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Current Status of the Red King Crab (*Paralithodes camtchaticus*) and Snow Crab (*Chionoecetes opilio*) Industries in Norway

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ABSTRACT

Red king crab and snow crab have both become important species for the Norwegian seafood industry. Since the first commercial harvest of red king crab in 2002 and of snow crab in 2012, the Norwegian seafood industry has developed new technology and knowledge for handling these species. This includes new fishing gear, conditions for live storage and processing, handling of by-products, and entrance into new markets. The total Norwegian quota for red king crab increased from 220 metric tons in 2002 to 2350 metric tons in 2017, with a free-red king crab harvesting zone to the west of the quota-regulated area to prevent further expansion of the crab. At present, there is no established quota for snow crab. In 2016, a volume of about 5300 metric tons of snow crab was landed in Norway. In 2016, the export of red king crab and snow crab in Norway amounted to 529 million and 338 million Norwegian Kroner, respectively. Based on regular surveys of crab populations in the Barents Sea, it is assumed that the volumes red king crab and snow crab will remain steady and increase, respectively. Thus, these industries will continue to be important to the Norwegian seafood industry.

KEYWORDS

Catch; live storage; processing; occupational exposure; by-products; market

Introduction

Commercial harvesting of red king crab (*Paralithodes camtchaticus*; RKC) and snow crab (*Chionoecetes opilio*; SC) represents a significant source of income for Norwegian seafood industry. The meat from both species obtains high prices on the market due to very attractive sensory properties. Since RKC was deliberately introduced into the Russian part of the Barents Sea in the 1960s, it has established itself as a viable, self-reproducing population that has occupied a steadily increasing territory. Indeed, the RKC population started to expand into Norwegian coastal waters in the late 1970s. Still, it was not until 1992 that a significant bycatch of RKC in the Varangerfjord (the fjord closest to Russia in the northeast of Norway) captured the attention of Norwegian environment and fisheries management and research institutions. Discussions on commercial harvesting started shortly after (Sundet and Hoel, 2016), and commercial harvesting began in 2002 (Norwegian Ministry of Fisheries and Coastal Affairs, 2007). Today, the RKC population in the Barents Sea supports small-scale commercial RKC fisheries that operate exclusively in the coastal waters of Finnmark county (the northernmost part of Norway; Figure 1). Their small size and area of operation make these fisheries different from king crab fisheries in other parts of the world. The RKC fishery in Norway is allowed a yearly catch of around 2000 metric tons, and the industry uses only collapsible pots for harvesting (Stiansen et al., 2008; Norwegian Ministry of Trade, Industry and Fisheries, 2015). The RKC fisheries are of vital importance for several local communities in Finnmark (Finnmark County, 2011).

In 1996, SC was first observed in the Barents Sea (Kuzmin et al., 1999), but the scientific community is not certain how long they have been in, nor how they reached, the Barents Sea (Kuzmin et al., 1999; Hansen, 2016). Commercial harvesting of SC in the Barents Sea only started in the last few years, but it is growing rapidly (Lorentzen et al., 2016a; Siikavuopio et al., 2017), and now appears to be permanently established. In 2016, export of frozen clusters of SC from Norway amounted to 3952 metric tons, corresponding to a value of 331 million Norwegian Kroner (NOK; www.seafood.no). This represents a value

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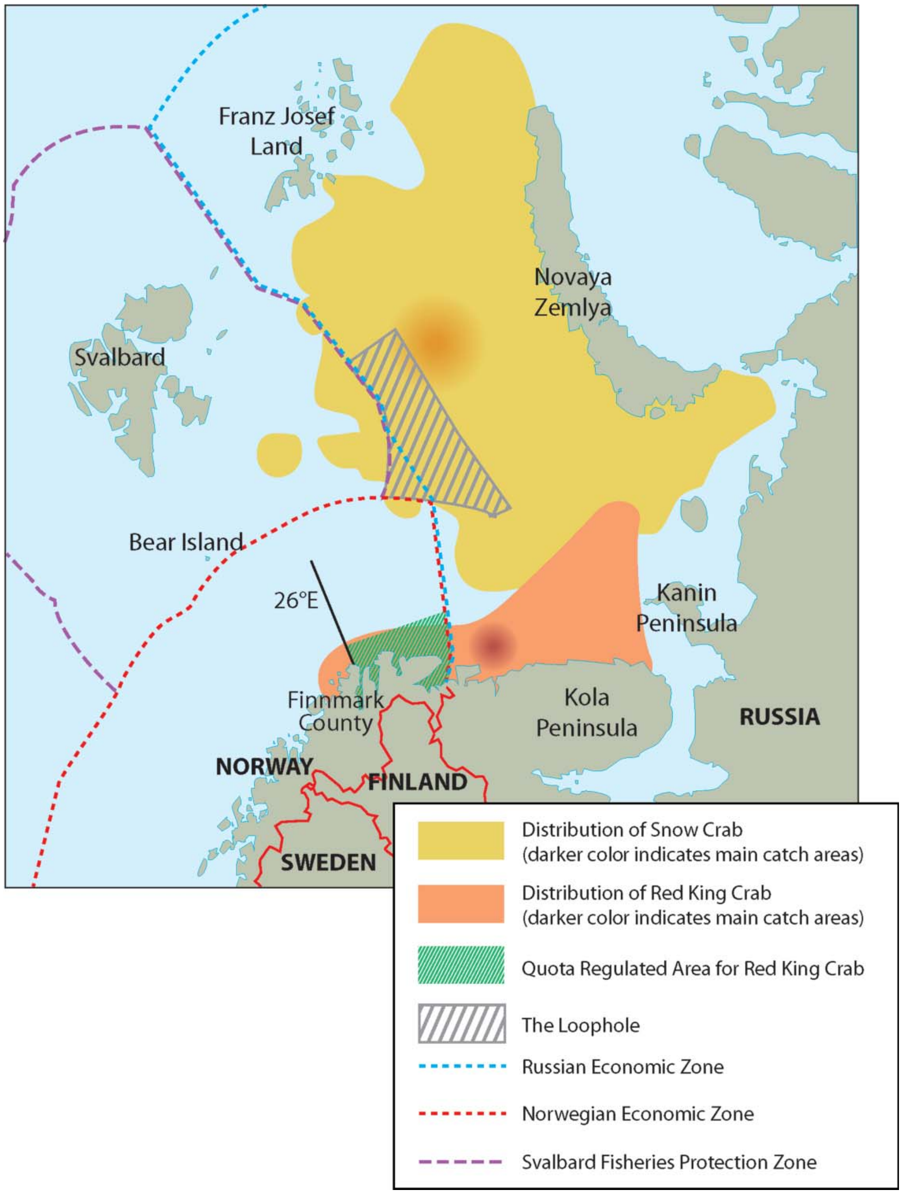

Figure 1. Distribution pattern of red king crab and snow crab in the Barents Sea (Institute of Marine Research, 2016).

increase of 80% compared to 2015, and the export value of this species is expected to continue to increase (Hvingel et al., 2015). The snow crab is mainly present in the eastern part of the Barents Sea, i.e., in Russian areas, but it has expanded its territory westwards into Norwegian areas and is expected to expand further to occupy most parts of the northern Barents Sea, including all Svalbard waters, in the near future (Figure 1; Pavlov and Sundet, 2011). Little is known about the biology of SC in the Barents Sea, but preliminary studies indicate strong similarities with SC in native areas. For the time being, there is no management plan nor quota for Norwegian commercial SC harvesting in the Barents Sea, however a management plan is expected to be put in place within the year.

This review presents an overview of the current status of the Norwegian RKC and SC industries by describing the whole supply chain in consecutive order from catch to market. This includes a description of the management of RKC and SC fisheries, fishing gear applied, conditions for live storage, processing of clusters including occupational exposures, food safety aspects, by-products, and finally a description of the main destination markets (Figure 2).

Management

Because it is an introduced species, RKC represent a potential threat to the ecosystem of the Barents Sea. Thus, regular research surveys have been conducted

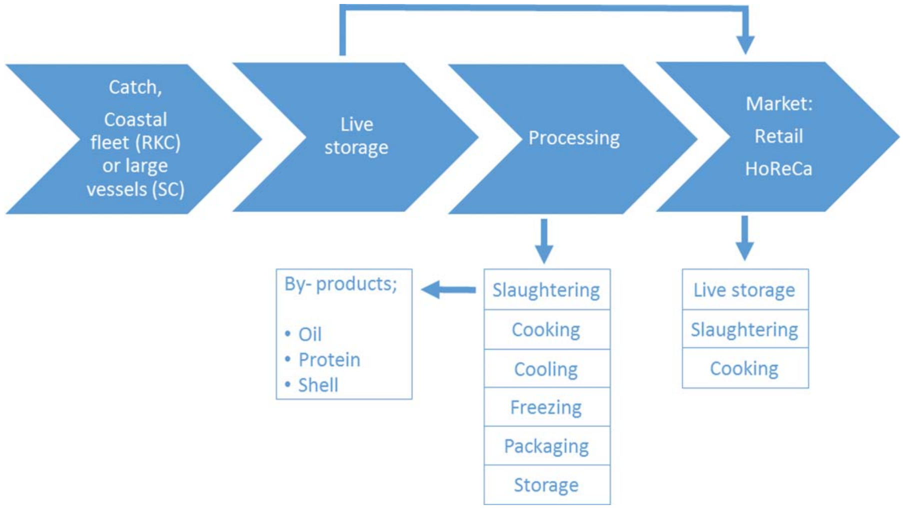

Figure 2. Illustration of a typical supply chain of red king crab (RKC) and snow crab (SC) from catch to market.

since 1993 to investigate their impact, population distribution, and biology (Falk-Petersen and Armstrong, 2013). A negative effect on the benthic fauna and destruction of fishing gear in coastal Norwegian fisheries has been documented (Falk-Petersen et al., 2011; Jørgensen and Nilssen, 2011). The RKC has continued its expansion westwards and today, the species can be found along the entire coast of Finnmark, and sometimes as far south as Tromsø (Jørgensen and Nilssen, 2011; Sundet and Hoel, 2016).

The Joint Norwegian-Russian Fisheries Commission first put RKC on its agenda in 1993 and the species were managed together until 2007. Afterward, the countries managed the RKC fisheries in their respective waters. From 1994 to 2001, only limited harvesting for research purposes was allowed. In 2002, the Norwegian government allowed commercial harvesting of RKC, with a quota of 100,000 crabs. In 1994, there were four research vessels, while in 2002 there were 120 vessels (Norwegian Ministry of Fisheries and Coastal Affairs, 2007). As the RKC population has grown, quotas have increased accordingly.

In 2004, the Norwegian government divided the RKC management area into two different zones. West of the 26° east meridian, which is approximately the longitude of the North Cape, is a free-RKC harvesting area that is accessible to anyone, both commercial and non-commercial entities. East of that meridian lies the quota-regulated area, where only commercial fisheries can operate (Norwegian Ministry of Fisheries and Coastal Affairs, 2007; Figure 1). The objective of this management regime is two-fold: to limit the westward expansion of RKC via the free-RKC harvesting zone, where all crabs, males and females of all sizes are to be landed; and to establish viable, long-term RKC harvests in the quota-regulated area (Figure 1). The allocation of quotas to the fishermen in the eastern area was also meant to compensate fisheries that experienced problems and economic loss in their ground fish harvests due to RKC-induced damage to their nets. Permanent quotas were allocated to active fishermen, both local and from outside the region (the so-called closed group), while people living in the area can apply for a quota and fish as long as they are living in this area (the so-called open group). In this way, the fisheries contribute to economic development in the northern part of Norway (ibid.).

As an introduced species, the management of the RKC is also influenced by the Norwegian commitments in international agreements such as the Convention of Biodiversity. The RKC in Norway is however not managed as an unwanted species to be eradicated (Sundet and Hoel, 2016). Indeed, it is considered impossible to eradicate the RKC from Norwegian waters, thus, the aim has become to minimize their expansion westwards, hence the two-fold management regime (Falk-Petersen and Armstrong, 2013). In this way, Norway is still addressing its obligation under the Convention of Biodiversity according to Sundet and Hoel (2016). The Convention of Biodiversity states that parties to the convention shall prevent the introduction, control, or eradication of alien species that threaten ecosystems, habitats, or species "as far as possible and as appropriate".

In 2015, the Norwegian government evaluated the management regime of RKC (Norwegian Ministry of Trade, Industry and Fisheries, 2015) and concluded that the two-fold management regime was successful due to two important changes. One was an effort to limit the number of vessels that could harvest in the quota-regulated area as the number was continuously increasing. In

2015, more than 550 vessels had a quota on RKC, many of which only harvest this species. From 2016, the quota allocated to a vessel depends on the value of other fish species captured, not including RKC. To receive a full quota, the vessel has to land fish (not RKC) for a value of minimum 100,000 NOK, half a quota is allocated with a landing of 50,000 NOK, etc. This was an attempt to prioritize established fisheries and maintain "reasonable" vessel quotas for active fisheries.

The other change was to change the quota year, i.e., to start the harvest season in January rather than in August/September as it has been since commercial harvesting started. The number of vessels taking part in the lucrative RKC harvest has increased steadily, and now includes vessels that do not harvest any other species (Norwegian Ministry of Fisheries and Coastal Affairs, 2007; Norwegian Ministry of Trade, Industry and Fisheries, 2015). The change of the start of the quota year was based on input from the processing industry that sells live crabs. By changing the quota year from September–September to January–January, the Norwegian RKC industry could offer live crabs at a time when demand is high and supply is limited, as RKC are not harvested in other countries at the beginning of the calendar year. As anticipated, this has resulted in bigger harvests in January and February and a corresponding increased export of live RKC at high prices.

As of 2017, the total Norwegian RKC quota is 2150 metric tons, including 150 metric tons of females and 200 metric tons of damaged RKC (Norwegian Directorate of Fisheries, 2017). Currently, 550 vessels hold quota rights. The only fishing gear allowed is pots, with a minimum carapace size of 130 mm, and the crabs are landed live. Male RKC are generally targeted in the quota-regulated area (Norwegian Ministry of Fisheries and Coastal Affairs, 2007; Norwegian Ministry of Trade, Industry and Fisheries, 2015). The 2017 quota of female RKC increased from 50 metric tons in 2016 with the goal to develop a market for females (Norwegian Directorate of Fisheries, 2017). The females carry a tasty roe, during most of the year, which is of high commercial value (Fjørtoft and Larssen, 2009).

The snow crab has also become important for the Norwegian seafood industry. As a new species, much is still uncertain, including stock size and distribution and the impact on the benthic ecosystems. Unlike RKC harvesting, SC harvesting occurs far up in the Barents Sea (Figure 1), and only a limited number of big vessels are involved. Currently, there is no management regime for SC harvesting in Norwegian waters. A general ban on SC harvesting was adopted in December 2014; and Norwegian vessels must obtain a license to harvest (Norwegian Ministry of Trade, Industry and Fisheries, 2014). Today, about 50 vessels holds a license, but only a handful is actually fishing for the SC. In the summer of 2015, Norway and Russia established that SC as a species is sedentary, and hence subject to national management rather than bilateral or multilateral management (Norwegian-Russian Fisheries Commission, 2015). In 2015, the countries cooperated and granted access to harvest in each other's zones, but the Russian government revoked this agreement as of January 2017 (Norwegian-Russian Fisheries Commission, 2016). As most of the SC in the Barents Sea is found in Russian waters, this led to a loss of SC harvesting opportunities for Norwegian vessels that now harvest SC in the Svalbard zone, as well as for foreign vessels which are now excluded from this fishery. Norway's right to the SC in the protected zone around Svalbard has been contested based on the Svalbard Treaty of 1920, and some vessels have challenged the Norwegian sovereignty in this area). For all these reasons, the number of vessels engaged in SC harvesting and their catches are expected to be lower in 2017.

The situation of the Norwegian SC industry as of April 2017 is still uncertain. The Norwegian government is working to develop a management plan and adopt measures to regulate access to and quotas on SC. It remains to be seen when a management regime for SC harvesting in Norway will be established and how the question of access to foreign vessels in the Svalbard protection zone will be handled.

Fishing gear

Both RKC and SC are caught using a box trap. During the first years of the commercial RKC harvest, conical pots with entries on the top, similar to the ones used in commercial fisheries in Far Eastern Russia and Japan, were commonly used (Stiansen et al., 2008, 2011). Research has been carried out in Finnmark in Northern Norway to compare those pots with square pots. The box-shaped design of square pots turned out to catch a significantly higher amount of RKC and also significantly more large males (Stiansen et al., 2008). The superior catching properties of the square pots led to their adoption by small-scale commercial fisheries in Norway (Godøy et al., 2003), where these are preferred due to their increased efficiency and handling and storing properties (Stiansen et al., 2008).

Conical pots are still the most common fishing gear used in commercial SC fisheries in the Barents Sea and were adopted from the practices of other SC fisheries, mainly those in Newfoundland and Labrador in Canada. The use of pots in Canadian fisheries is strictly regulated owing to needs of standardization when making population assessments based on catch-per-unit-effort from commercial fisheries (Divovich et al., 2015). Such restrictions and assessments are not performed in Norway. Hébert et al. (2001) compared the efficiency of pyramidal, conical, and square pots to conventional rectangular pots, and found that catch efficiency and crab size can be improved by adopting the correct pot shape.

Two bait receptacles are usually placed in RKC and SC pots: one mesh bag and one plastic jar. Herring is generally the preferred bait in RKC fisheries, sometimes in combination with saith, cod, haddock, or by-products from these fish species. The bait preferred by SC fisheries in Norway is squid in combination with herring (Siikavuopio et al., 2017).

Bait is the single most expensive operating cost (around 20 NOK per pot) in both RKC and SC fisheries. A single Norwegian SC vessel may set 1500 pots per day and operate up to 9000 pots in the same area per week. In addition, the current common bait types, such as mackerel, herring, and squid are also used for human consumption, and the growing demand for these fish species has led to increased prices. Thus, there is a growing need for alternative, effective low-priced, more sustainable bait (like by-products from commercial fisheries), but attempts to find or artificial bait have so far not been successful in Norway (Siikavuopio et al., 2017).

Live storage

After capture, RKC and SC are either processed immediately or kept alive. Live storage includes storage in water tanks near processing facilities and dry transport in polystyrene boxes to the destination market. Live storage enables the industry to control the processing time or transport of live crab. The development of live-storage technology requires a reliable, consistent supply of crabs. It is through live storage that crabs can be transported to overseas markets in good condition (Siikavuopio and James, 2015; Siikavuopio et al., 2017). Capture-based aquaculture of RKC and SC is developing in Norway, and some efforts have been made to establish small- and medium-sized enterprises using intensive aquaculture systems for live storage of RKCs (James et al., 2013; Siikavuopio and James 2015; Siikavuopio et al., 2017). Mortality rates during live storage of both RKC and SC depend on several biotic and abiotic variables. The SC is more sensitive to high temperature and high stocking density during live storage than RKC (James et al., 2013; Siikavuopio and James 2015; Siikavuopio et al., 2016). Generally speaking, RKC is more robust and exhibits a lower mortality rate than SC during live storage and live export.

To avoid the economic loss of high mortality during live storage, most SC is processed. Currently 99% of SC is processed as cooked and frozen clusters on board or at land-based processing plants; only 1% are exported live. Export of live SC is preferred as the price per kilo is about four times that of clusters (www.seafood.no). In addition, it is more favorable to be paid per kilo of the entire animal, rather than just the clusters, as by-products represent about 30% of the total SC weight (Beaulieu et al., 2009; Stenberg et al., 2012). As observed in RKC fisheries in Norway (Siikavuopio et al., 2017), that due to the higher price of live crabs, the proportion of SC exported live is expected to increase significantly if live storage methods improve. Unfortunately, for the time being, knowledge of optimal live storage conditions for SC is still lacking (Dutil et al., 1997; Siikavuopio and James, 2015). Thus, new techniques for both short-term (vessel) and long-term (land) live SC storage need to be developed. In RKC, increasing temperature and stocking density increase the risk of cannibalism, mortality, and injuries (Siikavuopio and James, 2015; Siikavuopio et al., 2016). Thus, it is important to determine the optimum environmental conditions for SC, such as temperature, water requirement, and stocking density.

South Korea is an important destination market for live RKC and SC, but its distance from Norway makes transportation challenging. Russia is closer to South Korea, making it more beneficial for them to export live crabs there. Usually, Russian crabs are transported in water tanks, making the crabs less stressed compared to dry transport in polystyrene boxes. Thus, these crabs arrive in better condition and exhibit a lower mortality rate compared to Norwegian RKC and SC exported to these markets.

Processing and occupational exposure

Processing of RKC and SC includes a series of operations, from slaughtering to the final product. In this context, the final product is a cluster. A cluster includes three (RKC) or four (SC) walking legs plus one claw. For both species, the legs are assembled in a shoulder joint. The edible meat of RKC is located in the legs and shoulders, while the edible meat in SC is located in the legs only. To-date, the entire volume of clusters from Norway from both species has been exported as frozen product. The entire volume of RKC clusters is processed in land-based plants, while SC clusters are processed both on board harvesting vessels (about 90% of volume) and in land-based plants (Norwegian Fishermen's organization, 2017). The majority of SC are processed on board mainly due to the long distance between the harvesting waters ground and land-based processing plants. In addition, spending four to five weeks at a time in SC harvesting waters can also limit the possibility of live storage due to limited space and viability of the SC for that duration of live storage.

In the 1960s, RKC processing procedures were developed in Canada. In Norway, these processing procedures were adapted in 1994 with no modifications. Later on, the same procedures were applied to SC. For both species, processing includes removal of the cluster from the carapace, cooking, cooling, freezing, and packaging. As an alternative to freezing, clusters can be processed and stored in refrigerated conditions (Lorentzen et al., 2014, 2016a). Processing is performed on a semi-continuous basis, where baskets with clusters advance in a stepwise manner in the processing line. For RKC, removal of carapace is performed manually due to a relatively large variation in size (weights can range from 2 to 7 kg). As SC is considerably smaller (from 400 g to 1.3 kg) and more equally sized compared to RKC, the clusters are either removed manually or by machine (e.g., Baader 2801). In Norway, such machinery is used in both vessel- and land-based processing facilities. After the clusters are removed from the carapace, any remaining gills are removed manually or mechanically using brushes, often in combination with fresh water.

From time to time, the shoulder joint of RKC and SC clusters turn blue minutes after slaughtering. When these clusters are stored in refrigerated conditions, the blue color can spread to the legs as well, resulting in a discoloration of the entire product and an "off" flavor, which are considered less attractive sensory properties. It has been suggested that the blue color is due to a hemocyanin copper complex in the hemolymph of the crab (Gonçalves and de Oliveira, 2016; Lindberg et al., 2017). Compared to RKC, SC meat is more prone to blue discoloration, especially when cooking is inadequate.

After the clusters are removed from the carapace, they are either put into fresh water to allow de-bleeding of the hemolymph or cooked immediately. In recent de-bleeding studies of SC performed at Nofima, a weight loss of about 5% was observed after one hour at 1–2°C, due to drainage of hemolymph (unpublished results).

In the Norwegian RKC and SC industries, the clusters are commonly size graded into separate baskets. Afterward, the clusters are cooked by soaking the baskets in boiling fresh water. Size grading allows workers to adjust the cooking time to obtain a core cluster temperature of about 92°C. As a cluster has different-sized legs and claws, the final core temperature is adjusted to the largest extremity, i.e., the claw. Thus, the final core temperature of the legs will be above 92°C. Despite this challenge, an adequate and uniform cooking procedure is essential, as overcooking results in moisture loss, shrinkage of the meat, and reduced yields. In case of core temperatures below 92°C, the risk of blue discoloration is higher (Siikavuopio et al., 2011; Lindberg et al., 2017).

Once the final core temperature is obtained, the basket is removed and placed immediately in refrigerated fresh water to cool. The baskets are exposed to additional cooling in refrigerated seawater. Cooling is considered finalized when the core cluster temperature reaches about 1–2°C. Handling of the clusters after cooking involves a risk of cross contamination. Thus, clean containers and utensils, adequate water quality, and good manufacturing practices are crucial. As already described, both RKC and SC clusters are mainly exported frozen. The clusters are either frozen in brine (saturated with NaCl, tempered to −18°C or lower) or in a tunnel freezer. Once a core cluster temperature of −18°C or below is obtained, the clusters are packed. Cardboard boxes coated with inner plastic bags are commonly used, in which clusters are packed with the shoulder facing outward. The typical final weight of these boxes ranges from 10 to 20 kg.

The meat of RKC and SC is highly prone to spoilage due to high quantities of free amino acids and nitrogenous compounds (Anacleto et al., 2011; Lorentzen et al., 2014; Lorentzen et al., 2016a). Following death, SC and RKC undergo rapid protein degradation due to endogenous and bacterial enzymes. Thus, time of and temperature during processing is critical in terms of the shelf life and quality of the cluster. Typical processing time from the removal of the clusters from the carapace until the clusters are frozen is about 1.5 hr.

Workers processing both RKC and SC are exposed to bioaerosols, i.e., particulate matter or droplets produced during crab processing that are suspended in air. A considerable portion of these are within respirable range and enter the workers lungs when inhaled (Jeebhay et al., 2001). Several specific work tasks generate bioaerosols, such as removal of clusters from the carapace, removal of gills, and cooking (Jeebhay et al., 2001; Jeebhay and Cartier, 2010; Jeebhay, 2011). Bioaerosols contain components derived from the crab, such as endotoxins, microorganisms, and proteinaceous allergens. Two major allergens found in RKC and SC are tropomyosin and arginine kinase (Abdel Rahman et al., 2012; Thomassen et al., 2016). Since tropomyosin is heat-stable, both raw and cooked crab are sources of aerosolized tropomyosin (Jeebhay et al., 2001; Lopata and Jeebhay, 2013). Antibody reactivity of crustacean tropomyosin can also increase after heating, a possible result of protein denaturation and exposure to new epitopes, aggregation, and chemical modifications (Abramovitch et al., 2013; Kamath et al., 2013). Workers handling cooked crab may therefore have an increased risk of developing food sensitivities to crab. When processing both RKC and SC, workers are exposed to several components, and these combinations could alter the individual effect each agent has on workers' health. Bhagwat et al. (2016) showed that a synergistic effect of endotoxin and seafood proteases augmented inflammatory cytokines in an in vitro respiratory cell model.

Studies of SC processing show that exposure to bioaerosols varies across different areas of the processing line and exposure groups (Griffin et al., 1994; Malo et al., 1997; Jeebhay et al., 2001, 2005; Jeebhay and Cartier, 2010; Jeebhay, 2011; Lopata and Jeebhay, 2013). The level of different components varies depending on several factors, such as the layout of the plant and the level of automation (Moody et al., 1993; Stellman, 1998). This was also observed in Norwegian RKC processing plants (Thomassen et al., 2016). Moreover, several studies have found a high prevalence and incidence of occupational allergies and occupational asthma attributable to bioaerosol exposure (Cartier et al., 2004; Neis et al., 2004; Howse et al., 2006; Gautrin et al., 2010; Jeebhay, 2011; Bonlokke et al., 2012). Immunological sensitization, respiratory symptoms, and bronchial hyper-responsiveness have also been found in exposed seafood workers. Sensitization has been documented in workers involved in processing fish, mussels, prawns, and crabs, with highest prevalence observed in the shellfish industry (Jeebhay et al., 2001; Cartier et al., 2004; Jeebhay and Cartier, 2010; Shiryaeva et al., 2010; Lopata and Jeebhay, 2013).

Occupational asthma is the most frequent work-related respiratory disease in the seafood industry with a prevalence between 4% and 36% among workers exposed to shellfish (Jeebhay et al., 2001; Lehrer et al., 2003; Howse et al., 2006; Jeebhay and Cartier, 2010). An increased prevalence of respiratory symptoms and sensitization to crab was also found in Norwegian RKC processing plants compared to unexposed controls, but no increase in asthma was found (Thomassen et al., 2017). A healthy worker effect, where workers who develop asthma leave the processing plants, is a possible explanation for this lack of occupational asthma in the Norwegian study compared to corresponding studies from Canada (Shah, 2009). The time from start of exposure to the presence of symptoms can vary from weeks to years, and the symptoms are characteristically worse when the worker is at work and improve during weekends and holidays (Malo et al., 1997). Prognosis for recovery depends on duration of exposure after symptoms occur; therefore early diagnosis and change of work tasks to reduce exposure is important (Hudson et al., 1985; Malo et al., 1997).

Norway lacks occupational exposure limits and standardized, reproducible methods for collecting and analyzing such samples (Douwes et al., 1995; Eduard et al., 2012). Since there are no known safe levels of exposure, the main measures taken by processing factories are to reduce exposure by installing shields on work stations and applying more automatic processing operations. Adequate ventilation is also important to reduce the release of bioaerosols. Personal protective equipment such as respirators may be necessary in work tasks with a high risk of exposure.

Food safety

In the context of food safety, the Norwegian Food Safety Authority, has screened the presence and levels of heavy metals in crab meat (Lorentzen et al., 2016b). Previously, the NFSA performed analyses of heavy metals in *Cancer pagurus* caught along the coast of northern Norway (Frantzen et al., 2015). Based on this study, analyses of cadmium, mercury, and arsenic have been carried out in RKC harvested in the Varanger fjord in northern Norway during November 2012 and in SC harvested in the Loophole in the Barents Sea in April 2015 (Lorentzen et al., 2016b). The RKC was processed directly after harvest, while the SC was starved for four weeks before processing and sampling. For both species, the level of cadmium and mercury in the meat was below the maximum limit (Commission Regulation No. 1881/2006). Since inorganic arsenic is more toxic than organic arsenic (Raber et al., 2012), levels of both organic and inorganic arsenic were determined and found to be below the set maximum levels in both species. No maximum limit is set by the EU for total arsenic, inorganic arsenic, and manganese. Lorentzen et al. (2016b) concluded that meat from RKC and SC contained levels of heavy metals below the maximum limit and was therefore safe to consume.

In a study performed by the Julshamn et al. (2015), the meat from the claw and leg of RKC was analyzed for dioxins, furans, non-ortho and mono-ortho polychlorinated biphenyls (PCBs), non-dioxin-like PCBs, polybrominated diphenyl ethers, arsenic, cadmium, mercury, and lead. From April to November 2012, the RKCs were collected from different areas of the Barents Sea, including the Varanger fjord. The concentration of persistent organic pollutants and metals in RKC were below the maximum limits laid down by the EU. Thus, the authors concluded that RKC was safe to consume.

Tropomyosin is a muscle protein. Thus, in addition to causing allergic reactions in processing workers, it may also cause allergic reactions among consumers of RKC and SC (Motoyama et al. 2007; Abdel Rahman et al., 2011). Tropomyosin is heat-stable, and as previously mentioned, its allergenicity may even be enhanced by the cooking process (Kamath et al., 2013; Prester, 2016). Moreover, tropomyosin is able to withstand most known food processing techniques (Kamath et al., 2013). Due to the presence of similar IgE-binding epitopes, cross-reactivity between crustaceans like lobster, crab, and shrimp, has been reported (Motoyama et al. 2007; Leung et al., 2014). Consumers allergic to other crustacean species should therefore be cautious of consuming SC and RKC.

Pathogens could be a potential threat in cooked crabmeat, as this is a ready-to-eat product. As the core cluster temperature exceeds 72°C during cooking, the pathogen *Listeria monocytogenes* should be eliminated (Lado and Yousef, 2007). Consequently, food safety issues are mainly related to the risk of recontamination after cooking. The consequences of such contamination could be harmful if the crabmeat is consumed directly without any additional heat treatment. As the leg meat of both species is protected against contamination, this is considered as a limited problem. On the other hand, the meat located in the shoulder of RKC is not protected by a shell, and is thereby more exposed. In fact, previous studies revealed that the shelf life of meat located in the shoulder of RKC clusters is three days less than that of meat located in the legs of the same product (Lorentzen et al., 2014).

By-products

By-products from the processing of SC and RKC amount to approximately 30% of the weight of the crab (Beaulieu et al., 2009; Stenberg et al., 2012). Due to the large quantities harvested, fisheries generate large amounts of crab by-products (Lage-Yusty et al., 2011; Stenberg et al., 2012). At present, most, if not all by-products from Norwegian RKC and SC fisheries are discarded and dumped at sea or close to the shore. In Nova Scotia, Canada, it is estimated that 25% of SC is waste, which is a problem for processors that need to truck their waste to landfills for composting (Stewart and Noyes-Hull, 2010). In Alaska, it has been reported that some SC and RKC processors produce fishmeal from the waste, while some grind and discard the waste at sea or close to the shore (Bering Sea Aleutian Islands Crab Fisheries, 2004). Notwithstanding the potential value of by-products, dumping causes a waste problem and is environmentally unsound due to the possible slow degradation of crab carapaces (Poulicek et al., 1986; Arbia et al., 2013) and the environmental pollutants they contain (Rouleau et al., 2001; Mok et al., 2014; Julshamn et al., 2015). Thus, utilizing these by-products can lead to added product-value and can benefit the environment. The by-products of RKC and SC consist of everything but the legs or clusters of claws: the shell, the cephalothorax, the digestive system including the hepatopancreas, and physiological liquid (hemolymph; Beaulieu et al., 2009). Several valuable components are present in these by-products, such as marine oils, antioxidants like astaxanthin, chitin, minerals, as well as proteinaceous compounds (Shahidi and Synowiecki, 1991; Beaulieu et al., 2009; Lage-Yusty et al., 2011).

Potential commercial products that can be created from such by-products include omega-3 rich oil from the shell and hepatopancreas (Latyshev et al., 2009; Lage-Yusty et al., 2011) and bioactive peptides, which have a variety of anticancer (Doyen et al., 2011) and antibacterial (Doyen et al., 2012) properties. In addition, chitin and shell meal are potential commercial value-added products (Stewart and Noyes-Hull, 2010; Stenberg et al., 2012). The Canadian company St Laurent Gulf Products Ltd., is currently marketing and selling products made from SC by-products, including chitosan, astaxanthin rich meal, and shells (http://www.abcfishmeal.ca/). An attempt to include meal from RKC in salmon feed has shown a potential growth benefit in aquaculture production (Stenberg et al., 2012). In the same study, crab tails and fish sauce from the gills of RKC were suggested as possible niche products. There has also been research regarding opportunities to offer the roe from female RKC to restaurants (Fjørtoft and Larssen, 2009).

The proteinaceous hydrolysate from SC by-products has displayed a well-balanced amino acid composition (Beaulieu et al., 2009; Lage-Yusty et al., 2011). Similar results have been reported when analyzing the meal obtained from the by-products and shells of RKC (Stenberg et al., 2012).

As mentioned above, both RKC and SC are accumulators of organic pollutants including PCBs and brominated flame-retardants (Vorkamp et al., 2004; Vorkamp and Rigét, 2014; Julshamn et al., 2015). The lipophilic pollutants will accumulate in the oil, underlining the need for refining if the by-products are intended for production of RKC or SC oils. On the other hand, meal produced from RKC contains acceptable levels of cadmium, mercury, and lead according to Norwegian and EU regulations (Norwegian Ministry of Agriculture and Food, 2002; Stenberg et al., 2012). Like other marine by-products, the challenges presented by seasonal variations, landing volumes, and treatment (i.e., handling, temperature, storage, etc.) must be recognized and met. In addition, the presence of biological components such as endogenous degrading enzymes can result in a loss of quality in the final product.

Bioprocesses must be established and optimized, and will depend on the desired product, i.e., oils, proteins, chitin, or antioxidants. When deciding what type of product to commercialize from the by-products, it is important to pair the development with potential market demand by conducting a thorough economic analysis, including investment costs, processing costs, and market possibilities. In this way, the industry can ensure that the most beneficial product is being developed and launched from by-products that currently have no value. This illustrates a great potential in valorization of by-products from RKC and SC, and by combining biotechnological processes with scale-up possibilities and market knowledge, a new by-product-derived industry can prove to be very profitable.

Destination markets for Norwegian red king crab and snow crab

As already stated, the majority of RKC and SC are exported from Norway, either live or as cooked, frozen clusters. In 2016, about 49% of RKC were exported live (www.seafood.no). This is compared to 1% of SC, due to the challenges of live transport for this species.

In 2016, the main export market for live Norwegian RKC was South Korea, followed by the U.S., while Japan was the main market for frozen clusters (Table 1). The U.S. is gaining importance as a market for live Norwegian RKC with an increase from 53 metric tons in 2015 to 161 metric tons in 2016 (live RKC re-exported from South-Korea to the U.S. is not included). The total Norwegian export of RKC in 2016 reached 2174 metric tons, while the corresponding volume was 1786 metric tons in 2015. The value of Norwegian RKC has increased substantially in the last years due to increasing export of live RKC to higher-paying market segments. In fact, the export value of live RKC increased by 49% from 2015 to 2016. The total export value of RKC, including live and frozen, amounted to NOK 529 million in 2016 (www.seafood.no). Russia and the U.S. are the largest suppliers of RKC.

The total world supply of SC has decreased the last couple of years due to stricter regulations on harvesting in Russian waters after the appearance of illegal Russian crabs on the market (Norwegian Seafood Council, 2016). The legal Russian quota for the Russian Pacific increased from 17,000 metric tons (2016) to 20,800 (2017) (Norwegian Fishermen's Sales Organization, 2017). In addition, the catch estimate from the Barents Sea for 2017 is 15,000 metric tons, whereas the majority of SC is assumed to be caught in the Russian part of the Loophole (Figure 1; FAO, 2008). Canada is the largest supplier of SC. One of the quota area in Canada, New Foundland, have decreased significantly since 2010, while the quota located in the Gulf of Saint Lawrence, have increased. The total Canadian quota might show a small decrease, but the main influence on the decreased supply will be less illegal caught SC after the measures taken by Russia in cooperation with Japan and South Korea to reduce illegal crab fishing. In 2014, Russia and South Korea signed an agreement to stop illegal unreported crab from Russian vessels to South Korea. The same agreement was signed between Russia and Japan in 2015. China have only so far made an oral agreement to join the measure, hopefully, China will join the agreement by the end of 2017. Central seafood actors interviewed in Japan, South Korea, and the US say a lot of crab from illegal unreported and unregulated fishing are landed in China, making an urge for more crab in these countries. In 2016, Norway exported 4012 metric tons of SC, with a value of NOK 331 million (www.seafood.no). Of this, 3952 metric tons were exported as cooked and frozen clusters.

Among Japanese and South Korean importers and wholesalers, it is considered a positive thing that Norway is able to export crab throughout the year, thus providing a supply during Russia's off-season. In Japan, it is also considered positive that Norwegian quotas include female RKC, which they appreciate due to the accessibility of the delicate tasting roe. Despite this, interviews with crab importers showed that RKC and SC from Norway still have low recognition in the Japanese and South Korean market (Norwegian Seafood Council, 2016; Norwegian Seafood Council, 2017). To increase the market share and position of Norwegian RKC and SC, marketing and promotion efforts are required. Nevertheless, it will be of the utmost importance that the product is handled optimally from catch to the destination market in order to secure the supply of consistent, quality products.

Concluding remarks

Commercial harvesting of RKC and SC has become important for the Norwegian seafood industry. Since the

Table 1. Main Norwegian export markets of red king crab and snow crab in 2016 (www.seafood.no).

	Japan		South-Korea		U.S.	
	Volume, tonnes	Value, 1000 NOK	Volume, tonnes	Value, 1000 NOK	Volume, tonnes	Value, 1000 NOK
Red King Crab (RKC)						
Frozen	463	107,835	22	5880	68	11,621
Live	–	–	776	161,370	161	36,672
Snow Crab (SC)						
Frozen	1005	92,272	108	10,552	1587	118,288
Live	1	106	30	3695	27	2763

first harvest of RKC, the industry has acquired knowledge and applied technology that is quite different from traditional fish harvesting. In the future, it is assumed that the harvesting of both species will become increasingly important. The main challenge for both crab species will be to optimize and improve existing processing conditions and to increase the valorization of by-products (oil, protein, and shell). For RKC, more cost-effective live storage systems on and off shore have to be developed to secure optimal animal welfare during transport to the destination market. For SC, the main challenge will be to reduce the mortality rate by improving live storage conditions from harvest to destination markets. Once this is achieved, the volume of live exported SC is expected to rise to the level of RKC.

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