisfied from increases in crabs from both locations rather than requiring competition.

Crab Production and Fisheries Management in Japan (Kanae Tokunaga, University of Tokyo – Ocean Alliance)

Japanese domestic fisheries production is managed through a Territorial Use Rights Fisheries system (TURF). Rights are area-based and managed by local fisheries cooperative associations. Offshore management requires prefectural licenses, or ministerial licenses for larger vessels further offshore. There are gear-based associations as well.

The Snow Crab has been managed offshore with TACs since 1997. The TACs are based on Allowable Biological Catch (ABC). The ABC is based on 7 scenarios. There are adjustments to the TACs during a season based on acquisition of new information. There is a TAC distribution for each license type (4 ministerial and 10 prefectural types). The TAC share is based on the previous 3 years of catch.

Red King Crab is fished from 30–400 m using pots and gillnet in small amounts (~85 tons or less). There is no management outside the TURFs and no stock assessment. The average ex-vessel price is 1247 JPY/kg. King Crab production comes mainly from the northern island f Hokkaido, with additional smaller amounts along the west coast.

The Snow Crab is fished from 100–750 m mostly by trawling. Recent catch is ~4.5 ktons. There has been management by TAC since 1997, and stock assessments are done. There are 4 stocks identified, of which 1 stock is shared with Russia. The average ex-vessel price is higher than that for RKC at 2280 JPY/kg. Snow crab production is mainly from the northern island of Hokkaido with additional production along the west coast and particularly centered around Hyogo prefecture. Snow crab

The Red Snow Crab is fished from 800–1200 m using pots. In some areas, there are individual quotas. Others are managed by TURFs. There are stock assessments. The production is high, at almost 18 ktons, while the price is lower, at 283 JPY/kg. Red SC production spans the west coast and is highest in Tottori prefecture. The Japan-Korea joint fishing area established in 1999 is important fishing ground for snow crab.

The non-Arctic substitute swimming crab is caught in shallow waters (5–30 m) using gillnets or pots; there is no management outside the TURFs and no stock assessment. Total harvests are relatively low at ~2.5 ktons. The average ex-vessel price is at 1110 JPY/kg.

Snow Crab and Red King Crab production by Japanese vessels peaked in the early 1970s at several orders of magnitude higher levels than today's catch. Statistics for Red Snow Crab are not available before the mid-1990s; production has been stable or slightly declining since then. There has been an increasing price trend since 2012. Ex-vessel prices for SC and RKC trend together with RKC consistently lower than SC. Red Snow Crab prices, to the extent they are known, are significantly lower.

A simple ex-vessel market analysis was conducted using data from the Japan Fishery Information Service Center covering 2009–2016 fishing out of 211 major ports. There is an assumption of perfectly inelastic supply – that is, fishermen do not respond to changes in prices when deciding their harvest or effort levels. Snow Crab prices are heterogeneous

across regions/ports; markets remain segmented spatially. Over time there is also heterogeneity in prices received in different regions, with a growing gap separating the Sea of Japan West (SOJW) at the highest price levels and Hokkaido (HKPN and HKJN) at the lowest.

Own-price flexibilities (where only the price and quantity of the item itself are considered and the price flexibility is the inverse of price elasticity) show elastic demand.

Red SC shows the same trend as SC in heterogeneity across ports but it is considerably muted in amplitude. Prices in the ex-vessel market are less spatially segregated, but a pattern remains where the Sea of Japan vessels receive higher prices. Demand is again elastic, though somewhat less so than for SC.

Red King Crab also has distinct prices segregated by port; Hokkaido ports in the Sea of Japan may be receiving higher prices than those in the Pacific; this gap has existed over time throughout the sample. There are too few observations (46 obs) to generate significant estimates of own-price flexibilities.

The heterogeneity across ports results in part from successful branding of locality, and crab tourism. This presents interesting opportunities for understanding consumer preferences over the crabs in future work, particularly in the context of willingness to pay for sustainable products.

There have been a number of external shocks to the fishing markets in Japan in the last two decades. These deserve further study. In particular, there have been efforts to reduce IUU fishing internally, and there have been impacts from external decisions to rationalize crab fisheries or to create markets for Barents Sea crabs.

A preliminary analysis using difference-in-differences (DID) estimators is done to look at two sets of impacts. First, impacts on ex-vessel market prices for the treatment group (RKC and SC, e.g. those directly affected by the Japan-Russia IUU agreement of 2012) and the control group (Red SC, those not directly affected) are estimated. Results indicate a significantly higher price for the treatment group, but no significance for the DID estimator. Second, impacts on catch and efforts by Japanese (port-based) fleets that target the shared stocks (SC and RKC) vs other ports. This also found no significance for the DID estimator.

There are two possible reasons for this. First, IUU agreement could have impacted not only RKC and SC but all crab products. Second, Hokkaido ports may serve different market than other ports in Honshu, the main island of Japan. While Honshu ports target local and domestic markets, Hokkaido ports may supply to both domestic and foreign market. Hokkaido brand is recognized in other Asian countries' and is increasingly targeting their high-end market in recent years.

3.5 Scaling up: Global Considerations

Global ecological and economic connections in Arctic and Sub-Arctic crab fisheries in trade policy (L. Fernandez, Virginia Commonwealth University)

There are trade policies that are likely to affect the international markets for the crabs.

The first of these is the Seafood Importing Monitoring Program under the Magnusen Stevenson Fishery Conservation and Management Act (50 CFR 300). The Act is aimed at

excluding illegal fish imports from entering the US, as well as reducing incentives for transit of questionable seafood worldwide. The rules reward legal fish products that have full information of origin. Such information may also generate premiums for suppliers and sellers to customers who value sustainability. There may be some substitution effect toward local species (e.g. Red Snow Crab in Korea and Japan) if reducing illegal trade raises the prices or decreases the availability of imported crabs.

Korea is identified as a transit zone, where illegal fish catches may enter the supply chain through the transfer of fish from fishing vessels to transport vessels, which have significantly less regulatory oversight. This has resulted in the US and Japan restricting imports labelled as "from Korea (since 2012).

Another regulation of potential import is that as of Jan. 1, 2017, all seafood exports from the US must comply with the US Marine Mammal Protection Act (Fed. Register 81 (157), 54390 (2016)). Though marine mammal – fishing vessel interactions for crab may be low, there is potential for damage. In 2017, Eastern Canadian SC fishing lines entangled seven right whales, with two fatalities. Another dead right whale was towed to shore with a SC trap still attached. Canadian laws do not require exclusion procedures to keep whales from becoming caught in SC gear or lines. Changing seasons (longer crab seasons, shifts in whale dynamics) and increased fishing pressure in the Gulf of St. Lawrence may be responsible for the increasingly apparent mortality. The increasing mortality also calls into question the 2012 Marine Stewardship Council's Certification of the St. Lawrence SC fishery.

Also as of 2017, exports to the US must meet the same standards as US seafood in terms of monitoring and bycatch mitigation in all waters where harvest occurs. Under this regulation, Canada (and other locations) may need to increase its measures for marine mammal protection. There is a maximum 5 year grace period to achieve documented compliance.

The International Maritime Organization (IMO) has established right whale rules for ships in the North Atlantic, with traffic separation lines to minimize overlap of activities. Increased use of such marine spatial planning may minimize future problems, but climate change impacts on the appropriate 'traffic lanes' must be understood and built into adaptive regulation.

4 Synthesis of the Presentations in the context of the ToRs

4.1 In response to ToR A

This workshop is intended to build on a growing body of research conducted by group members regarding the bio–economic consequences of the introduction of two crab species, the Red King (*P. camtschaticus*) and Snow crabs (*C. opilio*), into the Barents Sea in recent decades by expanding the scope to directly include research pertinent to other sources of these crabs (Alaska) and demand for these crabs (Asia). Full understanding of the ecological and economic dynamics requires this broader perspective of the crab species in world markets

There are growing challenges facing the management of profitable Arctic and sub-Arctic crab species in the US, Canada, Greenland, Norway, Russia, Korea and Japan. Arctic and

sub-Arctic waters are undergoing significant ecological change. Different ecosystems, priorities for production and use derived from ecosystems and ecosystem services, industrial structures, market size, distance to market, and potential profitability, all affect decisions ultimately reflected in the levels of regulation and harvest of these crabs. The details provided in the presentations reflect the many different ways communities have interacted with their natural resource endowments in crabs, and how those interactions are evolving in combination with changing economic and ecological parameters.

The crab fisheries range from small components of Japanese TURF systems to focused small-vessel coastal fisheries to offshore pots or trawling. Accounting for the crabs and the use of those accounts to generate stock assessments range widely as well, from very little if any accounting for stocks through to annual meetings incorporating industry stakeholders, scientists and regulators.

Various stages of development of the industry are represented, which stem in part from e.g. new populations resulting from species invasions to new management structures imposed to curb overharvesting and overcapitalization. The ability to examine simultaneously the different problems posed and solutions attempted in these different conditions is improving the information flow in ways that may improve efficient societal outcomes from global crab populations.

Furthermore, ecological, commercial, community and sustainability angles are all presented and considered together, so that questions of scale and scope might be addressed. For example, given the evidence provided from currently rising prices, it is not possible to imagine that artisanal fisheries for crab could meet demands in satisfactory ways. Alternatives to deepen the productivity of the natural capital are needed; they may e.g. take the form of pure aquaculture or they may involve stock enhancement at the post-larval stage. The choices made regarding investments require extensive dialogue between industry and science to identify the combined ecological and economic stumbling blocks to progress.

Such choices should also reflect flexibility and diversification; investments in e.g. stock enhancement of the crabs that are carefully tuned to life-cycle vulnerabilities may need further adjustments over time as climate change and related impacts such as ocean acidification change the framework conditions for ecosystem productivity.

Missing elements

The composition of the workshop included representation from all major producers of Arctic and sub-Arctic crabs, though some questions arose about populations of King Crab species in the southern hemisphere. These questions pertained mostly to questions of aquaculture capabilities. Intentions for follow up were expressed by the ecologists working with stock enhancement in Alaska.

Major consumer nations were also well represented, with the possible exception of China, where crab consumption may be rapidly rising. Several members from the workshop mention their interest on getting to know more about the Chinese perspective for both Red King Crab and Snow Crab. Continuous expansion of China's domestic consumption has the potential to change the established market dynamics for both international suppliers and neighbouring Asian Markets.

Current market dynamics, as introduced by Japanese and Korean members of the workshop, described South Korea as a distribution hub for international supply towards the Chinese market. Almost 40% of the volume that enters the South Korean market is redistributed to China. Although most of the distributed product is considered to be from Russian origins, a key issue regarding the role of South Korea as transportation hub includes concerns regarding the commercialization of potentially undetected IUU catch. [1]

In addition, distribution changes can also be traced back to China's national strategy, which recognizes the potential of expanding domestic consumption as a key contributor towards economic growth. In recent years, China continuously reduced the import tax of consumer goods in order to attract a larger share of the international supply. The most recent was in December 2017, when taxes on 187 products, which include both RKC and SC, were reduced by 50% (Yue, 2017). When considering the growing interest of Chinese consumers and policies that will continue to promote its availability, is expected that China will continue to increase its market share.

Another aspect discussed in the workshop was the different preferences for live or frozen crab products, which is important for both profitability and investment decisions. A characteristic of the Chinese market is the willingness of consumers to pay a premium for high quality live-crab with sustainability certification. The need for a constant supply of high quality products is expanding the investment in infrastructure for international suppliers beyond Russia. One example discussed by the Alaskan members was Golden Harvest Alaska Seafood, which established new infrastructure and logistic services to provide regular air-freight of live crab to Shanghai.

4.2 In response to ToR B

While the crab markets are themselves important, better understanding of the bio-economic changes underway also provides opportunity to investigate how ecological shifts in marine productivity will interact with other market shifts

The invasion of Arctic and sub-Arctic crab species to new waters at the same time that existing fishery stocks face declines due to human use and environmental changes, in combination with global rising incomes and reduced transportation costs that bring buyers and sellers closer together, is shifting the structure of the global industry in harvest and trade in these species. These shifts are complex, creating new beneficiaries and new costs both directly in the fisheries and indirectly through changes in ecosystem characteristics. These latter impacts are particularly poorly understood, though the changes in the fisheries themselves are also hard to summarize without a global perspective.

The same shifts that are happening in this industry can be expected to occur in many fisheries as climate change and related impacts, or human interventions in ecosystem productivity, affect the distributions and abundances of species.

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[1] In an effort to increase transparency, China and Russia are developing closer distribution methods. It is expected that most of the 2018 increase in Russian fisheries TAC for RKC and SC will be directly absorbed by Chinese consumers.(FAO, 2017)

The lessons the group identified as key for research needs and policy guidance include better understanding of how human decision-making affects the dynamics of ecosystem productivity; how investments in physical capital, including both fleet and on-shore investments, feed back into decisions that impact natural capital and its resource flows; how segmented market demands and high substitutability may make these investments less resilient to ecosystem and economic change, and how spatial and product differentiation may alleviate some of these concerns. The increases in resilience may be especially aided by greater cooperation amongst scientists, resource managers and resource users.

Management decisions at the local level are expected to have increasingly global spillover effects as stocks move in response to climate impetus. The feedback effects of reduced transactions costs in world markets will also increase the ways in which decisions in one fishing community will influence outcomes in another. New marketing approaches and investments in product quality may serve to better meet the needs of demand segmented based on quality ranging from live, individualized deliveries to market to large scale industrial production's supply chain transparency.

Annex 1: List of participants

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Annex 2: Agenda

Monday, 11 December

Day 1: Biology, Ecology & Economic Perspectives from the Barents

9.00 – 12.15: ***Morning session ''Knowledge exchange and Barents Sea Perspectives''***

9.00–9.30: Brief introductions

9.30–9.45: **Brooks Kaiser** Overview and Discussion of Goals

9.45–10.25: **Jan Sundet** Norwegian Barents Sea Overview, Red King (20 min) and Snow Crabs (20 min)

10:25–10.45: Coffee break

10.45–11.15: **Serge Bakanev** Russian Barents Sea and Far East Overview, Red King and Snow Crabs

11.15–11.45: **Bjorg Helen Nøstvold** Overview of Nofima fisheries science interest in the crabs

11.45–12.15: Panel discussion with Jan Sundet, Serge Bakanev, Bjørg Helen Nøstvold

Where should Barents Sea Research focus?

12.15 – 13.30: Lunch, DanHostel

13.30 – 17.15: ***Afternoon session ''Fisheries Management and Market Perspectives''***

13.30–14.00: **Melina Kourantidou** Economic uncertainties in the Barents Sea crab invasions and implications for management

14.00–14.30: **Benedicte Nielsen** Catch, landings and markets for Norwegian Red King Crab and Snow Crab

14.30–15.00: Panel discussion with Melina Kourantidou, Benedicte Nielsen, Brooks Kaiser

What are the challenges of crab fisheries management in the Barents in connection with the rest of the world?

15.00–15.15: Coffee Break

15.15–15.45: Panel discussion with Brooks Kaiser, Linda Fernandez, Dewan Ahsan

What are the economic, ecological & management concerns and how do those affect international markets?

15.45–16.30: Discussion & Working Groups & Brainstorming

Aims: a) Develop novel interdisciplinary and/or interregional interconnections and potential solution paths to priority unknowns, b) Discuss survey goals & refine survey plans

16.30–17.15: Full group discussion of Brainstorming outputs; rearrangement of small

groups if advisable

Intended output: Potential research questions needing collabouration between biology/ecology and economy

~18.30: Dinner, location TBA

Tuesday, 12 December

Day 2: Regional and Global connections

9.00 – 12.15: ***Morning session ''North American, Canadian & Greenlandic Perspectives''***

9.00–9.30: **Ginny Eckert** on scientific background and concerns for crabs' futures

9.30–10.00: **Chris Siddon** on concerns at the intersections of science and industry for the crabs

10.00–10.30: **Edward Poulsen** on conditions, questions and concerns for Alaska crab industry

10.30 – 10.45: Coffee Break

10.45–11.15: **AnnDorte Burmeister** on Greenland Snow Crab industry

11.15–11.45: **Anders Nielsen** Spatiotemporal dynamics of Snow Crab in the Gulf of St. Lawrence

11.45 – 12.15: Panel discussion with the above: *Future of North American, Canadian & Greenlandic Crab Industry*

12.15 – 13.30: Lunch, DanHostel

13.30 – 17.00: ***Afternoon session ''Korean and Japanese Perspectives''***

13.30–14.00: **Hyun Pyo Hong** on Korean interests in Arctic crab fisheries markets

14.00–14.30: **Hojeong Park** on Data needs for understanding Korean crab market-climate change interactions with real options

14.30–15.00: **Masashi Yamamoto** Consumer Preferences for Food Safety in Japanese Markets

15.00–15.15: Coffee Break

15.15–15.45: **Kanae Tokunage** on Japanese crab production/ fisheries management in Japan (tentative title)

15.45–17.00: Discussion & Working Groups & Brainstorming

Intended output: Potential research questions needing collabouration between producers and consumers

Small working group conversations for pooling information about challenges and information needs

(big and small picture questions of future scenarios).
Intended output: Landscape portrait of priority unknowns.

Finalization of surveying plans

17.00: Adjourn to Tivoli for relaxed networking opportunities

~18.30: Dinner in Tivoli

Wednesday, 13 December

Day 3: Scaling up the research: Next steps

9.00–9.30: **Linda Fernandez**, Strategic circumarctic market structure considerations

9.30–10.00: **Brooks Kaiser**, Bringing the big picture together: From the Barents to N. America and Asia

10.00–10.30: **Anastasia Emelyanova**, an e-discussion with UArctic about funding possibilities for the network.

10.30–11.30: Interactive Discussion, Dewan Ahsan and Brooks Kaiser

Brainstorming & Working Groups

Discussion of research interests and potentials for collabouration

11.30–12.30: Summary; Development of future research plans, survey finalization, grant applications, academic papers out of the scaled up discussions.

Scaling up of small group components for new global connections, UArctic thematic network grant planning.

Timeline and distribution of work; identification of appropriate funds and research/publication outlets, the latter of which might include e.g. Marine Policy, Fish and Fisheries, Ecological Applications, Ecosystems, PNAS, Journal of Environmental Economics and Management.

12.30: Sandwiches and evaluation