UiT
THE ARCTIC UNIVERSITY OF NORWAY

Faculty of Bioscience, Fisheries and Economics | Norwegian College of Fisheries Science

Gear selectivity and bycatch reduction in the Norwegian Red King Crab (*Paralithodes camtschaticus*) fishery

A study on size-selective performances of different escape openings

—

Peter Starbatty

Master thesis in International Fisheries Management (30 ECTS), June 2016

Acknowledgement

First and foremost, I would like to express my gratitude to my supervisor Roger B. Larsen and co-advisor Stein Siikavuopio for their guidance, advice, encouragement and support throughout the whole process. I appreciate your valuable feedback.

I would like to thank Erling Haugan from Bugøynes who helped me during and after the data collection. Private conversations that we had together deepened my knowledge about king crabs and made my thesis richer. I would extend my thanks to Jan Sundet, who shared his valuable feedbacks with me.

I would like to gratefully acknowledge Arne Eide, who guided me perfectly to find a study topic.

I would like to thank my dear friend Tannaz Alizadeh who contributed her greatest effort for my success and motivation. I would also thank Ayça Eleman for her help.

Moreover, I would like to thank NOFIMA for their financial support during the field trip in Bugøynes.

I would like to thank to my lovely wife Özge Işın Starbatty for everything that she has done for me. The amount of patience, forbearance, help and love that you gave me to support my graduation is incredible. This thesis is dedicated to you! Furthermore, I want to thank my parents Frank and Ines Starbatty, my sister Julia Starbatty, my mother-in law Yadigar Gül and my sister-in law Özlem Pasin. It was a very nice feeling to know that your endless support was with me whenever I was in need of it. I am a really lucky person to have such a nice family.

Abstract

This thesis aims to investigate ways to improve the size selective performances of the fishing gear that is currently employed in the fishery for Red King Crab, *Paralithodes camtschaticus*, in Northern Norway. High bycatch rates of undersized crabs are a source of concern since these individuals have to be sorted out and dicarded into the sea, a procedure that increases the risk for injuries and unaccounted mortality. Bycatch-related problems and knowlegde of king crabs' behavior in relation to fishing gear are explained in detail. Escape vents which are implemented into the side panels of the presently used rectangular pots can faciliate the egress of captured sublegal-sized animals while the pot is on the seafloor and are regarded as a commom tool to reduce their unintentional retention.

Comparative fishing trials have been carried out during February and March 2016 in the Varangerfjord in order to compare the catch compositions of traps equipped with escape vents of different shapes and sizes. Their abilities to sort out undersized crabs while keeping legal-sized ones inside the gear have been analysed by running Kruskal-Wallis H-tests. The results of these experiments did not reveal one of the tested escape opnenings to be superior to the others in all terms, though certain tendencies are recognisable.

Keywords: Red King Crab, *Paralithodes camtschaticus*, Barents Sea, Varangerfjord, Norwegian fishery, crab pots, catch dynamics, bycatch, bycatch reduction, escape openings, size selectivity

Table of contents

List of tables

List of figures

1. Introduction

The Red King Crab, sometimes also called Kamchatka Crab (*Paralithodes camtschaticus*), ranks among the world's largest arthropods. It is a highly-valued delicacy and a species of great commercial interest. After its deliberate introduction into the Barents Sea during the 1960s, it has established a viable and self-reproducing population that steadily increased its distribution range. Today, the Barents Sea king crab stock is supporting a commercial small-scale fishery along the coast of the Finnmark County in Northern Norway. Yearly allowable catches presently range around 2,000 tons per year, and collapsible pots are the only gear in use. This thesis aims to investigate ways to improve gear efficiency and catch selectivity of the pots that are used in this fishery. Comparative fishing trials were conducted to find out if and how the integration of different types of escape vents into the traps is affecting catch compositions.

1.1 Geographical distribution

The Red King Crab is a boreal anomuran crab species that is naturally native to the Northern Pacific Ocean. Its distribution range at the Asian side of the North Pacific extends from as far south as Korea to the Northern coast of the eponymous Kamchatka peninsula, including parts of the Northern and Eastern Japanese coast as well as the Amur region and the Okhotsk Sea in the Far East of Russia. At the North American side, Red King Crabs are found between Bristol Bay in the Alaskan Bering Sea and British Colombia in Canada. Furthermore, they are common along the Aleutian island chain (Jørgensen et al., 2005). The Northern Pacific Ocean has traditionally been the most important area for commercial exploitation of Red King Crabs.

Based on population structure and genetic characteristics, the Pacific Red King Crabs are divided into three main populations (Grant et al., 2014). A fourth population nowadays exists in the Southern Barents Sea. King crabs have colonized coastal waters between Cape Kanin in Russia and Tromsø in Northern Norway after having been transferred to the Murmansk area by Soviet scientists about fifty years ago. Figure 1 illustrates the current distribution range of this newly established population.

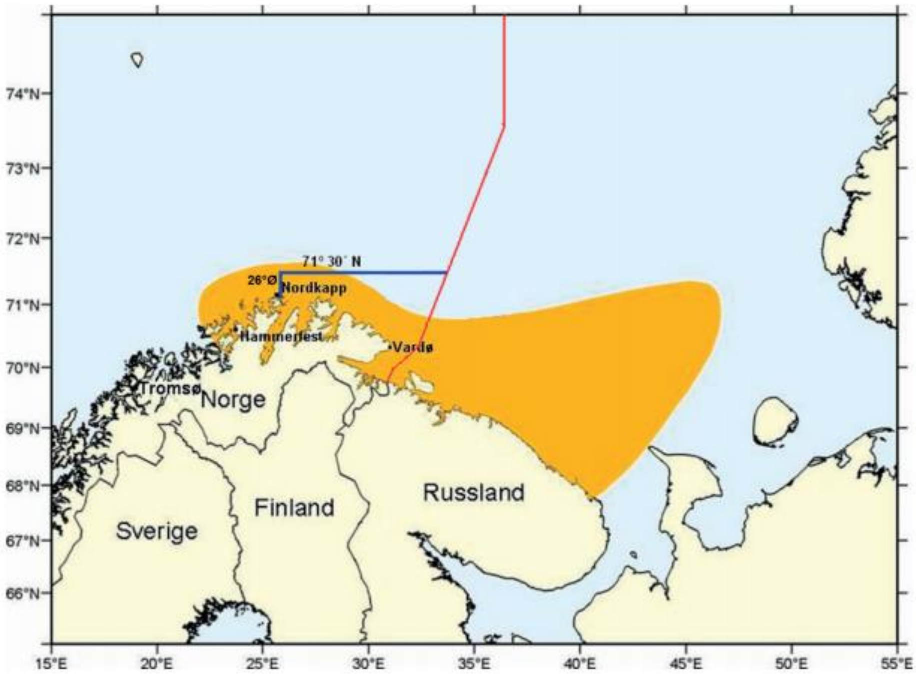

Figure 1 *Present distribution range of the Red King Crab* (Paralithodes camtchaticus) *in the Southern Barents Sea (yellow). Border between regulated and unregulated fishing area in Norway (blue line). Source:* Anonymous (2015).

1.2 Invasion history

The only lithodid crab species that is originally native to the North Eastern Atlantic Ocean is the Northern stone crab (*Lithodes maja*) (Zelenina et al., 2008), which can reach a maximal carapace width of up to 134 mm (Moen & Svensen, 2014), but is usually much smaller than adult Red King Crabs (Jørgensen et al, 2005). This species has never been targeted by a commercial fishery in the area since it does not form suitable aggregations (Dvoretsky & Dvoretsky, 2014). Hence, there has not been any commercial crab fishing activity in the Barents Sea previous to the introduction of the Red King Crab.

The idea of transferring Pacific king crab species to the Barents Sea in order to establish a crab fishery arose in the former USSR during the 1920s (Zelenina et al., 2008). The first introduction attempts during the early 1930s, however, were not crowned by success – mainly due to the lack of adequate technical and logistical possibilities for long-distance transportation of living crabs in that period (Dvoretsky & Dvoretsky, 2014). The idea was taken up again in the 1960s. Facing signs of overfishing in many Pacific king crab fisheries, the establishment of a new population in the area around Murmansk was regarded to be a potential goldmine for the export industry as well as an enrichment for local consumption, leading to an increased standard of living for the population of the Soviet Barents Sea region (Orlov & Ivanov, 1978). Approximately 2,600 adults, 10,000 juveniles and 1.5 millions of Red King Crab larvae hatched from incubated eggs have been released into the Southern Barents Sea (predominantly into Kola Bay) during the years between 1961 and 1969. These specimens were caught in the Peter the Great Gulf (Sea of Japan), an area characterized by high abundances of large-sized individuals, and to a lesser extent off the South-Western coast of the Kamchatka peninsula (Sea of Okhotsk), where crabs were smaller in size, but considered to be quite tolerant to severe environmental conditions (Orlov & Ivanov, 1978). Norwegian or other countries' authorities have neither been consulted nor informed previous to and during the transplantation project (Anonymous, 2007). Another 1,200 adult individuals from the East have been transferred during 1977-78 (Kuzmin & Olsen, 1994). There were suggestions to transplant a second king crab species, the Blue King Crab (*Paralithodes platypus*) from the Northern Pacific to the Barents Sea (Orlov & Ivanov, 1978), but these plans have never been realized.

1.3 Establishment in the new environment

The first large berried Red King Crab female in Soviet Barents Sea waters was recorded in August 1974 (Orlov & Ivanov, 1978), indicating successful reproduction in the new area. In Norway, the first specimen was caught in 1976 in the inner part of the Varangerfjord (Kuzmin & Olsen, 1994)[1]. It took until 1992 for the crab to become abundant in Norway, and the following decade was characterized by rapid geographical spread and massive increases in numbers. The colonization of the entire Varangerfjord was completed by 1994. Thereafter, the species gradually established itself in the other major fjords of Eastern Finnmark, reaching Tanafjord in 1995 and Laksefjord as well as Porsangerfjord in 2000 (Jørgensen & Nilssen, 2011). In the same year, the first crabs were caught off Sørøya (Anonymous, 2007), which was regarded to be the Western border of the coherent Barents Sea population until very recently (Anonymous, 2015a). Other authors of recent publications, such as Sundet (2014) have already assumed “that the crab has moved by itself at least to areas around Tromsø in the West”, a statement that was strongly supported by new evidence in February 2016, when divers observed hundreds of king crabs close to Eidkjosen (Kvaløya) (Medby, 2016).

[1] Other sources, such as the Parliament Whitepaper from 2007 (Anonymous, 2007) state January 1977 as the date in which the first king crab has been caught in Norway. The author decided to stick to Kuzmin & Olsen (1994) due to the more detailed description of the circumstances of this catch in their publication.

1.4 The Barents Sea population today

The large majority of king crabs in Norwegian waters is found in coastal waters not further offshore than 12-15 nautical miles (Anonymous, 2015a). In the Russian Barents Sea, where the bottom slopes more gradually, the highest densities are about 30-50 nautical miles ashore (Sundet, 2014b). The estimated total population in Norwegian waters used to be below 0.5 millions of individuals until 1998. Three years later, however, there were already more than 3 million king crabs (Anonymous, 2007). The estimates have since then never fallen below this mark, peaking with more than 5 million individuals in 2008. The latest estimate for 2014 stated an overall Norwegian king crab population of well over 3.5 million (Anonymous, 2015a). It is important to note, however, that all these numbers only refer to individuals of at least 70 mm carapace length and living at depths of 100 m or deeper (Anonymous, 2015a; Jørgensen & Nilssen, 2011). Hence, they must be regarded as underestimates. Britayev et al. (2010) stated a total adult population of more than 40 million in the whole Barents Sea (Norway and Russia).

Although the species still continues to extend its area towards the West and South, the core distribution range in Norway – and hence the range of commercial exploitation – is so far restricted to the Eastern and Central parts of the Finnmark County. Occasionally reported findings of individuals further south (for example around the Lofoten archipelago or Bergen) are assumed to be the result of either accidental or deliberate releases from fishing vessels (Pinchukov & Sundet, 2011). The border of the contiguous population range in Norway has been around Sørøya (Finnmark) at approximately 22ºE for some years, and colonizing of new areas has not been observed during 2011-2014 (Anonymous, 2015a). The International Council for the Exploration of the Sea (ICES) (Anonymous, 2015b) concluded that the spread of the species has substantially reduced since 2010 and that this development is attributable to the free fishery regime west of 26°E. However, as mentioned before, recent discoveries in 2016 are strongly indicating that the king crab is about to firmly establish itself in the Tromsø region.

1.5 Research objectives

The objective of this work is to investigate ways to reduce bycatch rates in the king crab fishery in Norway. Data on bycatch rates in Norway are scarce, but there is agreement on that high bycatch rates are undesirable. Crabs that are going through handling procedures may suffer mortality or injuries. The dimension of the problem under commercial conditions is difficult to quantify and might depend on several conditions (Zhou & Shirley, 1996), but it is clear that the risk for death or physical traumata is existing whenever crabs are sorted and handled. Beyond the additional work that high bycatch rates mean for the fishermen, increased mortality and injury rates are implying potentially harmful consequences for the crab stocks and hence for the crab fishery. This thesis also seeks to summarize knowledge on king crabs' behavior towards fishing gear and the topic of unwanted mortality as well as possible ways to reduce it in sections 2.3 and 2.4.

Crabs with visible injuries – partly or completely autotomized or regenerating appendages being the most common and most obvious ones – are economically much less valuable than crabs with an intact outer appearance. The total biomass (and therefore also the total harvestable biomass) of the stock decreases when the amount of injured crab increases. Autotomized legs will require energy for regeneration and as a consequence reduce overall growth. In addition, injuries might make crabs less successful in defense and reproduction.

Given the currently used gear that fishermen in Norway's small-scale king crab fishery are employing, the best and easiest way to improve size-selectivity would be the implementation of effective escape openings. Fishermen presently prefer round escape rings, if any, but a round design is not necessarily the best one. King crabs squeeze themselves sideways through escape vents (Stevens, 2014) and rectangular or squared openings could facilitate their egress.

Hence, we aim to find out if the size-selection properties of the present-day king crab gear in the Norwegian fishery could be improved by implementing escape vents that ensure a reduction in the retention of unintentionally caught sublegal crabs without negatively affecting the catch of legal-sized individuals. This investigation was done by comparing the performances of pots with four different escape openings (one of them round, two of them squared and one of them rectangular) as well as traps without any escape opening under commercial conditions.

In order to test if improvements are possible, the following null hypothesis (H_0) and alternative hypothesis (H_1) have been formulated:

H_0: There is no difference between the total catch performance of king crabs, the total retention of sublegal-sized king crabs, the total retention of small legal-sized king crabs and the total retention of larger legal-sized king crabs across traps with four alternative escape vents and a control trap.

H_1: There is a difference between the total catch performance of king crabs, the total retention of sublegal-sized king crabs, the total retention of small legal-sized king crabs and the total retention of larger legal-sized king crabs across traps with four alternative escape vents and a control trap.

As a summary, the thesis aims to answer the following two question:

- *Is it possible to improve the gear's size-selective performance by implementing a certain type of escape openings?*

1.6 Limitations

The field work has been carried out in one small part of the Varangerfjord in Northeastern Norway during five weeks in February and March. Therefore, its results are probably hardly generalizable for the Norwegian king crab fishery as a whole. The species is known to undertake seasonal vertical migrations, and size and sex structures at one particular location are therefore changing throughout the year (Sundet & Hjelset, 2014). King crabs – especially smaller ones - are known to form aggregations, and the presence or absence of such aggregations might influence catch performances and size distributions. This applies all the more so when the sample size is comparatively small, as it is the case in this study.

Furthermore, the escape devices that have been tested only present some possible forms and dimensions rather than a perfect continuum. For obvious reasons, only a limited number of different escape openings could be tested. Hence, eventual results in terms of selective superiority must be understood as pointing into a certain direction, not as necessarily optimal solutions.

2. Background

2.1 Biology of the Red King Crab

2.1.1 Taxonomy and appearance

The species was scientifically described for the first time by Tilesius (1815) after the type specimen has been collected off the Kamchatka peninsula during the Russian round-the-world-expedition (Pinchukov & Sundet, 2011). Its present taxonomic classification according to the World Register of Marine Species (Ahyong, 2015) is as follows:

Kingdom: Animalia

Phylum: Arthropoda

Subphylum: Crustacea

Class: Malacostraca

Order: Decapoda

Infraorder: Anomura

Family: Lithodidae

Genus: *Paralithodes*

Species: *P. camtschaticus*

The Red King Crab is the largest out of five species within its genus *Paralithodes* (Stevens & Lovrich, 2014; McLaughlin, 2014). The dorsal side is typically colored reddish brown or burgundy, while the underside ranges between golden yellow and whitish. King crabs possess three apparent pairs of walking legs and one pair of clawed legs (chelipeds), the larger of them generally being on the right side. The last pair of legs is reduced and hidden in the gill chambers (Stevens & Lovrich, 2014). The strongly calcified exoskeleton and the legs are covered with spines. The most apparent difference between males and females is the size and shape of their abdominal plates (see figure 2). Abdominal plates of females are larger and asymmetrical, with the largest plates usually on the left side. The maximum recorded weight in Alaska was 10.9 kg for a male and 4.8 kg for a female (Stevens & Lovrich, 2014); the absolute maximum size was 227 mm carapace length (CL) and 283 mm carapace width (CW) for a male and 195 mm CL and 213 mm CW for a female. Large specimens can reach leg spans of up to 1.8 m (Moen & Svensen, 2014).

Figure 2 *Ventral view of a male (left) and female (right) Red King Crab. Both individuals measure between 110 and 120 mm carapace length.* (Photos by Peter Starbatty)

2.1.2 Requirements for temperature, depth and salinity

An Alaskan study carried out in three different areas between May and July found king crabs in water temperatures ranging from -1.8 to +12.8 °C, with means between 3.2 and 5.5 °C, depending on the region (Stevens & Lovrich, 2014). The stated temperature interval might not represent the whole range of tolerable temperatures, since data have only been obtained during a comparatively short seasonal period. Falk-Petersen et al. (2011) stated 18°C as the species' maximum tolerable temperature. Temperature requirements, however, are likely to depend on life stages, and can be critical particularly for larval survival (Stevens, 2014). The acclimation temperature for a berried female is assumed to have a proportional effect on the upper lethal temperature of larvae (Pinchukov & Sundet, 2011). Hansen (2002) found that king crabs smaller than 100 mm CL, caught in the Norwegian part of the Barents Sea, showed a clear preference for sea water colder than 3°C. Other experiments showed that the absolute lethal temperature for larvae can theoretically be higher as 20ºC if they were acclimated accordingly (Sparboe & Christiansen, 2008). Incredibly, one single male individual of 150 mm CL has been caught by a gillnet at 20 m depth in the Ionian Sea in Southern Italy during August 2008 (Faccia et al., 2009). The circumstances of this incident are completely mysterious, but obviously the animal managed to survive at least for a certain time in a Sea where surface temperatures in August reach as much as 26ºC. The question of how far the crab will be able to spread itself remains a subject of lively discussion.

Post-larval king crabs can be found between shallow, rocky habitats of the intertidal zone and depths of about 510 m (Falk-Petersen et al., 2011), but there has been little indication for occurrences at greater depths than 300 m in Norway so far (Anonymous, 2015a). The species prefers salinities of 28-30 PSU or even higher (Falk-Petersen et al., 2011), but juveniles have shown to be tolerant to typically lower salinities of the lower intertidal zone (Thomas & Rice, 1992).

2.1.3 Growth

Although growth in crustaceans is a continuous process, it appears to be discontinuous since size increments are only obtained when the animals change their exoskeleton during the molting (ecdysis) process (Nilssen & Sundet, 2006). Very young king crabs are known to molt several times per year. The frequency can be as high as 9 times during the first year, and then decreases with time to one molt at age 5 (Powell & Nickerson, 1965). While adult females continue to renew their shells annually prior to mating, males of 110 mm CW or more usually don't undergo molting every year anymore. The frequency goes down to one molting every four years for males larger than 190 mm CW (Pinchukov & Sundet, 2011). It is believed that most male king crabs that undergo molting do not participate in mating during the same season, implying that roughly half of the mature males in a population do not reproduce in a particular year (Dew & McConnaughey, 2005). Nilssen & Sundet (2006) estimated the mean growth increment for king crabs in the Varangerfjord to be 17.0 mm in CL for both immature and mature males, while the growth of females slowed down from a mean of 14.4 mm increase in CL per molt to 5.1 mm per molt after becoming ovigerous. Similar observations were made by Rafter et al. (1996). Adult molting is happening in spring, with peaks in March/April for males and in May for females (Pinchukov & Sundet, 2011), but individuals showing signs of molting can also be observed earlier (as in the fieldwork for this thesis; see later).

2.1.4 Life history

Red King Crabs can achieve a lifespan of 20 years (Jørgensen et al., 2005). Sexual maturity can be reached at age 5, when crabs measure 66-105 mm CL (Falk-Petersen et al., 2011), but generally seems to be achieved at larger sizes in the Barents Sea compared to the crab's native Far Eastern habitat. Rafter et al. (1996) estimated the CL at sexual maturity in the Varanger area to be 104 mm for both males and females. Hjelset et al. (2009) found 50% of the females in three fjords of Eastern Finnmark ovigerous at about 109-111 mm CL and essentially supported previous findings of Rafter et al. (1996) who calculated this value to be 112 mm CL for crabs in the Varangerfjord. Coupling takes place in spring, especially in April and May (Pinchukov & Sundet, 2011).

Females lack the ability to store sperm and need a male present to fertilize the eggs (Hjelset, 2014). Mature individuals of both sexes gather during spring in shallow waters. Females have to undergo molting immediately before mating, and probably do not feed until mating and egg extrusion (Sundet & Hjelset, 2010). The male king crab grasps the female's anterior legs with its claws, carries it and protects it during molting before fertilization takes place. The male is necessarily larger than the female (Hauge & van der Meeren, 2012). Eggs are fertilized externally: After extruding its sperm packages (spermatophores) and spreading them around the female's gonopores, the male releases the female and does not show further interest (Donaldson & Byersdorfer, 2005). The female extrudes the eggs from its gonopores, which are located on the underside of the second walking legs, and carries the fertilized eggs under her abdominal plates until they hatch after a period of about 11-12 months (Donaldson & Byersdorfer, 2005). Total female fecundity is positively related to size (Hjelset, 2014) and varies between 15,000 and 500,000 eggs[2] per female (Jørgensen, 2006), implying a huge potential for rapid population growth in so far uncolonized and ecologically suitable areas. Males can couple with up to seven females within one spawning season. Again, their fertilization rate is positively related to their size and, in case of mating with several females, decreases significantly after the first two or three copulations (Pinchukov and Sundet, 2011).

After hatching from the eggs, king crab larvae pass through several pelagic larval stages before transforming to their post-larval appearance. The first one of them, the prozoea stage, lasts only for a few minutes (Stevens, 2014). The subsequent four stages (zoea I to zoea IV) last for about two months, and ocean currents can transport the passively drifting larvae over long distances during that period (Jørgensen & Nilssen, 2011). Finally, the zoea transform to the glaucothoe stage, during which settlement takes place in waters not deeper than 20 m. The abundance of sponges, bryozoans and macroalgae is critical for recruitment as larvae need them to settle (Jørgensen & Nilssen, 2011). After one more metamorphosis, the glaucothoe enter the first instar and take up a benthic existence (Donaldson & Byersdorfer, 2005). Juvenile crabs remain

[2] According to Pinchukov and Sundet (2011), total female fecundity even amounts to 70,000 – 700,000 eggs with a weighted mean of 250,000 eggs.

in the shallow waters of the littoral zone until they reach adulthood. In their very first year, they live a cryptic life between rock crevices or kelp patches (Powell & Nickerson, 1965). In the North Pacific, juveniles were observed to seek shelter in recesses between sea star arms or between stalks of anemones as well (Dew, 1990). Especially during their second and third year, at carapace lengths of up to 69 mm, crabs tend to form so-called pods which can contain many thousands of individuals of both sexes. These spherical aggregations are unique to Red King Crabs (Dew, 2010) and thought to minimize the vulnerability to predators during foraging. Forming discrete aggregations of lesser structural and numerical density might persist until adulthood (Dew, 2010). Podding behaviour among juveniles has been observed in Norwegian waters, too (Anonymous, 2007).

2.1.5 Migrations

It has been confirmed that king crabs have essentially maintained their migrational patterns from the Pacific Ocean after their transfer into the Barents Sea (Sundet & Hjelset, 2010). Prerecruits of both sexes are distributed on mixed bottoms in shallow waters between 20 and 50 m and rarely found together with mature individuals in deeper layers (Jørgensen et al., 2005). Adult king crabs undergo two seasonal migrations, one mating-molting migration and one feeding migration (Jørgensen & Nilssen, 2011). The mating-molting migration towards shallow waters lasts from early winter to March. Males start moving to shallower waters as early as November, followed by multiparous females in December[3] (Sundet & Hjelset, 2010). Mating generally happens in April and May (Pinchukov & Sundet, 2011), but primiparous females seem to have their peaks probably earlier than other crabs (Sundet & Hjelet, 2010). Mating is followed by the feeding migration, during which the adult individuals go back to depths of up to 300 m (Jørgensen et al., 2005). During the summer and autumn months, both sexes remain in deep waters and are usually not found together until the next mating season.

[3] This is the pattern in the Barents Sea (Sundet & Hjelset, 2010). In the Northern Pacific Ocean, the beginning of the migration into shallower waters, and hence the mating-molting events, appear to happen somewhat later.

2.1.6 Mobility

King crabs are highly mobile and have been observed to travel more than 10 km per day (Falk-Petersen, M.Sc. 2004) or 426 km during one year (Jørgensen et al., 2005). Adult king crabs actively migrate to new areas in situations of low availability of food (Jørgensen, 2006). This and the passive transport of pelagic larvae by ocean currents may considerably contribute to a rapid dispersal of the species. At least until 2007, there was indication for a net immigration from Russian to Norwegian waters (Anonymous, 2007). This could still be the case, but more recent research on the topic could not be found.

2.1.7 Feeding

King crabs in their larval stadiums feed on phytoplankton and, to an increasing amount as time passes, zooplankton (Jørgensen & Nilssen, 2011). After settling, they start to feed on benthic organisms. Juvenile crabs in the Russian part of the Barents Sea were observed to predominately feed on bivalves and gastropod mollusks (Britayev et al., 2010), but also sea urchins are within their prey spectrum (Pavlova, 2009).

Post-settlement king crabs can be characterized as large, bottom-feeding opportunistic omnivores (Falk-Petersen et al., 2011). Their feeding strategy is flexibly adapted to local conditions and can include polyphagous or monophagous behavior (Pinchukov & Sundet, 2011), depending on the availability and abundance of benthic prey organisms. The composition of preferred food can vary seasonally (Oug et al., 2011). Adult crabs may grasp or tear apart food items with their chelae (pincers), eventually crush them, or scoop sediment by the lesser chela in order to sieve it through their third maxillipeds (Jørgensen, 2005). The diet of the crab includes roughly 100 different species (Britayev et al., 2010). Not only animals, but also plant material can play a role (Jewett & Feder, 1982), though it is not sure whether plants are eaten incidentally along with other items or constituting an opportunistic food by themselves. Rafter et al. (1996) identified benthic mussels and polychaeta to be the dominant food items in king crab stomachs in the Varangerfjord. Echinoderms seem to become an important part of the diet as crabs migrate to shallower waters in spring. Crab predation was estimated to be responsible for losses of more than 30% in local sea urchin (*Strongylocentrotus droebachiensis*) populations in Kola Bay, Russian Barents Sea (Pavlova, 2009). Furthermore, fish remnants, algae and gastropod mollusks were regularly encountered. King crabs are not likely to regularly catch fish actively. Hence, scavenging on waste from fishing vessels or dead fish is presumably accounting for the bulk of fish remnants in their stomaches (Rafter et al., 1996). King crabs are known to occasionally feed on eggs of bottom-spawning fish, too. In the Barents Sea, the commercially relevant capelin (*Mallotus villosus*) and lumpsucker (*Cyclopterus lumpus*) are the most important fish species in this context (Anonymous, 2015a). Food intake in king crabs declines for about 2-3 weeks during the period of molting, growth and reproduction (Jørgensen & Nilssen, 2011).

Although cannibalistic behavior has been documented in captivity, especially among younger crabs and across different cohorts, it does not necessarily play a major role in the wild (Stevens & Jewett, 2014). Cannibalism can help crabs to alleviate eventual nutritional deficits (Stevens & Jewett, 2014) and is thought to be a regulating factor in situations of high abundance and scarce food (Anonymous, 2015a).

In the Barents Sea, predation on king crab larvae is documented for Atlantic salmon, saithe, halibut and some flounder species (Falk-Petersen et al., 2011). Juveniles and adults, or parts of their bodies, have been found in the stomachs of big cods, catfish and halibuts. Even large individuals can be vulnerable to predation, particularly after molting, and have been documented in large cod and halibuts. Cannibalism of large king crabs on recruits seems to be a prevalent phenomenon in Norwegian waters as well (Anonymous, 2015a).

2.1.8 Ecosystem impacts

The appearance of the invasive and continuously spreading Kamtchatka Crab as a large, generalist and bottom-feeding predator has raised concerns about its possible threats to native benthic communities and the Barents Sea ecosystem as a whole. Alien species may impact recipient ecosystems by competition for food and space, predation, introduction of pathogens or modifications of habitats (Oug et al., 2011). The long-term consequences of the king crab invasion are still uncertain.

Russian research in Motovsky Bay found biomass ratios of important benthic taxa significantly changed compared to the early 1930ies and concluded that the presence of red king crabs was "one of the most probable reasons" for the observed alterations in certain benthic communities (Anisimova et al., 2005). However, it was speculated that fishing was at least equally responsible for the decreases in benthic biomass and the impact of the crab was generally thought to be moderate. Extensive bottom trawling used to be very common in parts of the

Motovsky Bay (Oug et al. 2011). When assessing the soft-bottom faunal composition of Bøkfjord and Kobbholmfjord (Southern Varanger area) and comparing the findings to data from 1994 – just prior to the massive increase in king crab abundance – Oug et al. (2011) identified noticeable reductions in biodiversity. A severely impoverished representation of echinoderms (particularly brittle stars and mud stars), larger mollusks and burrowing polychaetes was striking. The commercially valuable Iceland scallop (*Chlamys islandica*) might be locally threatened by king crab predation or foraging behavior as well (Jørgensen, 2005). All these organisms are characterized by low mobility and therefore constitute easily accessible prey items for king crabs. Rafter et al. (1996) identified remnants of these organisms to be among the most common ones in stomachs of king crabs in the Varanger area. Species that increased their abundance after the king crab invasion turned out to be primarily those species with effective physiological or behavioral traits allowing for escape (Oug et al., 2011). Several of the cited studies indicated that king crabs often remove predominantly adult individuals of their preferred prey species. Sundet (2014a) suggested differences in the bottom topography to be the reason for the generally lower magnitude of crab-induced impacts on benthic communities in Russian studies. Since the Finnmark coast is characterized by many inlets and large, deep fjords rather than having a gradual slope, higher crab concentrations in coastal waters could lead to more pressure on the local benthic fauna.

The impact on capelin stocks by king crab predation on their eggs seems to be negligible (Anisimova et al., 2005), but is apparently a more serious issue in the case of the lumpsucker. King crabs are assumed to markedly contribute to low recruitment of this fish species by consuming and destroying clumps of lumpsucker eggs. The crabs' presence can scare away the male lumpsucker, which is guarding the clutches. If necessary, king crabs even push the lumpsucker away with their legs. Consequently, the eggs remain unprotected and exposed to other ovophagous predators such as sea urchins (Mikkelsen & Pedersen, 2012), even if the crab eats just some of them. Concerns have also been expressed because the crab's feeding behavior, which includes frequent scooping of surface sediments. In combination with the reduction of certain bottom-living species, this is thought to negatively influence the sediments' biochemical functionality (Oug et al., 2011).

2.2 The Norwegian king crab fishery

2.2.1 From research fishing to commercial fishing

The Red King Crab was recorded for the first time in Norwegian waters in 1976, but it took some years until it became abundant. Bycatch of king crabs in other fisheries in the Varangerfjord has been commonly reported since the 1980s (Kuzmin & Olsen, 1994). Though its frequency gradually increased, the overall level of bycatch in that decade was comparatively low. The king crab invasion gained great attention in spring 1992, when mass bycatch of crabs enraged many fishermen in the Southern tributaries of the Varangerfjord. Entanglement of crabs happened particularly in cod, shellfish and lumpsucker gillnets of local small-scale fishermen and to a smaller amount in bottom trawls (Rafter et al., 1996). King crabs in gill nets caused a massive amount of extra work for fishermen and considerably reduced gear efficiency and hence catches of target species, sometimes resulting in complete damage of fishing gears (Godøy, Furevik & Løkkeberg, 2003). The crab also impacted longline fisheries by removing bait from hooks or causing damage to commercially valuable hooked fish (Sundet & Hjelset, 2002). As a reaction to the dimensions that the bycatch problem had suddenly achieved, the issue was brought to the attention of the Joint Russian-Norwegian Fisheries Commission, which has been established in the 1970s in order to bilaterally coordinate the management of shared living marine resource stocks (Kuzmin & Olsen, 1994). Since there has never been a commercial crab fishery in the Barents Sea area before, knowledge of both fishermen and management authorities has been very limited at that time. This was also due to the fact that parameters from the native areas of the crab are not necessarily transferable to the crab's new environment. The Commission therefore decided to initiate an experimental crab fishery in 1993 (Sundet, 2014a). Main goals were to obtain stock estimates, to investigate the general population biology and to gain knowledge on the effects that the crab has on local coastal ecosystems (Rafter et al., 1996). The period of this research fishery started in 1994 with a Norwegian Total Allowable Catch (TAC) of 11,000 legal males (Jørgensen & Nilssen, 2011) and lasted until 2001. Norway and Russia equally shared their annually defined total quota in that period. Commercial fishing in Norway was launched in 2002 and in Russia in 2004 (Pinchukov & Sundet, 2011). The national exploitation rate per annum was set to be 20% of the estimated total harvestable male stock (Sundet, 2014a), which translated to a Norwegian quota of 100,000 individuals in the first year of commercial fishing (Anonymous, 2007). After continuing to share mutually agreed total quota during the following years, the two countries decided to manage king crabs separately in their respective economic zones from 2007 on (Anonymous, 2007).

2.2.2 The two management regimes

Since its appearance in Norwegian waters, the Kamchatka Crab has caused controversial debates on how its management should look like. While some societal actors emphasized the species' commercial value and its potential to economically support coastal communities along the Finnmark coast, others were concerned about its possible negative impacts on ecosystems or traditional fisheries and called for eradication measures. In addition, references were made to international agreements obliging Norway to take action against the spread of non-indigenous species. The most important of these multilateral treaties are The United Nations Convention on the Law of the Sea (UNCLOS) from 1982 (particularly article 196), and the Convention on Biological Diversity (CBD) from 1992 (particularly article 8 (h)).

Being regarded as a valuable resource and as a pest at the same time, the king crab in the Barents Sea challenged Norwegian management authorities to develop a unique regulatory regime in which two conflicting objectives are reflected. On the one hand, the aim was to establish a profitable and predictable long-term fishery, and on the other hand, it was sought to prevent further spread along the Norwegian coastline (Anonymous, 2015a). Based on these considerations, Norway divided the distribution area into two different management zones in 2004 (Jørgensen et al., 2011). West of 26°E, which is approximately the longitude of the North Cape, there is a zone of free fishery which is accessible to everyone. All caught king crabs, regardless of their size and sex, have to be landed in that area. Release of individuals is prohibited and no quota system is in place. It is furthermore not allowed to equip traps with escape openings.

Between 26°E and the Russo-Norwegian border, there is a commercial area in which access to the fishery is restricted. Moreover, the fishery is regulated by Total Allowable Catches and vessel quotas, and several legal constraints regarding vessels, gears and the crabs that fishermen are allowed to land.

The borders of these areas have slightly been modified in 2010, when the inner part of the Porsangerfjord was integrated into the commercial area and the Northern border of the commercial area was extended to 71°30'N (Anonymous, 2015a), but the regime that has been introduced in 2004 is in principle in place until today. Figure 1 depicts the current geographical location of the two different management areas.

Though fishing West of 26°E started in 2004, catches in this area averaged not more than 43 tons annually until 2007 (Anonymous, 2007). Extraordinary peaks were achieved during the years 2008 and 2009, when catches were 3.035 tons and 4.439 tons, respectively. This was not only explained by a generally high abundance of crabs in that time, but most importantly by presumed misreported landings that actually have been fished in the regulated area. As a reaction, authorities introduced a more efficient tracing system in November 2009 and catches in the open area declined. A subsidy to stimulate higher fishing effort in the open area has been introduced in 2010. This was considered to be necessary due to a too high percentage of small crabs in this area and a resulting lack of economical attractiveness of the fishery (Anonymous, 2015b). An overview of the landings in both areas since 1995 and an illustration of the dimension of the aforementioned remarkable peak in catches in the Western zone in 2008 and 2009 is provided in figure 3.

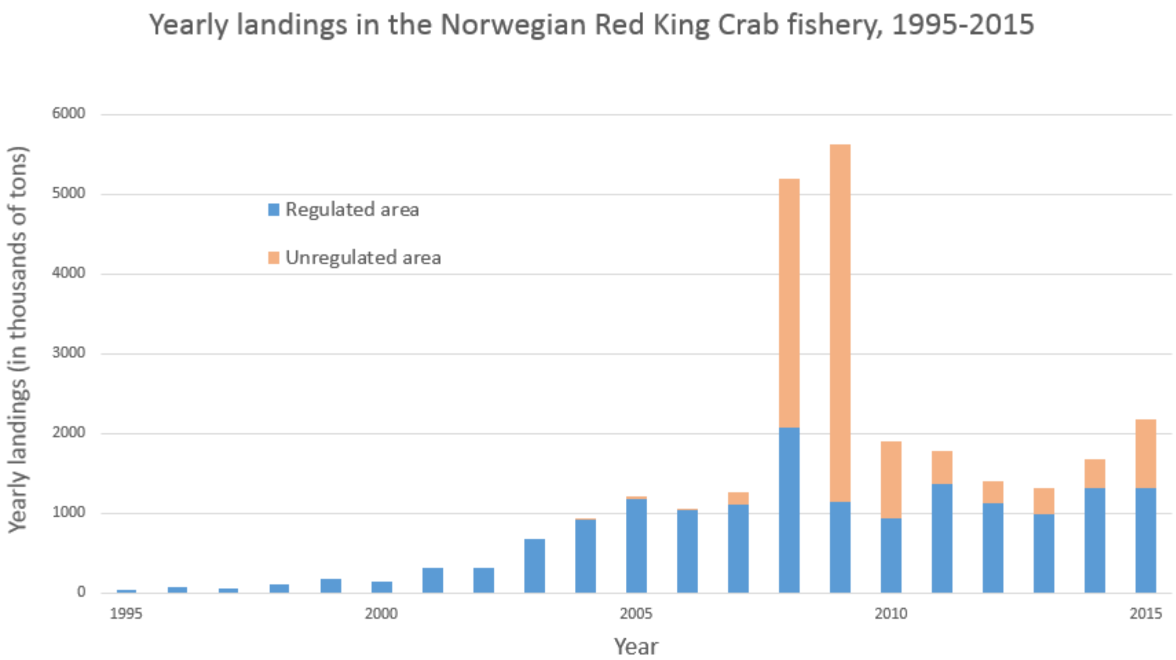

Figure 3 *Total landings in the Norwegian Red King Crab fishery between 1995 and 2015, divided into regulated area East of 26°E (blue) and unregulated area West of 26°E (orange). Figures from the regulated area refer to legal males only, even though a small quota for females was introduced in 2008.* Source: Norges Råfisklag, provided by Jan Sundet.

2.2.3 Gear history

During the first years of the commercial fishery (1994-1997), the common gears were conical pots with entries on the top as they have been used in the Far Eastern Russian and Japanese fishery (Stiansen et al., 2008). Research has been carried out in the Varangerfjord in 1998 to compare them with squared, collapsible pots similar to those in the fieldwork for this paper. Their bottom frame is made of steel, while their top frame is made of aluminium and has a smaller diameter to keep it lighter in weight. Several float rings are attached to the top mesh webbing and ensure that the pot is lifted while being submerged. The two entrance tunnels taper inward and form ramps leading to tunnel eyes at two opposite sides. This box-shaped design turned out to catch significantly more crabs and also significantly more large males (Stiansen et al., 2008). The superior catching properties of the squared pots led to an adoption of them in the Norwegian small-scale fishery. Both types have been used during the 1998 season, before the conical design was entirely replaced by rectangular pots in 1999 (Godøy, Furevik & Stiansen, 2003). Besides of their efficiency, the Norwegian small-scale fishermen seem to prefer them also because of their handling and storing properties (Stiansen et al., 2008). Figure 4 illustrates the typical design of a collapsible, rectangular pot as used in Norway today, while figure 5 draws a typical conical crab trap. Current regulations allow Norwegian fishermen to employ up to 30 traps per vessel (Sundet, 2014a).

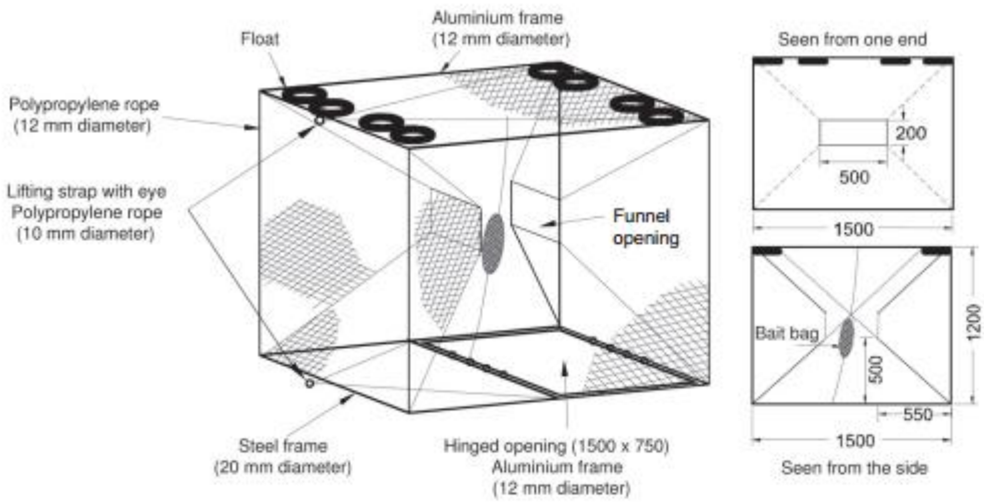

Figure 4 *Typical design of a collapsible rectangular king crab pot* (Source: Stiansen et al., 2008)

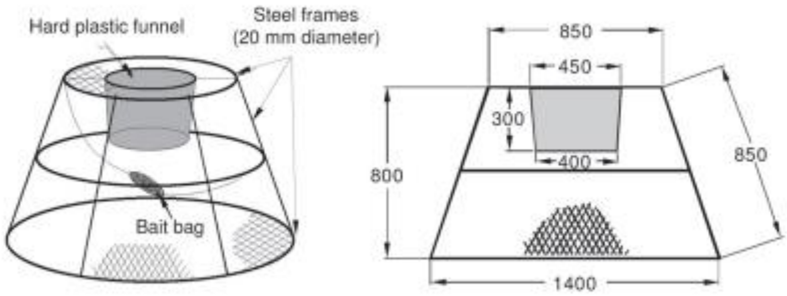

Figure 5 *Typical design of a conical king crab trap* (Source: Stiansen et al., 2008).

2.2.4 Regulatory history in the commercial area

Minimum legal size in Norway used to be 137 mm CL until it was lowered to 130 mm CL in 2011 (Anonymous, 2015a). This 130 mm is still in place for both males and females. Males that are caught at this minimum size are assumed to have participated in mating only once in their life, and females are expected to have spawned twice (Anonymous, 2015a). Nevertheless, recruitment remained relatively stable and allowed for maintenance and even increase in quota during recent years. The removal of large males by the fishery is affecting stocks in different indirect ways. Large males contribute to higher recruitment because of their superior reproductive performance, but also by providing important shelter to the biggest of the molting females (Windsland, 2014). Until 2008, a "3S" regime was in place (Sex, Size, Season), but then the catch of females was allowed in order to counteract the considerable population growth and further spreading at that time (Hjelset, 2014). The king crab fishery is presently not restricted to any season, but August, September and October were the months with highest average landings during the last three seasons (Norges Råfisklag, 2015). The integration of escape vents with diameters of at least 130 mm into king crab gear was mandatory at times (Sundet, 2014a), but currently, fishermen are not forced to employ them.

2.2.5 Access regulation

When the commercial fishery started in 2002, the declared objective of Norwegian management authorities was to allocate participation rights first and foremost to those fishermen that have suffered most from the previously mentioned bycatch of king crabs. Fishing on the new crab species was meant to be more of a compensation for experienced losses in other fisheries rather than an activity to exclusively build livelihoods on (Anonymous, 2015a). Hence, access was given only to fishermen that have been catching certain amounts of cod or lumpsucker during the years prior to their application for king crab quota. Commercial fishing started with a fleet of 127 quota-owning vessels (Anonymous, 2007) that grew gradually during the following years. These vessels formed the so-called "closed group" to which an "open group" has been added by the beginning of the 2008/09 season. Participation in the latter group was possible for all small vessels (< 11 m) registered in Eastern Finnmark (plus Nordkapp and Porsanger municipalities). Over the years, qualification criteria for the two groups have undergone some changes (in the closed group, for instance, maximum vessel length has been increased step by step from 11 m to 21 m between 2008 and 2016), but the division is still valid.

2.2.6 The Norwegian king crab fishery today

The king crab fishery in Norway is different from most king crab fisheries at other places. In contrast to the Alaskan fishery, and also the neighboring fishery in the Russian part of the Barents Sea, it can be characterized as a small-scale fishery that operates exclusively in coastal waters. Current regulations require crab vessels to be smaller than 21 m in the closed group and smaller than 15 m in the open group, while the minimum required length is 6 m in both groups (Anonymous, 2015c). Most vessels, however, are between 10 and 15 m long and operated by one or two fishermen (Sundet, 2014a). The current (2016) commercial quota amounts to 1,850 tons of male crabs, 50 tons of female crabs and 150 tons of injured male crabs (Anonymous, 2016). A minor quantum of 6 tons of males in total can be fished for leisure, research and tourism-promoting purposes. The number of vessels in the "closed group" has constantly decreased during recent years (from 220 in 2008 to 168 in 2014). The "open group", on the other hand, has grown from 243 to 382 vessels during the same time (Anonymous, 2015a). The value of Norwegian king crab catches from both the unregulated and the regulated area amounted to about 130 million Norwegian crowns in 2014 (Norges Råfisklag, 2015).

2.3. King crabs and fishing gear

2.3.1 The power of traps

Traps[4] are among the most important and powerful fishing gears, and used in a number of fisheries for crustaceans as well as some fish and mollusk species around the globe (Miller, 1990). They are currently the only lawful gear to catch Red King Crabs in Norway, Alaska (ADF&G, 2015) and Russia. Advantages of traps include their robustness, their ability to fish without requiring the attendance of a fisher, their adjustability to many different depths and their modest requirements to a vessel's engine power and deck equipment (Miller, 1990). The power of a crab trap depends on its abilities to provide high catches, thereby selecting the desired species, size and sex in the best possible way. Miller (1990) identified ease of entry, soak time, trap size, bait quantity and quality, the prevention of escapes and the reduction of gear saturation effects as important parameters in determining the size of catch. The goal of this thesis is to investigate the question, whether or not the selectivity of the pots that are commonly used in the Norwegian king crab fishery can be increased by modifying their escape openings. Increased selectivity would lead to a lower level of bycatch and positively contribute to the "power" of the traps. The following section will present the knowledge on king crab behavior in connection with fishing gear. It will also delve into the topic of bycatch, discussing its dimensions and possible impacts.

2.3.2 King crab traps

Many different traps have been used to catch king crabs in different regions at different times, including variations of the two principle designs in figure 4 and figure 5. Furthermore, there are round or pyramidal traps (Zhou & Shirley, 1997a). Similar to the conical ones, pyramidal pots also have their entrance on the top; they used to enjoy a certain amount of popularity on smaller vessels with less deck storage in Alaska (High & Worlund, 1979). Standard commercial pots in the North Pacific today are box-shaped, but much bigger and heavier (up to more than 300 kg, High & Worlund, 1979) than Norwegian ones. In Alaska, king crab pots can nowadays legally measure up to about 305 × 305 cm (ADF&G, 2015). However, the metal frames of commercial pots normally rank in size between 198 × 198 cm and 244 × 244 cm with heights between 70 and 99 cm (Zhou & Kruse, 2000). The tunnel entrances tend to be wider than in Norway: 89 ×

[4] Throughout this thesis, the author has taken liberty to treat the words "trap" and "pot" as synonyms if not explicitly specified otherwise. Using both terms as equivalents is thought to add to a better degree of legibility.

19 to 102 × 20 cm (Zhou & Shirley, 1997c) compared to 50 × 20 cm (Stiansen et al., 2008). Tunnel eyes are usually solid and angled upward (Stevens, 2014b). Moreover, a fundamental difference is that the Alaskan traps are rigid (non-collapsible). Russian vessels in the Barents Sea have also adopted standard Alaskan traps when launching commercial crabbing in 2004 (Pinchukov & Sundet, 2011). This fishery is carried out by larger vessels (> 60 m) which operate comparatively far from the coastline (Sundet, 2014b), and harvested king crabs are processed directly on board.

The results of research on responses of crabs to fishing gears are presumably highly specific to their design. Hence, the following sections are focusing on gear and selectivity research that has been carried out with traps similar to the ones in the fieldwork, and studies from Norway have been used as primary sources, if possible.

2.3.3 King crabs' reception of bait

Chemoreception is governing many processes throughout a crab's life, including foraging behavior. Tracking chemical cues of potential food resources is directing king crabs towards them, while vision appears to play either no or only a very subordinate role (Zhou & Shirley, 1997a). A king crab's main chemosensory organs are located on its antennules (Stevens, 2014b). When hungry crustaceans detect concentrations of food odor, the following general behavioral pattern is stimulated: alerting, locomotion, location and consumption (Rittschof, 1992). Alerting responses are measured by means of an (increased) flicking of antennules, which is comparable to sniffling in air breathing vertebrates (Rittschof, 1992). Resting king crabs in experiments have shown spontaneous flicking rates between 13 and 53 times per minute without exposure to stimuli (Zhou & Shirley, 1997b). In response to a chemical stimulus, this frequency increases. In king crabs, the eventually triggered feeding behavior that follows the perception of an odor does not only include increases in antennular and buccal appendage flicking, but also cheliped grabbing, leg movement, body elevation and active searching for food (Zhou & Shirley, 1997b).

2.3.4 Reaction to different baits

Zhou and Shirley (1997b) conducted a laboratory study in order to investigate the species' chemosensory behavior and the efficiency of baits. Crabs were exposed to varying concentrations of five different test solutions and increases in antennular flicking rates were used as an index for detection of bait extracts. Crabs were considered to display foraging behavior in addition to the mere perception of a test solution when they started to move their maxillipeds, grasp their claws, move their legs or elevated their body. The five extracts that have been introduced into the test aquarium were opal squid (*Loligo opalescens*), Pacific herring (*Clupea harengus*) and blue mussel (*Mytilus trossulus*) - typical food items - as well as conspecific muscle and ovary. Crabs were observed to be most sensitive to king crab muscle, in terms of chemosensation, followed by herring. On the other hand, crabs appeared to be least sensitive to blue mussels.

However, herring extract was the most effective solution to trigger first signs of feeding behavior (waving of maxillipeds), followed by the other two potential baits, mussel and squid, while conspecific muscle and ovary required the highest concentrations in order to stimulate feeding behavior. Their medium effective concentration to trigger feeding responses in 50 percent of the crabs was significantly higher than for the three prey items, although crabs appeared to be most sensitive to crab muscle extract in terms of mere chemosensation. These results support the assumption that king crabs tend to perceive chemicals from conspecific body parts as an alerting signal rather than being attracted by them.

In Zhou's and Shirley's (1997b) experiments, different groups of crabs (Juvenile females, ovigerous females, males ≤ 110 mm CL and males > 110 mm CL) did not show significant differences in chemoreceptive sensitivity across the five solutions. Ovigerous females showed feeding behavior at significantly lower solutions than the other three groups, a result that was thought to be attributable to their molting cycle. Hence, the idea of (additionally) baiting traps with king crab ovaries in order to increase sexual selectivity could not be supported by experimental evidence. Zhou's and Shirley's (199b) laboratory experiments supported field observations of High and Worlund (1979), who found entry rates of new, untagged king crabs into repeatedly hauled pots to be much higher when re-baiting them with chopped herring. Dead king crab, on the other hand, proved to be a very ineffective bait to attract live crabs into pots.

2.3.5 Location of bait

The most common way of baiting crab traps is to put the bait material into a mesh bag or a perforated plastic jar, which is often cylindrical. Alaskan commercial traps were usually baited with such jars (Zhou & Shirley, 1997a), and chopped bait was also combined with an entire fish (for example a cod) as hanging bait (Zhou & Shirley, 1997c). In Norway, the usage of mesh bags is more common today (Erling Haugan, pers. comm.). The bag is usually hung in the center of the trap and eventually connected to the bottom as well in order to prevent it from moving too much in currents while the trap is submerged (as in figure 4). Another way is to attach the bag to a location close to the center of the pot's bottom. This is preferred by many fishermen in Norway not least because it is quick and easy (Erling Haugan, pers. comm.). Substances emitted from the bait travel downstream with the current and create an odor plume which can be detected by crabs with their chemosensory organs. Only continuous reception of the chemical stimulus ensures that the intended behavioral response is sustained (Zhou & Shirley, 1997a). Direction and strength of currents play a significant role in attracting crabs. Vienneau et al. (1993) found that stronger currents were responded by higher numbers of snow crabs (*Chionoecetes opilio*) approaching conical traps from the downstream side. Entrances from upstream can occur – as in the experiments of Zhou & Shirley (1997a) for king crabs - but are presumably happening randomly. Hence, the location of the bait can be crucial, particularly if currents are strong. The area in which an odor plume can effectively attract animals appears to adopt a lemniscate shape when the trap is submerged for an entire tidal circle with two opposite directions of current (Vienneau et al, 1993). Bait should be placed close to the center of the trap in order to ensure that the odor plume leads crabs inside by being strongest in the area of the entrance tunnels (Vienneau et al., 1993). However, if the bait is located in the vertical middle of a pot, it is easier for crabs, particularly large ones, to reach the bait without entirely entering the pot. Such behavior has been commonly observed in conical pots for snow crab (Vienneau et al., 1993) but can presumably occur in a similar way in rectangular king crab pots with two opposite tunnel-shaped openings as well. The effect of hanging bait too high off the bottom can lead to an odor plume that hits the seafloor somewhat downstream from the pot (Zhou & Shirley, 1997a). Crabs usually follow the strongest chemical cue, and snow crabs have been observed to move away from a trap that they were already about to approach as the current became stronger and the strongest odor concentrations reached the seafloor further away (Vienneau et al., 1993). Fixing the bait close to the bottom has been suggested by Vienneau et al. (1993) to be more effective in attracting crabs, but can be a disadvantage if the trap's entrance is high and crabs have to climb above the plume in order to enter. Losing the chemical stimulus could demotivate crabs to search for entry. This aspect has been made responsible for comparatively low entry rates of Red King Crabs into conical pots, where the entrance in on the top and the animals have to move out of the plume before entering (Stiansen et al., 2008). That might more than offset the general advantage of the conical design to principally offer a 360º area of entry and therefore being independent from current directions, which is not the case for standard box-shaped pots. Zhou and Kruse (2000) tested a rectangular pot design that offered a continuous opening around the trap, but that model has failed to establish itself in commercial fisheries for reasons that are discussed later.

2.3.6 Entry and escape behavior

The number of crabs present in a pot at any given moment is usually the result of a dynamic process. Approach, entry and escape rates of animals are influencing the catch, and these rates may change and mutually influence each other during the time that a trap is submerged. Several video studies have demonstrated the substantial dimension of entry and exit dynamics in commercial crustacean pots. *In situ* observations revealed escape rates as high as 94% for entering American lobsters (*Homarus americanus*) (Jury et al., 2001) and a mesocosm experiment with Blue crabs (*Callinectes sapidus*) showed that 85% of the entering individuals managed to leave the pot before hauling (Sturdivant & Clark, 2011). In both cases, the number of animals that approached the gear, but avoided to enter into it was many times higher than the number of those who successfully entered. Mesh size, however, has been shown to influence search behavior and to be negatively related to the conditional probability of entry (given approach) for Red King Crabs (Zhou & Shirley, 1997c).

In situ investigations of the species' entry behavior into standard pots and under commercial conditions have not been carried out so far.

Stevens et al. (1993) studied the escape behavior from traps by placing three unbaited pots filled with previously caught king crabs on the seafloor and surveying their behavior with video cameras. Zhou and Shirley (1997a) examined the species' approach, entry and escape behavior under laboratory conditions. The design and mechanisms of employed gears in these two studies were closest to the pots in our fieldwork, which is why crab behavior in connection to them will be discussed in this section. In the laboratory study of Zhou and Shirley (1997a), a squared pot with two entrance openings was placed between the center and the wall of a round experimental tank in which water was circulating. The generated current was hitting the pot at its upstream entrance. Only roughly half of all king crabs were observed to approach the salmon-baited pot within the 2 h of experimental time, although they have been deprived from food during two days prior to the experiments. In a commercial fishery, however, it is important to keep in mind that traps usually do not have the ideal orientation towards the current (as in the experiment) and many animals have to be attracted from much longer distances. 90 percent of the approaches happened from a 135° range of the pot at the downstream side. A positive relation between the number of approaches and the entry success rate was observed. While searching for an entrance, insertion of chelipeds into meshes, gripping, waving, pushing the mesh and raising empty chelae to the mouth were commonly observed behavioral features. These could last between a few minutes to 30 minutes, and were sometimes repeatedly shown. Most crabs were searching only within ¼ of the trap's outer range. The animals spent up to one hour for searching the entrance, and those who eventually entered invested significantly more time. 72% of the crabs entered from the downstream side, apparently following the highest concentrations of bait odor. Crabs that entered from the upstream side often crawled directly into the entrance. They seemed to expose wandering behavior rather than trying to find a food source. Zhou and Shirley (1997a) failed to find significant evidence for different behavioral patterns in approach, search and entry between juvenile females, ovigerous females, legal males (≥ 178 mm CW) and sublegal males.

Both Zhou and Shirley (1997a) and Stevens et al. (1993) identified usual behavioral patterns of crabs within the pots to consist of randomly moving around and occasionally climbing the side panels as well as crawling on each other. A tendency to spend more time in the upstream direction was observed is both studies. Stevens et al. (1993) also reported a preference for eventual aggregations in the corners.

Zhou and Shirley (1997a) observed the highest escape rates from the side panels. It is notable, however, that the design of their experimental pot probably influenced escape patterns and that not all results are necessarily transferable to commercial conditions (the entrance funnels measured 90 × 20 cm, and the distance between side panel and entrance was just 5 cm at either side). Crabs who started their escape from the bottom panel had to be larger in size to succeed. Usage of chelae to grasp meshes of the lower tunnel while supporting the elevation of the body with the third walking legs was commonly observed. Escape rates turned out to be lowest for legal males (12.5%) during the 2 days of experimental time, and also their Escape Attempt Rate was comparatively low. The rate of successful escapes was significantly higher for the three other groups with a mean of 54.2%.

According to the observations of Stevens et al. (1993), escape was a quite rapid process and escaping crabs seemed to be more determined than entering ones. Escape through one of the two tunnels[5] was always realized within less than one minute and did not appear to be too

[5] Unfortunately, the report of Stevens et al. (1993) does not contain a detailed description of the dimensions and characteristics of the employed pots and their entrance tunnels. Comments on that article in Zhou & Shirley (1997c), however, strongly indicate that Stevens et al. (1993) used a standard Alaskan pot where the distance between side panel and entrance opening is about 50 cm.

challenging, especially for legal-sized individuals (> 135 mm CL). Most successful escape attempts (80%) started from a position below the tunnel opening. Some crabs crawled over the tunnel and probed the exit from the top, but most of them fell on the bottom of the pot during these attempts. Only 15% escaped successfully from the sides of the tunnel. Stevens et al. (1993) found that the first walking leg - the longest of all four visible appendages – was inserted first into the opening in 55% of the cases. Reaching up into the tunnel appeared to be easier for larger crabs than for smaller ones. However, high densities inside a pot probably facilitate escape of smaller crabs through the tunnel since they could step on other crabs in that situation.

The low escape rate of males in the laboratory experiment was mainly attributed to molting, which happens earlier in males than in females. However, only males were capable of escaping by crawling from the underside of the entry funnel. Their larger size makes it easier for them to escape from rectangular pots.

For conical pots, escape seems to be harder to realize for trapped crabs when using a vertical plastic funnel to prevent them from climbing up to the top – at least as long as the catch is not big enough to enable individuals to overcome that obstacle by stepping on each other. On the other hand, there is indication to assume that rectangular pots are superior gears to catch more and better selected Red King Crabs (Stiansen et al., 2008).

2.4 Bycatch and unintended mortality of king crabs

Alverson et al. (1994) defined “bycatch” as the sum of discarded catches and incidental catches. Incidental catches are defined as non-target species that are retained and sold. Discarded catches are to be understood as the “proportions of both target and non-target catches discharged overboard either 'live' or 'dead'” (Eliasen et al., 2014). Species or certain sizes and sexes of species are discarded by fishermen “as a result of economic, legal or personal considerations” (Alverson et al., 1994). Bycatch issues connected to king crabs might include incidental catch of king crabs as a non-target species (for example in gillnet, longline or trawl fisheries) as well as the catch and subsequent discard of unwanted individuals in the dedicated king crab fishery. This thesis is focusing on the latter aspect. Legal constraints on size or sex are the most important reason for fishermen to discard parts of their catch, but also legal individuals are frequently discarded. This usually happens when individuals are damaged or when a fisherman decides to use his vessel quota for very large individuals, which gain him higher prices than small legal-sized crabs[6].

Bycatch of unwanted crabs usually makes it necessary for the fishermen to sort them out and to release them into the water again. This activity can be hard and time-consuming. Increased selectivity could furthermore contribute to improved economic performance of a fishery because of its potential to decrease the number of pot lifts that are necessary to achieve a quota (Zhou & Kruse, 2000). In addition, there is concern about detrimental effects on the crabs to be released and the associated negative implications for stocks and fisheries.

2.4.1. Unintended mortality in net and trawl fisheries

The waters around the Kamtchatka peninsula have been exploited in larger scales since the 1920s by Japanese and, albeit with some delay, Soviet vessels (Ivanov, 2002). Until their replacement by conical pots in the early 1970s, tangle nets used to be the standard gear in that fishery. Contrary to regulations that required careful handling, the general practice was to beat entangled females and sublegal males out of the nets with sticks. Ivanov (2002) points out that the dead loss of crabs was much higher than the reported landing, a fact that has to do with the way they were handled, but also with the high bycatch rates as such.

King crabs have limited abilities to avoid moving trawl nets on the seafloor, and if they are unintentionally caught they will pass handling and discarding procedures with the addition that tumbling back into the codend of a trawl creates an additional risk for injuries (Stevens, 2014b). Encounters with trawl nets without subsequent retention have also been a source of concern. However, recent research suggests that mortality rates after such encounters are not as big as it has been assumed for many years (Stevens, 2014b).

2.4.2. Unintended mortality in pot fisheries

The discard of sublegal-sized and female crabs in pot fisheries has potentially harmful effects on them and might result in injuries or mortality. Such mortality is referred to as "handling

[6] In March 2016, for instance, the first-hand value of king crabs in Bugøynes (where the fieldwork for this thesis has been carried out) was 100 Norwegian Kroner (NOK) for crabs under 2 kg total weight and 145 NOK for crabs of 2 kg or more. Crabs with a carapace length only slightly above 130mm - the present minimum legal size - normally weigh less than 2kg.

mortality" (Stevens, 2014b). Immediate death rates and obviously fresh injuries of king crabs on deck of trap fishing vessels have been observed to be extremely low (0.2%, and 0.02% respectively for Bristol Bay in 1991-1993, compare Zhou & Shirley, 1996). Nevertheless, handled crabs might be lethally or sublethally affected in the medium and long run. Hence, delayed and unobserved mortality is a source of concern and a factor of uncertainty for fisheries management authorities.

Pot lines are attached to the gear at one side, and hence, the pot is first dragged across the seafloor and then tipped up at one side during hauling. This process goes on quite fast, and retained crabs tumble together at the bottom (Stevens, 2014b). Crab-laden pots can crush against the fishing vessel's rail and hurt the animals inside, particularly if legs are protruding through meshes (High & Worlund, 1979). Under handling procedures, crabs suffer desiccation due to aerial exposure, crushing, pinching and various impacts while dropping on the deck, being sorted on the deck and thrown back into the sea (Zhou & Shirley, 1996). Moreover, there are considerable temperature differences between sea water and air during most of the year. Physical traumata may lead to autotomy of legs or infections of received wounds (Zhou & Shirley, 1995). Handling-induced increases in injuries and mortality rates have been observed in a number of crustacean fisheries. A mortality of 100% was observed for Dungeness crabs (*Metacarcinus magister*) after handling them four times under conditions that simulated the ones of a commercial fishery (Zhou & Shirley, 1995). This mortality was mainly not attributable to acute injuries, but rather occurred over a period of three months following the handling operations.

In a laboratory study simulating commercial fishing conditions, Zhou and Shirley (1996) showed that handling of Red King Crab results in damages of body parts (spines, legs, rostrum or carapace). The percentage of damaged crabs increased from 26% to 89% when handling the crabs three times (in intervals of three days) instead of once. However, these damages were mostly limited to spines and considered to be unlikely to influence the animals' survival. Mortality was very low and did not show significant differences between different frequencies of treatment (Zhou & Shirley, 1995). Righting time (the time that a crab needs to turn over when placed on its back underwater – a general indicator for well-being), feeding rates, weight gain, growth and mortality were not found to be significantly different between the quantity of treatments (0-3) over an experimental period of four months. These results suggest that king crabs are able to endure the stress that they suffer during "conservative handling techniques", as applied in Zhou's and Shirley's (1996) experiments, without being detrimentally harmed.

However, many factors like longer aerial exposure, harder or more frequent crushing on a rolling vessel, increased number of crabs in a trap, presence of very large crabs in a trap, higher temperature gradients, accidental kicking as well as the level of fishermen's skills and concerns might lead to an increase in mortality and injury rates under commercial conditions compared to the experiment. Furthermore, particularly smaller crabs might be prone to predation by seabirds or pelagic predators immediately after being discarded and while descending to the bottom. After reaching the benthos, disorientation could negatively influence their feeding behavior and their responses to predators (Zhou & Shirley, 1996). These indirect effects have been poorly investigated so far, but they give reason to assume that casualties and severe physiological damages are very likely to be somewhat higher than in the described experiment. In addition, crabs are certainly more vulnerable during the molting season. The Norwegian king crab fishery used to be a seasonal fishery operating during autumn and winter, but it is open during the whole year now. This increases the potential amount of crabs that are handled during the molting period in spring. Godøy, Furevik & Stiansen (2003) observed a comparatively high mortality when repeatedly hauling traps during the molting season and speculated that both cold temperatures during handling and the fact that the crabs underwent molting were the responsible factors.

2.4.3 Ghost fishing

Another source of fishery-induced unaccounted mortality is ghost fishing, which is defined as "the ability of fishing gear to continue fishing after all control of that gear is lost by the fisherman" (Smolowitz, 1978). Despite the general repulsion effects that dead conspecifics seem to have on decapods (Miller, 1990), ghost fishing can be a severe problem since abandoned or lost pots can continuously "re-bait" themselves when trapped animals die inside. They can attract king crabs as well as other crustacean or fish species (High & Worlund, 1979). In this situation, entries and exits very often stabilize at a "steady-state" of continuous occupancy at low levels (Stevens et al., 1993). This cycle may last until a trap eventually degrades by rusting, bacterial degradation, storm damage, fouling by other gear or biological fouling (Stevens, 2014b).

Reasons for occasional losses of crab traps include cutting of lines by propellers of vessels, breaking of the upline during hauling or strong currents that force dan-buoys under the water surface (Godøy, Furevik & Stiansen, 2003). Buoylines can also get entangled during setting and consequently be too short when the trap reaches the bottom (High & Worlund, 1979). Ice-drift is another potential threat since it can cut lines of buoys. This phenomenon is of some relevance in protected inlets of the Varangerfjord with substantial freshwater run-off and has led to losses of a few pots in the past (Erling Haugan, pers. comm.). The magnitude of the problem amounted to an estimated 10% loss per year in the Alaskan commercial fishery, which was estimated to correspond to a total of 27,000 derelict pots during 1960-1975 (High & Worlund, 1979). In Norway, however, the problem does not seem to have achieved such dimensions at any time (Erling Haugan, pers. Comm.). High & Worlund (1979) found that 80-92% of crabs managed to escape from pots over a period of 16 days, and bait in the pot (chopped herring or dead king crab) did not seem to prevent them from leaving. Godøy, Furevik & Stiansen (2003) found observable mortality to be pretty low in experiments (which included tagging and repeatedly hauling) in Northern Norway between 1999 and 2001. The highest rate of dead crabs in the rectangular pots was 16.7% when hauling a trap in April after having set it in March (during molting) and between 0 and 8% in all other long-term trials. The actual mortality rate could be even lower when taking into account the unknown, but probably high number of crabs that have entered and left the trap in the period between two hauls without being registered or tagged (Godøy, Furevik & Stiansen, 2003). Moreover, the fact that trapped crabs went through handling procedures could contribute to a higher mortality in the experiment compared to real conditions. An indication for this assumption is the higher rate of dead crabs in spring, when the animals are most vulnerable. On the other hand, crabs could still be negatively affected and suffer delayed mortality due to handling or longer periods of starvation within the trap, even if they manage to escape (Godøy, Furevik & Stiansen, 2003). Indication for lower recovery rates after longer periods of confinement was found by High & Worlund (1979). Combining the results of Godøy, Furevik & Stiansen (2003) with the generally low rate of lost pots, is seems reasonable to conclude that ghost fishing is not having considerable influences on unaccounted king crab mortality rates in Norway. In addition, the currently used rectangular pots achieve high escapement rates compared to conical ones (Stiansen et al., 2008). Mitigating bycatch is possible by using corrodible or biodegradable fasteners to attach trap panels (Miller, 1990). Such equipment is neither mandatory nor common in the Norwegian king crab fishery. A Galvanic Timed Release (GTR) mechanism that closes and eventually dissolves another buoy connected to the trap has been developed to make retrieval of lost pots possible, but this innovation could not succeed to establish itself in commercial fisheries yet (Stevens, 2014b).

2.4.4 Reducing bycatch

Mortalities and injury rates could be reduced by avoiding bycatch and subsequent discarding. A common way to avoid bycatch is to modify the fishing gear so that undesired individuals are either prevented from entering or given the opportunity to escape. This is not only to prevent them from suffering handling procedures, but can also reduce the density in the trap while it is catching and thus allow for accumulation of preferably targeted large males because of less saturation. Plastic panels attached to conical snow crab pots turned out to discourage small individuals from climbing the slope towards the entrance (Chiasson et al., 1993). A similar feature, however, is not suitable for rectangular king crab pots with tunnel-shaped entrances.

One approach to reduce bycatch in this gear type is the incorporation of greater mesh sizes. Implementing a webbing of $\geq$ 230 mm stretched meshes at the lowest third of one vertical net panel was mandatory in the Alaskan king crab fishery since 1993, for instance (Zhou & Kruse, 2000).

In many commercial or recreational trap fisheries for crustaceans, however, escape openings of somewhat larger dimensions than the ones of a pot's meshes are a successful tool to reduce the percentage of small individuals while facing little negative influence on the legal catch. These escape vents are generally made of rigid material and can have different shapes (for example circular, square-shaped or rectangular). They are integrated into the net that covers a trap and allow for egress of crabs while the pot is submerged. All entering individuals being too big to escape through the regular meshes, but small enough to leave through the inserted escape openings can easily get out of the pot without being subject to handling procedures. There are numerous examples for crab fisheries in which the introduction of escape openings was very successful. They have been able to reduce the sublegal catch by 75-80% for Blue Crabs (*Callinectes sapidus*) in the USA (Guillory et al., 2004). The use of squared escape gaps in the circular traps of the Giant Mud Crab (*Scylla serrata*) fishery in Australia led to a reduction of up to 84% for undersized crabs and furthermore considerably reduced the retention of a common non-target bycatch fish species, the Yellowfin Bream (*Acanthopagrus australis*) (Rotherham et al., 2013). Also catches of undersized snow crabs (*Chinonoecetes opilio*), a large cold water species such as the king crab, could be significantly reduced in two out of three experimental sites in Canada without negatively influencing the retention of targeted crabs (Winger & Walsh, 2011).

Miller (1990) argued that the most precise catch selectivity is achieved by rigid openings because of the rigid exoskeleton of decapods and their dexterity to orient themselves to the optimal escape position. Crabs usually move sideways through an escape vent (Stevens, 2014), and therefore total body length (the straight line distance from the tip of the rostrum to the posterior end of the rostrum, Zhou & Shirley, 1997c) and body height are critical dimensions to be taken into account. After reaching maturity, molt and growth patterns are different between sexes in king crabs. At a given CW, female Red King Crabs have a higher body length and a higher body height than males (Zhou & Shirley, 1997c). Furthermore, the variability in total body length can be expected to be higher for adult females compared to their male conspecifics at the same CL due to the variable amount of eggs that they may carry (Salthaug & Furevik, 2004).

Increased sexual selectivity of king crab gear by controlling entry, i.e. attracting males into traps while preventing the entry of females, could not be convincingly achieved so far. Altering bait (Zhou & Shirley, 1997) has been as ineffective in that context as several experimentally tested gear modifications (Zhou & Shirley, 1997c; Zhou & Kruse, 2000). Probably more than other things, the size-sex structure of crabs in vicinity to the submerged trap is what the composition of entering individuals depends on (Salthaug & Furevik, 2004). Thus, facilitating escape for unwanted crabs is the primary adjustment screw when trying to reduce bycatch, and escape openings are probably the most powerful tool given a certain pot design. Throughout our experiments, we did not focus explicitly on sexual selectivity. The main purpose of our study was to examine size selective properties of different escape openings, and taking into account that there also exists a quota for females in Norway (with the same minimum size that is valid for males), we focused on size compositions rather than sexual compositions. Following the current Norwegian regulations, too many legal females in a catch would mean high bycatch and discard rates as well, but in this study we concentrate only on size selectivity. Due to the fact that females considerably decrease their growth after reaching maturity, there are by far not as many females as males in large size classes. Thus, size selection can – to a certain degree – be regarded as a form of "indirect" sexual selection as well.

2.4.5 Modifications in gear design

A box-shaped design with two side entrances has demonstrated its higher efficiency compared to the conical type (Stiansen et al., 2008) and is nowadays the dominant gear to target Red King Crabs. Escape openings and greater mesh sizes are widely established features to promote selectivity, but also modifications of the pot design itself have been investigated to achieve the same goal. Zhou and Shirley (1997c) conducted laboratory experiments to compare a standard Alaskan pot of reduced dimensions (100 × 100 × 60 cm) with a newly designed pot that had a smaller mesh size (4.7 cm instead of 15.2 cm). In addition, the two entrances of the alternative pot were lowered from 40 cm to 20 cm and equipped with vertical bars serving as one-way opening triggers. These were meant to allow all crabs to enter, but prevent exit of individuals that are too large to fit between two bars, which were spaced 13 cm apart from each other. As mentioned before, inserting chelipeds through meshes while forcing the body against the panel was part of king crabs' behavioral repertoire when searching for entrances (Zhou & Shirley, 1997a). When mesh sizes are too small to enter the chelae through them, crabs appear to be more motivated to search for the entrance around the pot instead of remaining at one location (Zhou & Shirley, 1997c). The probability of entry given that a crab approached the pot was significantly higher for the alternative design, although significant differences between crab groups could not be found. Hence, smaller meshes are *ceteris paribus* believed to increase the probability of finding one of the entrances into standard traps. The two tested designs led to significantly different escape probabilities, and the triggers in the modified trap led to a significantly lower escape probability of legal males compared to juveniles of both sexes and ovigerous females. Densities of all categories of crabs reached an asymptotic level after about 10 hours in the standard trap. Occupation levels of the modified pot, on the other hand, peaked after approximately 10 hours and then declined to reach their asymptote after about 30 hours. Within the 48 h of experimental time, the different catch dynamics of both traps reduced the catch probability of females and sublegal males by 62.9% (92.2%)[7] while increasing the catch probability of legal males by 55% (26.5%).

Based on the previously described superior selectivity properties of traps with low entrance tunnels furnished with inward opening triggers in experiments, Zhou and Kruse (2000) compared these innovations with standard pots under commercial conditions. Both pots

[7] The numbers in parenthesis are the results of Zhou's and Shirley's (1997c) study if escapes from side panels are excluded. The tunnel eye of the standard pot in the experiment was only 10cm away from the side panel. As mentioned before, escape from side panels is harder for crabs in commercial standard traps (compare Stevens et al., 1993)

measured 213 × 213 cm, but the height of the standard pot (86 cm) was reduced by 25% for the experimental pot. The mesh size was 90 mm for both pots, and some sections of both pots included 240-mm mesh webbing. The lower edge of the entrances was lower (25 cm instead of 45 cm) for the alternative pot. Additionally, it offered a 360º angle for entry independent from ocean currents by having 4 tunnels that created a continuous opening around the gear. The triggers in the entrance opening were spaced 10 cm apart from each other. The herring-baited pots were tested in 6 blocks containing 8 traps of either group. Soak time varied between 2 and 4 days and fishing depths were around 70 m.

Although Zhou and Shirley (1997c) identified vertical opening triggers and lowered entrances to contribute to increased selectivity in the laboratory, the alternative design failed to reduce the retention of sub-legal crabs or increase the catch of large males in the field experiments of Zhou and Kruse (2000). By contrast, the standard pots caught significantly more crabs bigger than 130 mm CL in half of the blocks. The advantage of being able to facilitate entry by offering a 360º tunnel was obviously more than offset by the differences in effective volumes (space below entrances) due to the lower entrances in the alternative trap. King crabs used to aggregate in the pot until the effective volume was filled and then obviously prevented the entry of new crabs by blocking the trigger bars. However, the alternative pot retained about 60% more crabs when catches were standardized by effective pot volume. Thus, the suggested alternative design could be a solution if all dimensions of the trap would be larger, but the associated increased difficulties in handling of such big traps prevented the industry from adopting it (Stevens, 2014b). However, Zhou's and Kruse's (2000) alternative pot could theoretically be used for an effective exploitation of areas of low crab densities.

3. Materials and methods

Field work was carried out between February, 18th and March, 22nd, 2016. Starting point was Bugøynes, a village at the Southern shore of the Varangerfjord. Bugøynes is located in the Sør-Varanger municipality of the Finnmark county and has around 200 inhabitants of which 15 own the present (2016) individual full king crab quota of 4,650 kg and 6 others own either half of it or one tenth of it (Erling Haugan, pers. Comm.).

3.1 Experimental set-up

In total, five experiments were run. Each experiment included the setting of 15 traps, their consequent hauling and the sampling of all retained king crabs. The 15 traps per experiment were attached to three different strings, each of them being connected to five pots. The main rope, which was attached to a buoy, consisted of 12 mm thick polypropylene of which the first 55 m was so-called sinking rope to prevent propellers of vessels from destroying it or getting entangled in it. The distance of pots to the main rope (the length of the pot strap) was 7.3 meters and the distance between two junction points between main rope and pot strap was around 27 meters. Hence the whole length of one such string – the distance between the trap at position 1 and the trap at position 5 - amounts to approximately 110 m. Figure 6 draws the rigging formation of a string as it was used throughout all experiments.

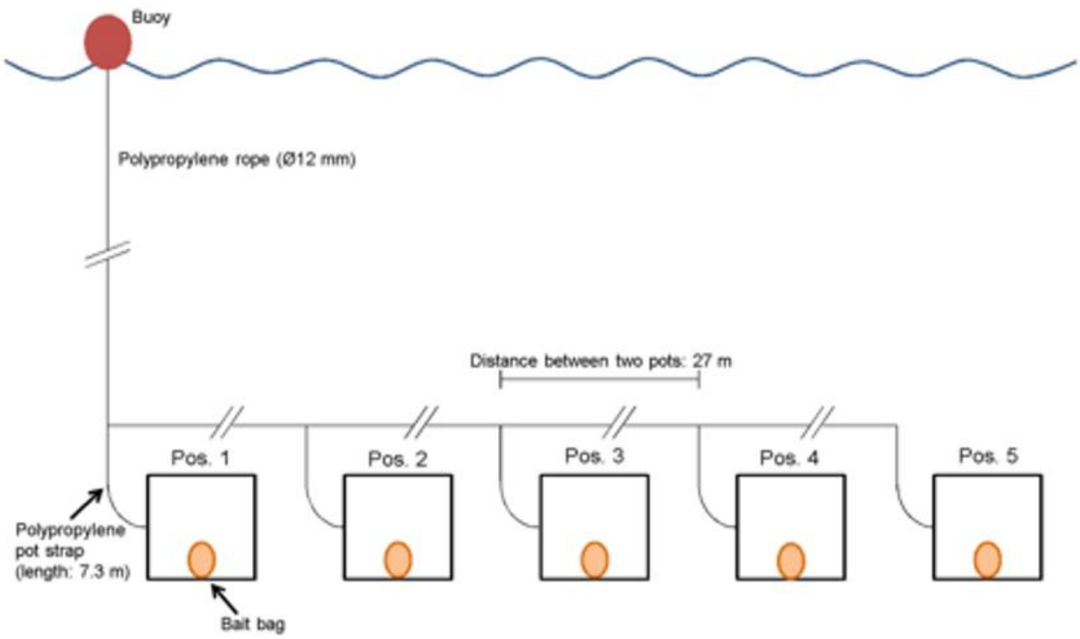

Figure 6 *Drawing of the rigging formation in all strings during the experiments.*

All three strings were repeatedly set while being on course 130° SE and the first trap to be released into the water (the trap at position 5, which is furthest from the buoy) has always been released at exactly the same geographical position for each string respectively. The only exception is the first string in the fifth experiment, which was set while being on course 310° NE and on a different geographical position. All traps were soaked at depths around 150 m.

3.2 Area

The area of research for this study was the Varangerfjord. It is situated in the very Northeast of Norway, not far from the border to Russia. It is the fjord where the Kamtchatka Crab has been recorded for the first time in Norway in 1976, where it first became abundant during the early 1990s and where most of the research on the species in Norwegian waters has been carried out. It is east of 26°E and hence entirely located within the regulated commercial fishery area for king crabs. The Varangerfjord extends from west to east, where it has a wide opening to the Southern Barents Sea. Depths at the inner part of the fjord range mostly between 100 and 300 m (Oug et al., 2011), with a maximum depth of 450 m (Dvoretsky & Dvoretsky, 2014). The Southeastern shoreline is characterized by numerous bays, inlets and branching narrow fjords. These are considered to be the favored areas of king crabs with the highest densities in the Varanger area (Oug et al., 2011).

The selection of suitable locations for setting the experimental traps was based on the personal experience of local fisherman Erling Haugan. The chosen area is locally known as an area of generally high crab density, which was desirable to obtain a reasonable sample size. The seafloor in the study area is characterized as loamy and sandy. There has been an aquaculture facility closed to where the experiments have been carried out. This plant has ceased its operations around two years prior to the experiments, but fishermen often report that higher densities of crabs attracted by waste from aquaculture plants are frequently encountered even years after their eventual closure (Erling Haugan, pers. Comm.).

Figure 7 shows the study area within the Varanger region. All four locations on which experiments have been carried out are depicted in the map. The orientation of the strings on the map is according to the course of the vessel at the time of setting. The first pot of each string to be released into the water is highlighted in purple color. The geographical positions and exact depths of these pots are recorded and can be seen in table 1.

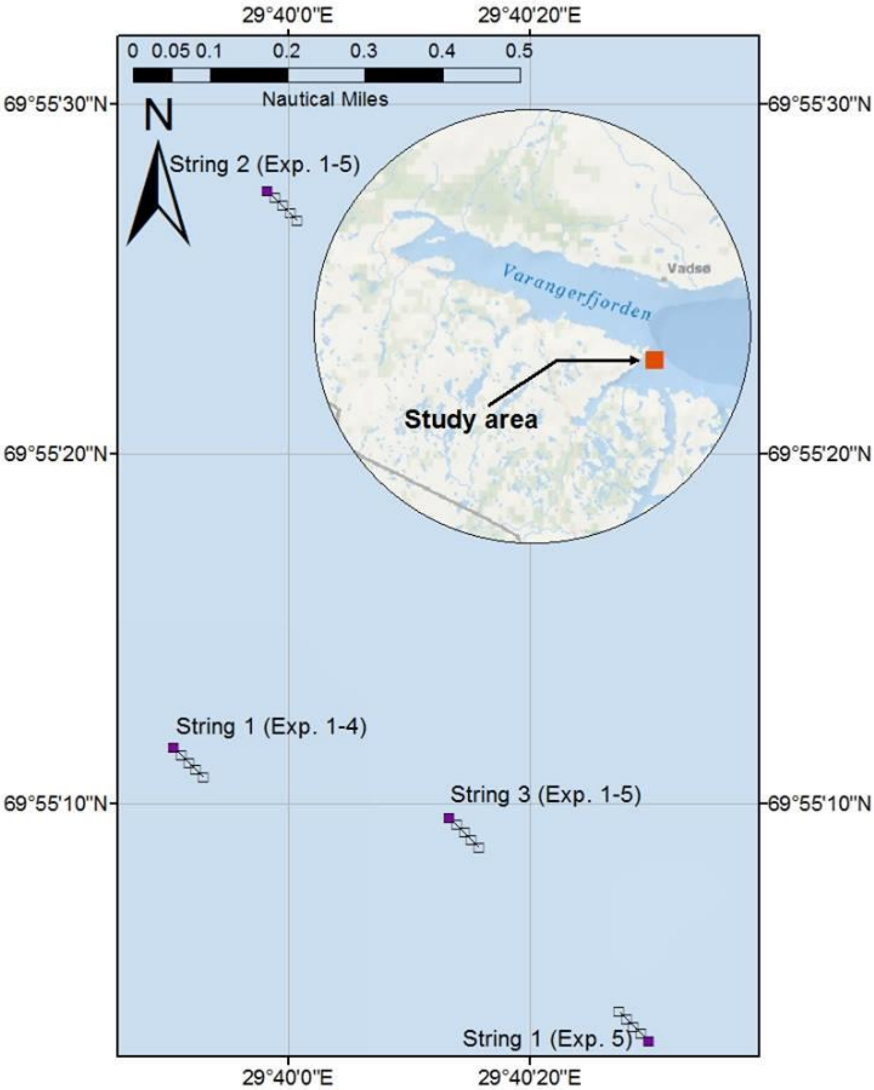

Figure 7 *Positions of strings in the study area during field work experiments (The GPS positions in table 1 refer to the traps coloured in purple).*

3.3 Vessel and technical equipment

The research vessel was 10.30 m long and has been operating in coastal fisheries since 1989. It is presently owned and operated by Erling Haugan, who holds a full individual king crab quota of 4,650 kg. The boat is not only used to catch king crab, but also employed to target other species with other gear types, especially fishing cod with gillnets. It is normally operated by a two-man crew.

During the field work, the color digital echo sounder FCV-295 by Furuno has been used. The device is displaying the seafloor in both high and low frequency and offers the opportunity for zooming on the seafloor. The software "Olex" is mapping and displaying the seafloor using data from both GPS and the echo sounder. It is therefore able to continuously update the plotted maps while being offshore and providing maps which are completely updated at any time.

King crabs on board are stored in double-wall stackable, and lockable plastic tubs produced by Sæplast (Promens). The inner dimensions of these tubs used during the fieldwork are 85 cm (length) × 64 cm (width) × 55 cm (height). Their volume is 310 liters and their weight is approximately 25 kg. The fishing vessel has the capacity to store four such containers under deck (two in front and two at the back), while additional tubs might stand on deck. Under commercial operations, legal-sized king crabs to be landed are thrown into these tubs, and seawater is pumped into them through a hose in order to avoid mortality and loss of quality. Figure 8 shows how the catch is usually stored under commercial conditions.

Figure 8 *Storing of king crabs in plastic tubs under the deck of the fishing vessel.* Photo: Erling Haugan

3.4 Traps

The traps that have been used in the field work were collapsible rectangular pots produced by Bugøynes Redskap. They have been designed in 2004 and underwent further development in 2008 and 2012. Their mesh size was 145 mm on the top, bottom and side pannels and 120 mm in the entrance funnel. For reasons of availability, two types of traps have been used for the experiments. The two types slightly differed in size and weight and are regarded as they were one design for the analysis. The first type (5 traps) was used in string one throughout all experiments. It measured 135 × 115 × 100 cm and had a total weight of 16 kg. The entrance was located approximately 60 cm above the bottom panel. The second type (10 traps) was used in string two and three throughout all experiments. With a size of 150 × 150 × 100 cm and a total weight of 22 kg, it had its entrance at 70 cm over the bottom panel. Note that tunnel eyes in the fieldwork, unlike the ones in figure 4, have been angled upward. Both traps had a steel frame at the bottom and an aluminium frame on the top. Either floating rings or small buoys were implemented in the top panels of all traps to ensure that the gear maintained an upright position while being submerged.

3.5 Escape Openings

In our experiments, we equipped the crab traps with four different escape openings: small squares (150 × 150 mm), large squares (170 × 170 mm), rectangular (170 × 300 mm) and round (diameter: 170 mm). The fifth group of traps were control traps where escape openings have been sewn up by ropes. They can functionally be regarded as pots without escape vents. Traps were equipped with two escape devices per pot, and both of them have always been integrated into one of the side panels, so that one side panel had two escape vents while the other had none. The two escape vents were placed close to the middle of the side panels and their distance to the bottom panel has always been 1-2 meshes. Placing them exactly at the very bottom of the side panel was thought to be unfavourable since the side panel might not be perfectly tight while the trap is on the ground. The round escape vents consisted of plastic, while the other three types were made of metal. Figure 9 illustrates the different escape openings that have been integrated into the mesh structure of the crab pots for the experiments. Note that the rectangular frames were placed upright so that their 150 mm sides paralleled the sea floor.

Figure 9 *Escape openings as used in the experiments: Small square (left), large square (second from left), rectangular (middle), round (second from right) and control (sewn up, right).* Photos: Peter Starbatty

The arrangement of traps along one string was randomly and different for every string. Figure 10 shows which type of trap has been at which position for all three strings. The reason for string 1 to be depicted twice is that although the placement of traps along it was the same throughout all experiments, it has been set in another direction and at a different location during the last experiment (compare also figure 7).

Figure 10 *Arrangement of traps along the strings throughout the experiments (left and right) and legend (middle).*

3.6 Baiting

In all experiments, frozen Atlantic herring (*Clupea harengus*) was used as bait. Herring is generally known as a quite effective bait to attract king crabs (compare also the previously discussed experiments of Zhou and Shirley, 1997b or High & Worlund (1979)), yet crab pots in the Varanger area are commonly baited not only with herring, but also with other fish such as cod, saithe, haddock or waste products of them (Erling Haugan, pers. Comm.). All bait bags have been emptied after hauling and refilled with new herrings before setting them again. Throughout the experiments, four whole herrings have been filled into the bait bags, and in most cases they have been broken into two pieces. This amounts to an average bait mass of approximately 1.5 kg or slightly less. Commercial fishing in the area is often carried out with somewhat more bait (Erling Haugan, pers. Comm.), but research on gear selectivity in Norway has also been done with as little as 600 g or 1,000 g herring per trap (compare Salthaug &

Furevik, 2004 and Stiansen et al., 2008). Hence, the type and amount of bait that has been used in this study can be regarded as suitable in many respects.

Bait bags were produced by Bugøynes Redskap and are made of old capeling seines. Their mesh size was 5 mm. The size of the bag's opening can be adjusted by moving a cordlock up or down the drawstring. The baited bag is attached to the pot by a steel clip. During all experiments, we attached this clip to the meshes of the bottom panel of traps while placing the bait bag centrally on the same panel. The drawstring was tight and did not allow the bait bag to move. The bag was therefore fixed in the center of the pots' bottoms while the gear was submerged. Figure 11 shows an unbaited bait bag, the bait used, and the bag after being baited.

Figure 11 *Empty bait bag (left), amount and shape of herring as used throughout the experiments (middle) and readily baited bag (right)*. Photos: Peter Starbatty

3.7 Soak time

Although the initial intention was to carry out all experiments with a comparable soak time, retrieval and setting of pots could only happen when weather conditions allowed for it. Hence, the five experiments partly differed in soak time. While long soak times (7-11 days) were applied in three of the experiments, the traps were in the water for 2 days in the remaining two. Soak times applied by king crab fishermen in the region may vary with the season and soak times of up to several weeks are not uncommon during early spring (Erling Haugan, pers. Comm.). A detailed overview of all settings, containing on the exact geographical position and depth of the traps at position 5 (furthest from the buoy – the ones that are colored purple in figure 7 and figure 10) is provided in table 1. In addition, this table contains information about setting and retrieval time and states the overall soak time for every string in all experiments.

The setting and hauling procedures were always carried outin the morning between 9 and 12 o' clock. The first chain to be retrieved was string 1, and after sampling and rebaiting it was soaked again before repeating the procedures for string 2 and string 3. Hence, even though soak times are given in table 1 as rounded in days, their precise soak time in hours does not deviate much from the stated number of days multiplied by 24 hours.

Experiment	String	GPS Position (Pos. 5)	Depth (Pos. 5)	Date of setting	Date of retrieval	Soak time
1	1	69º54'71.6"N 29º39'50.5"E	151.9 m	February 18th, 2016	February 25th, 2016	7 days
1	2	69º54'87.5"N 29º39'58.3"E	152.5 m	February 18th, 2016	February 25th, 2016	7 days
1	3	69º55'09.6"N 29º39'73.4"E	154.4 m	February 18th, 2016	February 25th, 2016	7 days
2	1	69º54'71.6"N 29º39'50.5"E	151.9 m	February 25th, 2016	March 7th, 2016	11 days
2	2	69º54'87.5"N 29º39'58.3"E	152.5 m	February 25th, 2016	March 7th, 2016	11 days
2	3	69º55'09.6"N 29º39'73.4"E	154.4 m	February 25th, 2016	March 7th, 2016	11 days
3	1	69º54'71.6"N 29º39'50.5"E	151.9 m	March 7th, 2016	March 9th, 2016	2 days
3	2	69º54'87.5"N 29º39'58.3"E	152.5 m	March 7th, 2016	March 9th, 2016	2 days
3	3	69º55'09.6"N 29º39'73.4"E	154.4 m	March 7th, 2016	March 9th, 2016	2 days
4	1	69º54'71.6"N 29º39'50.5"E	151.9 m	March 9th, 2016	March 11th, 2016	2 days
4	2	69º54'87.5"N 29º39'58.3"E	152.5 m	March 9th, 2016	March 11th, 2016	2 days
4	3	69º55'09.6"N 29º39'73.4"E	154.4 m	March 9th, 2016	March 11th, 2016	2 days
5	1	69º54'63.2"N 29º39'89.9"E	151.7 m	March 11th, 2016	March 22nd, 2016	11 days
5	2	69º54'87.5"N 29º39'58.3"E	152.5 m	March 11th, 2016	March 22nd, 2016	11 days
5	3	69º55'09.6"N 29º39'73.4"E	154.4 m	March 11th, 2016	March 22nd, 2016	11 days

Table 1 *Overview of geographical positions, depths, dates and times of setting and retrieval and soak time for all settings.*

3.8 Crab sampling

The sampling of crabs followed the same procedure throughout all hauls. Provided that crabs were inside the pot, it was brought into a position in which the pot was hanging closely over an empty 310 liter plastic container that was standing on board (see figure 12). After solving the ropes, all retained traps tumbled from the trap into the container. Eventually, a few individuals had to be pushed or shaken if their appendages were entangled between meshes. This was always done in a careful manner in order to prevent the animals from receiving injuries and physical traumata.

Figure 12 *A full pot immediately before being opened. King crabs will tumble into the container to be sampled individually*. Photo: Peter Starbatty

After having emptied and put aside the trap, all crabs in the container were sampled. Sampling included the measurement of every individual's CL (the distance between the tip of the rostrum and the posterior end of the carapace) with a yardstick as well as the determination of its sex. The CL of crabs was always recorded in intervalls of 10 mm. Figure 12 shows the measurement of a king crab’s carapace length during the field work.

Figure 13 *Determination of a king crab's carapace length during the field work*. Photo: Erling Haugan

During the first experiment, the largest size class on the datasheet to be filled out during the sampling was “160 mm or larger”. After catching more crabs in this size class than expected, a differentiation between crabs in the highest size class was taken into consideration. Hence, more detailed data on the size distribution of very large crabs (in intervals of 10 mm) are only available for experiments 2, 3, 4 and 5.

In addition to their size, the animals' physical condition (injured / not injured) was recorded. Crabs were classified as “injured” when showing visible injuries of the carapace (for example cracks), entirely or partly missing appendages or limbs in the process of regeneration but clearly identifiable as having undergone autotomy previously (see figure 14). Finally, it was recorded whether the sampled individual showed signs of ecdysis without making differentiations between pre-molting and post-molting.

Figure 14 *Legal-sized male Red King Crab from the Varangerfjord. The individual shows several injuries: The right chela as well as both third walking legs have been autotomized. The third right walking leg is apparently at an early stage of the process of regeneration.* (Photo: Peter Starbatty)

3.9 Statistical analysis

The aim of the present study was to determine whether there are statistically significant differences in the catch performance and catch compositions of different types of escape vents or not. In order to get a more differentiated image, we divided crabs into three main size categories (sublegals – all crabs smaller than 130 mm CL; smaller legals – all crabs of at least 130 mm CL, but smaller than 160 mm CL; and large legals – all crabs of 160 mm CL or larger) and compared the performances of the tested escape openings for each of these groups.

All the analyses were done by the use of the software SPSS 21® and an a priori 95 % confidence interval ($\alpha = 0.05$) was defined for tests of significance.

Operating with one independent variable (escape vent type) that has five categories and a continuous dependent variable (number of crabs), the most appropriate statistical test for our study was One-way ANOVA. This test requires assumptions such as normality, no significant outliers and homogeneity of variances to be met. In order to test normality, Shapiro Wilk's tests were run. When the normality assumption was not met, as assessed by Shapiro-Wilk's test ($p > .05$), a Kruskal-Wallis H-test (which is generally considered to be the non-parametric alternative test to the one-way ANOVA) was performed. To be able to perform Kruskal-Wallis H-tests, four assumptions must be met. Our study met the first three assumptions which are; One dependent variable measured at a continuous level (number of caught crabs), one independent variable that consists of two or more categories (in our sample, the independent variable - trap types - had five different categories), and independence of observations which means that there is no relationship between the observations in each group of the independent variable. The fourth assumption of the test is a critical assumption because it affects the way to interpret the results. It had to be determined whether the distribution of catches for each category of independent variable had the same variability or a different variability. In case of distributions with same variabilities, the Kruskal-Wallis H-test can be used to make inferences about the difference in medians between groups. In case of different variabilities, however, judgements have to be based on mean ranks. In the present study, visual inspection of box-plots gave reason to assume different variabilities and thus to present results in mean ranks. Whenever statistically significant differences were found, post-hoc analyses were run to determine where the difference is. Detailed results with related graphics are presented in chapter 4.

4. Results

4.1 Selectivity experiments

Since five traps formed one string of traps and each of the five experiments included the placing of three strings, the obtained dataset consists of 75 traps in total. In the appendix of this thesis, detailed information on every trap's catches during every haul is provided (tables A1 – A5). Throughout all the experiments, a total of 1473 individual king crabs was sampled[8], 1008 of them (68.4%) being male and 465 of them (31.6%) being female. The total number of sublegal-sized crabs (<130 mm CL) was 505 (34.3%), while 968 (65.7%) of the sampled crabs measured 130 mm CL or more. The overall size distribution of crabs sampled during the field work is presented in figures 15 and 16. The first shows the accumulated number of crabs in every size class for all four types of employed escape openings, while the latter is showing the size distribution across experiments. In both figures, every value is the sum of 15 observations. As mentioned before, a differentiation for very large crabs (160 mm CL or more) has only been done during experiments 2-5. Visualizations of the size distributions for these four experiments including differentiated size classes up to 190 mm CL and the shares of male and female crabs in all size classes can be found in the appendix (figures A7 – A10).

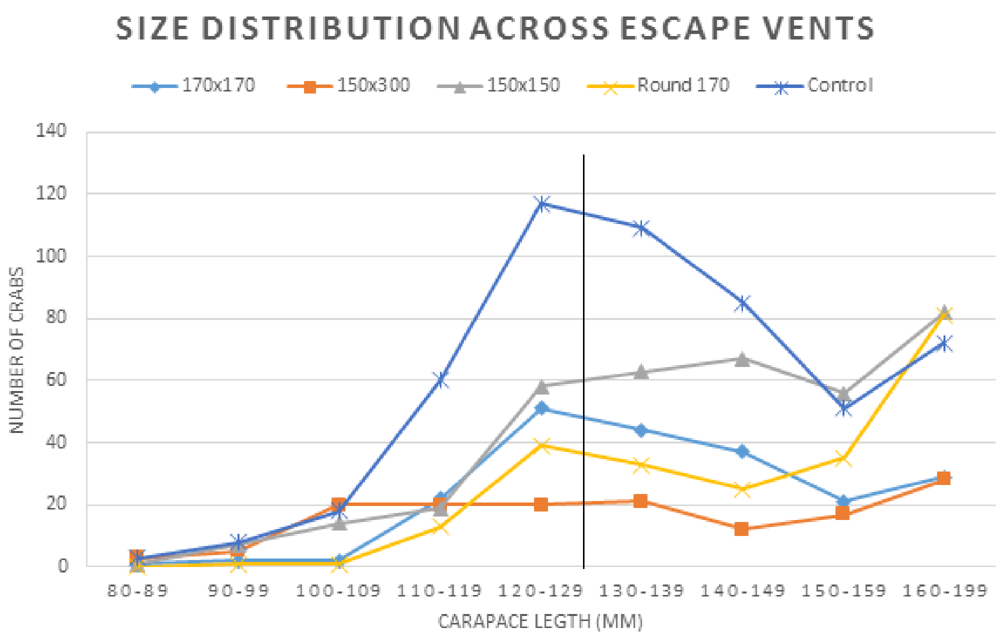

Figure 15 *Size distribution of retained Red King Crabs for all four types of escape vents plus control traps.*

8 Due to the repeated nature of the experiment, it is possible that some individuals have been sampled more than once.

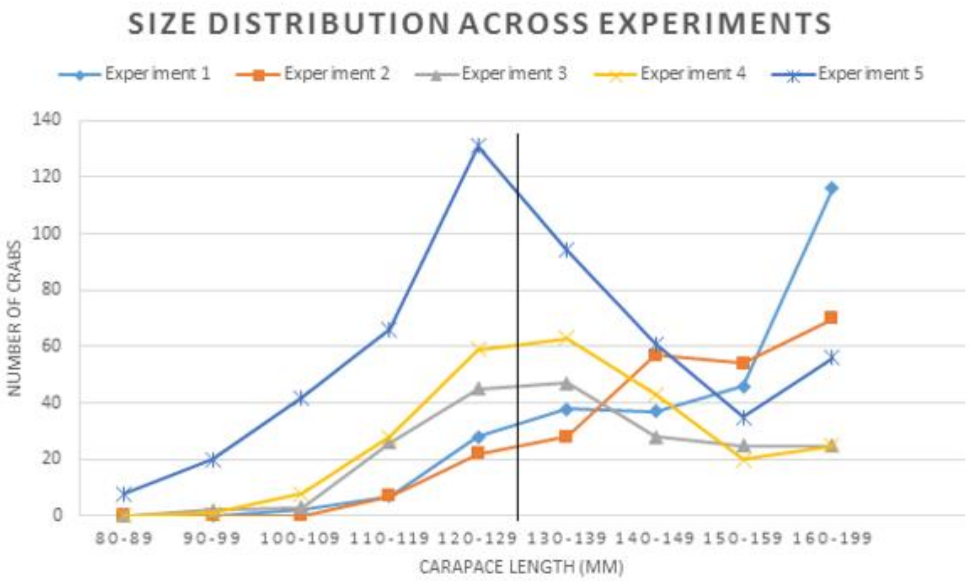

Figure 16 *Size distribution of retained Red King Crabs throughout all five experiments.*

A total of 405 crabs (27.5%) has been classified as "injured". The percentage of crabs that were identified as showing signs of molting was 7.7% in during the first experiment, 21.4% during the second experiment, 35.8% during the third experiment, 51.4% during the fourth experiment and finally 53.6% during the fifth experiment.

4.2 Pecularities

Two pots showed strikingly weak performances in terms of total catches. The first one of them was the Control trap attached to string one (at position 4), and the second one was the 170 × 170 mm squared trap attached to string 2 (at position 2). After the second experiment, a visual inspection of these two traps has been carried out in order to find out if damaged meshes, irregularities in the entrance funnels, problems regarding the bait bag or similar things could be responsible for the observed low catches. However, the inspections failed to identify any irregularities. The reason for the lower catches of these particular traps was either coincidence or, more probably, some unknown features at the sea floor. Since all traps have been repeatedly released at the same location, rocks on the seafloor could have been responsible for an unsuitable positioning of the gear on the bottom, leading to more difficult entry conditions or to the distraction of the odor plume. As a reaction to the ongoing poor catches of the control trap in the first four experiments, it was decided to soak that chain at a slightly different location during experiment 5 (see figure 10). After that measure, the trap generated catches comparable to the other control traps during experiment 5, supporting the hypothesis that some physical obstacle on the seafloor has prevented crabs to enter it in the same degree as they entered other traps during the first four experiments. However, since the reason for the observed pecularities could not be assigned to gear defects and since the traps still caught crabs (although in a smaller number), it was decided that an exclusion of these two traps' data from the statistical analysis was not justified. Variations in catches, even if they are difficult to explain, are ultimatively a part of the nature of fisheries. Other traps, such as the one with round escape vents at string 1 (position 5) also performed strikingly worse than the others just during two experiments (in this case experiments 1 and 3), but totally in line with other traps during all other experiments (compare table A2).

4.3 Relative catch efficiency

Figure 17 illustrates the estimated catch efficiency of traps equipped with escape vents relative to control traps. For each of the size classes, the ratio between the number of crabs in traps with escape openings (accumulated over all 15 observations) and the number of crabs in the control pots (also accumulated over all 15 observations) was calculated.

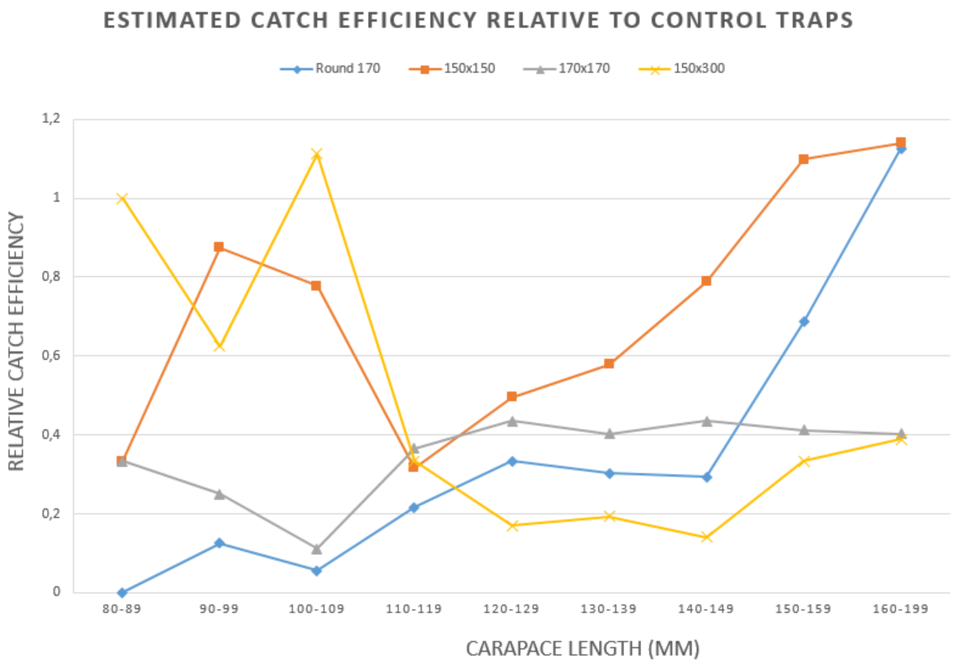

Figure 17 *Estimated catch efficiency to control traps of all four types of escape openings.*

4.4 Total catch performance

A Kruskal-Wallis H-test was run to determine if there were differences in total crab catch performance between five different types of traps: Control, Round 170 mm, 150 × 150 mm, 150 × 130 mm and 170 × 170 mm. Distributions of total catch performances were not similar for all groups, as assessed by visual inspection of boxplots (see figure 18). The mean rank of total crab catch performances was statistically significantly different between different types of traps, $\chi^2(4) = 14.463$, $p = .006$. Subsequently, pairwise comparisons were performed using Dunn's (1964) procedure with a Bonferroni correction for multiple comparisons. Adjusted p-values are presented. This post hoc analysis revealed statistically significant differences in total crab catch performances between 150 × 300 mm (mean rank = 24.33) and Control (mean rank = 51.50) ($p = .006$) trap types, but not between any other combination.

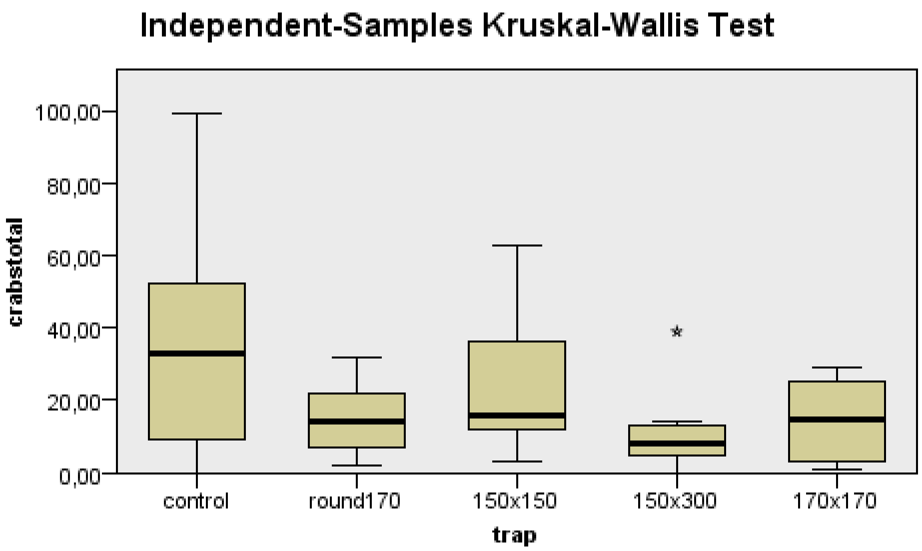

Figure 18 *Boxplot of variations in total catches for all four types of escape vents plus control traps.*

4.5 Sublegal-sized crabs

A Kruskal-Wallis H-test was run to determine if there were differences in retention of sub-legal (<130 mm) sized individuals between the five different types of traps: Control, Round 170 mm, 150 × 150 mm, 150 × 130 mm and 170 × 170 mm. Visual inspection of boxplots (see figure 19) revealed the existence of outliers in the data. Distributions of sub-legal sized individuals were not similar for all groups, as assessed by a Shapiro-Wilks tests ($p < .05$). The mean rank of sub-legal sized individuals was not significantly different between groups, χ^2 (4) = 8.656, $p = .07$.

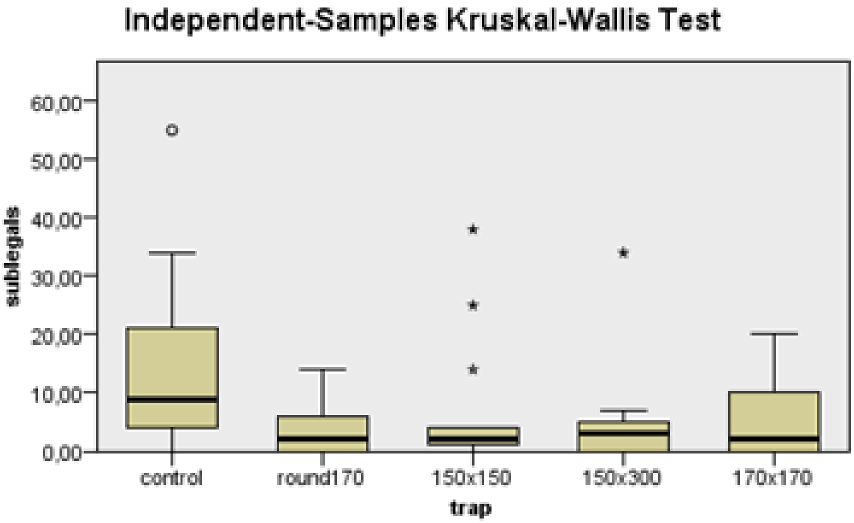

Figure 19 *Boxplot of variations in catches of sublegal-sized crabs for all four types of escape vents plus control traps.*

4.6 Small legal crabs

A Kruskal-Wallis H test was run to determine if there were differences in retention of smaller legal sized individuals (≥ 130 mm and < 160 mm) between the five different types of traps: Control, Round 170 mm, 150 × 150 mm, 150 × 130 mm and 170 × 170 mm. The catch variations are visualized in the boxplots in figure 20. Distributions of smaller legal sized individuals were not similar for all groups, as assessed by Shapiro-Wilks tests (p<.05). The mean rank of smaller legal sized individuals was statistically significantly different between different types of traps, χ^2 (4) = 17.901, $p = .001$. Subsequently, pairwise comparisons were performed using Dunn's (1964) procedure with a Bonferroni correction for multiple comparisons. Adjusted p-values are presented. This post hoc analysis revealed statistically significant differences in total number of smaller legal sized individuals between 150 × 300 mm (mean rank = 23.07) and 150 × 150 mm (mean rank = 48.00) (p = .017) and between 150 × 300 mm (mean rank = 23.07) and Control traps (mean rank = 52.10) (p = .003), but not between any other combination.

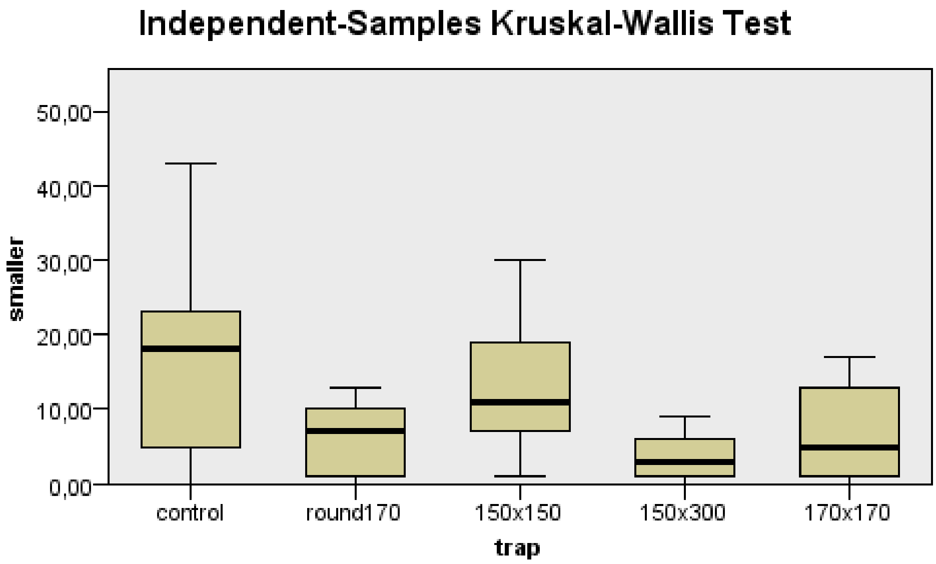

Figure 20 *Boxplot of variations in catches of smaller legal-sized crabs for all four types of escape vents plus control traps.*

4.7 Large legal crabs

A Kruskal-Wallis H-test was run to determine if there were differences in the retention of larger legal sized individuals (≥ 160 mm) between the five different types of traps: Control, Round 170 mm, 150 × 150 mm, 150 × 130 mm and 170 × 170 mm. Inspection of boxplots (see figure 21) showed that there were outliers present in the data. Distributions of larger-legal sized individuals were not similar for all groups, as assessed by a Shapiro-Wilks tests ($p < .05$). The mean rank of larger legal sized individuals was statistically significantly different between different types of escape vents, χ^2 (4) =11.461 p = .022. Subsequently, pairwise comparisons were performed using Dunn's (1964) procedure with a Bonferroni correction for multiple comparisons. This post-hoc test revealed no statistically significant differences between any other combination. We concluded that statistically significant differences between any combination do not exist since "it is perfectly possible to have a statistically significant Kruskal-Wallis H-test but no statistically significant pairwise comparisons" (Leard statistics, 2015).

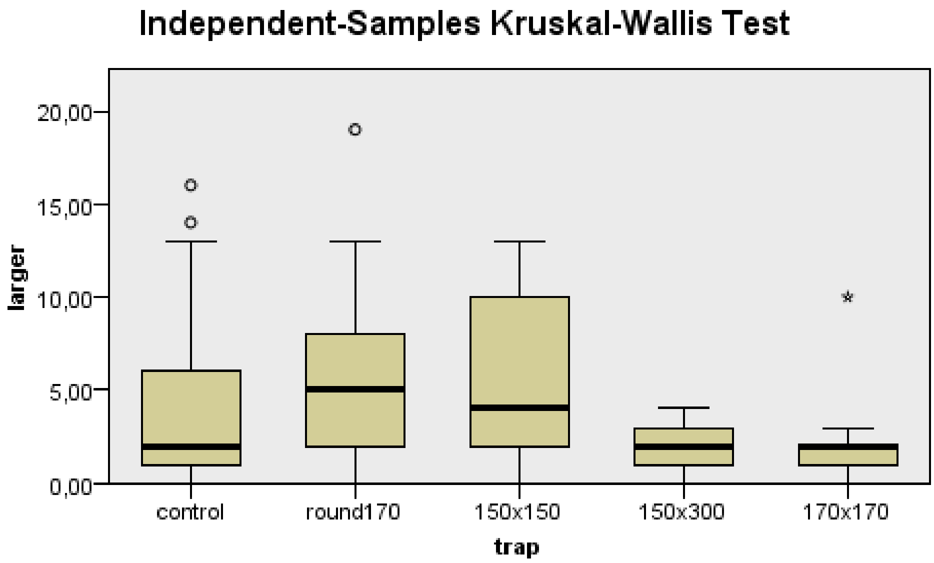

Figure 21 *Boxplot of variations in catches of larger legal-sized crabs for all four types of escape vents plus control traps.*

4.8 Summary of results

The selectivity experiments failed to identify any of the tested escape vents as superior in terms of statistically significant reduction in unintended catches of sublegal crabs. Furthermore, no significant differences in retention of large crabs (160 mm CL or larger) could be found. In the group of legal crabs under 160 mm CL, however, the control traps as well as the ones with small squared escape openings performed significantly better than the traps with rectangular escape vents. In the case of the 150 × 150 mm squared escape openings, this effect was strong enough to make this type superior in terms of the total catch compared to the rectangular design.

5. Discussion

5.1 General evaluation of catch compositions

Due to the species' seasonal migration patterns, depth and season are assumed to crucially influence catches and catch compositions of Red King Crabs. Sundet & Hjelset (2010) investigated the abundance of king crabs at different depths throughout the year in the Varanger area and found immature crabs of both sexes to be quite uncommon during the first four months of the year. If they were retained during that period, then almost exclusively in shallower waters. In terms of numbers, they were most common during two peaks: one of them being in May/June at depths of 150 m or deeper, and the other one being in November at depths of around 50 m. Catches of mature males peaked in summer (June to September), especially in deep waters, and ovigerous females were most numerous in September, November and December at depths of 150 m or deeper. It is noteworthy that mature crabs were defined by Sundet and Hjelset (2010) by presence of external eggs for females and a CL of 110 mm for males, so that mature and immature are not congruent with the terms „legal" and „sublegal" in our study. Still, the size distributions resulting from the experiments for the present study are confirming the previous research, indicating that very small crabs are hardly found at depths of around 150 m during February and March. Juvenile crabs are typically found in very shallow waters, hence the poor catches of crabs under 100 mm CL in our experiments are most likely attributable to general depth distribution patterns rather than gear selectivity properties. During the time of our fieldwork, adults are likely to be encountered more densely in somewhat shallower waters, as mating is happening there during April and May. Sundet & Hjelset (2010) obtained an overall sex ratio of 2.3 : 1 in favor of females during February and 1.5 : 1 in favor of males during March, with approximately equal relative shares of the total catches at 150 m depth. The sex ratio in our experiments was 2.9 : 1 and 2.0 : 1 in favor of male crabs during February and March, respectively[9]. In spite of the generally identifiable patterns related to seasonal depth migrations, certain annual or local variations are little surprising when considering that both the research of Sundet & Hjelset (2010) and our experiments have been carried out in one limited area and based on relatively small numbers of hauls. Probably first and foremost due to specific local or annual conditions, Sundet & Hjelset (2010) did not catch any crabs at 100 m depth in

[9] The results of experiment 2 (when traps were set on February 25th and hauled on March, 7th) are assigned to the month of March here. They have been submerged longer during March compared to February and the final catch composition is assumed to be influenced more by entry/exit dynamics in March.

September, while Salthaug and Furevik (2004) sampled many individuals at that depth and month, for example.

5.2 Injured and molting crabs

A share of 27.5% of all sampled crabs was classified as “injured”, with autotomized limbs being the most common and most obvious injury type. Autotomy, the severage of chelae or walking legs at a preformed break-age line, is a common reflexive response to received injuries or threats in many decapod crustaceans (Juanes & Smith, 1995). Autotomy can provide short-term survival by avoiding predators and by limiting wounds, and autotomized limbs are usually regenerated after the wound gets sealed and slowly hardens (Stevens, 2014b). Regeneration of missing limbs is happening during the period before molting, and after the first molt following the limb loss, a morphologically complete, but clearly smaller regenerated appendage gets visible (Skinner, 1985). This regenerated limb can grow to obtain full size again. For Red King Crabs, Edwards (1972) estimated the process of regaining complete symmetry to take at least four instars. Accordingly, juveniles with their frequent molts might be able to completely replace a limb within one year, while the process takes longest for large males that are not undergoing molting every year. Though crabs can benefit from their capability of casting off limbs and survive predator attacks or injuries, autotomy involves costs as well. Spending energy for regeneration might reduce their growth increment during molting, and with growing magnitude of occurrences, the result can be a reduction in overall harvestable biomass (Stevens, 2014b). Ecological consequences of autotomy and reduced growth can include lowered mating success, lowered foraging efficiency and higher vulnerability to intra- and interspecific attacks (Juanes & Smith, 1995). Apart from predation, there is no doubt that fishery-induced factors are contributing to limb losses in king crabs as well, though quantification is often difficult. Careless handling, or handling under difficult conditions, has been discussed previously. Autotomy as well as carapace injuries due to encounters with fishing gears, particularly trawls, are documented (Rose et al., 2013).

After the first years of commercial fishing in Norway, the increasing amount of crabs missing one or more appendages led to the introduction of a separate quota for injured crabs in 2008. Fishermen previously tended to discard all those individuals in order to sell only undamaged ones. Anonymous (2007) reports that the resulting accumulation of injured individuals in the stock led to an estimated share of 20-25% of all legal males in the Varanger area. A percentage of 27.5% injured crabs, as in our experiments, is in line with observed injury rates in the area since the beginning of commercial fishing. The magnitude of occurances of injuries has never experienced dramatical changes since then and is regularly reported to be somewhat over 20% (Jan Sundet, pers. Comm.). Comparisons between fished and unfished populations in terms of limb losses are hardly available (Stevens, 2014b), but in order to avoid the risk of a decrease in the valuably marketable stock and lowered biomass growth due to regeneration, handling procedures should always be carried out in a conservative and careful manner.

The percentage of molting crabs has steadily increased from 7.7% in the first experiment (retrieval of pots: February, 25th) to 53.6% in the last experiment (retrieval of pots: March, 22nd). Mating is peaking in April and May (Pinchukov & Sundet, 2011) and all females necessarily undergo ecdysis before being fertilized. Larger males, however, do not molt every year. The general increase in the share of molting crabs is predominantly attributable to the mating season, but the fact that frequently molting immature crabs (under 110 mm CL, compare Sundet & Hjelset (2014)) were retained in higher amounts during the fifth experiment might have contributed to an even higher percentage than the one that is to be explained by the mating season alone. However, experiment 4 had a similar percentage of molting crabs (51.4%), even though there were only quite a few immature crabs in the catch. Hence, the results show that a large share of the king crabs in the area was close to mating by the middle of March.

5.3 Soak time

Soak time – the time between setting and hauling of a trap - is another important parameter to influence size and composition of catches. The catch is an outcome of entry and exit rates, which is in turn influenced by – among other things – exhaustion of bait odor and gear saturation (Miller, 1990). These factors are expected to increase the trapped animals' motivation for escape, while simultaneously leading to a drop in entry rates (Pengilly & Tracy, 1998). Hence, there should be a net migration out of the trap rather than into it after a certain point of time. Pengilly and Tracy (1998) found sublegal king crabs in catches under commercial conditions to outnumber legal ones - the latter group being defined as males of more than 165 mm CW, which corresponds to an estimated 137 mm CL – for all tested soak times (12 h, 24 h and 72 h). Increased soak times were responded by higher catches, but this increase was underproportional. Both legal and sublegal crabs obtained higher mean numbers at higher soak times. However, the bycatch ratio – the number of incidentally caught sublegal crabs per legal crab – was declining from 2.4 : 1 to 2.0 : 1 when soak time was increased from 12 h to 24 h and furtherly dropped to 1.3 : 1 at 72 h soak time. The relative share of very small males (≤ 109 mm CL) has constantly decreased as traps were soaked longer. In our experiments, the overall bycatch ratio was 0.6 when applying short soak times (2 days) and decreased only slightly to 0.5 at long soak times (7-11 days). Stiansen et al. (2008) found slower accumulation to lead to a continuous increase in catch for conical pots beyond two days of soak time, while squared pots like the ones used for this study appeared to have stabilized their catches at that point of the catch cycle. A net migration out of the squared pots has not been observed until a soak time of 7-8 days, which was the longest applied (Stiansen et al., 2008). However, the traps in those experiments were not equipped with escape vents. A stabilization of the catch at some point before 48 h soak time has presumably been the case in our field work as well, since bycatch ratios after the second day appeared to be far from reacting as sensitively to extended soak times as observed by Pengilly and Tracy (1998) for soak times between 12 h and 72 h. Zhou and Shirley (1997c) observed catches in rectangular traps (without escape openings) to reach an asymptotic level after about 30 hours.

5.4 Estimated relative catch efficiency

The smallest four four groups are characterized by comparatively low total numbers of individuals (compare figure 15), which might explain the partly irregular patterns and strong deflections for crabs smaller than 120 mm CL in figure 17. The small number of individuals in these size classes makes it generally more difficult to make reliable statements on the bycatch-avoiding properties of the different escape vents. On the other side, the small-squared escape vents exceeded the control traps in efficiency for all crabs longer than 150 mm, while the round escape openings did so only for the largest individuals (160 mm CL or more). The remaining two (large squares and rectangular) remained at an estimated relative efficiency level of around 0.4 or lower for all legal-sized classes. Salthaug and Furevik (2004) found round escape vents with 160 mm diameter to catch as least as much as control traps for all large size groups starting with 135-139 mm CL. For 180 mm vents, the respective length class was 145-149 mm. Since our round escape opening with its diameter of 170 mm is just in between these two referance values, one would expect the ratio to exceed the value 1 in the size intervall of 140-149 mm, but in fact it was still well below 0.4 for that class. Again, a limited sample size as well as differences soak time, size composition of crabs in the area or other conditions might have contributed to the observed shift.

5.5 Sublegal crabs

In pots with escape openings, small crabs are given the possibility to get out of the gear as soon as the bait is exhausted and densities inside get too high, and escape vents rather than meshes or entrance funnels are thought to be almost exclusively the way for them out of the gear (Stevens et al., 1993). However, it is important to notice that escape vents do not only allow for egress of undersized individuals, but can also serve as additional and easy entrance openings for small crabs into the trap (Salthaug & Furevik, 2004), though quantitative research results on this phenomenon are scarce. Small crabs might also repeatedly enter and exit pots (Zhou & Kruse, 2000) and perhaps perceive the fishing gear as a kind of protective object at times. Hence, the fact that sublegal crabs did not show significantly different retention rates in our experiments is not necessarily unusual, even when considering the partly long soak times. It can be speculated that young crabs were able to make use of all four of the tested escape openings, but constant escape and (re)entering was probably what prevented any trap to significantly reduce the amount of sublegal crabs in comparison to the Control traps. However, even though statistical significance could not be found for the group of sublegal crabs as a whole (80-129 mm CL), control traps turned out to catch more sublegals, especially in the size groups of 110-119 mm CL and 120 – 129 mm CL (compare figure 15). It is noteworthy that podding behaviour (Powell & Nickerson, 1965) might have influenced catches of sublegal crabs. The younger king crabs are, the more likely they are to show clustering behavior (Dew, 2010). Relatively high abundances of small king crabs, especially during experiment 5, are probably explainable by the coincidental presence of aggregations in parts of the study area (Jan Sundet, pers. Comm.).

5.6 Small legal crabs

The size group between 130 and 159 mm CL is expected to have a harder time to squeeze themselves through escape openings of comparatively small dimensions like 150 × 150 mm, but might not be large enough to climb out of the pot through the entrance funnel.

According to our results, the rectangular escape vents performed significantly worse than both control traps and 150 × 150 mm squared escape vents in terms of retention of individuals between 130 and 159 mm CL. Climbing along the side panels as well as stepping on each other are usual behavioral patterns of trapped king crabs (Stevens et al., 1993), and doing so the probability of finding an escape vent is high during relatively long soak times. Apparently the dimensions of the rectangular escape openings facilitated their egress. Possibly, they did so by enabling them not only to leave by side-walking, but also by walking straight ahead with their anterior part first (which is not uncommon in king crabs; compare Zhou & Shirley, 1997a).

It is however questionable in how far the “superiority” of a specific type of escape vent in this size group is really making it preferable in terms of bycatch reduction and handling avoidance. According to current Norwegian regulations, all individuals of 130 mm CL or more are in principal legal, but the overall quota for females is only around 5 % and female individuals beyond that rate have to be discarded. Since females rarely grow bigger than 160 mm CL, a high abundance of females in the catch due to clustering or combinations of season and depth (compare Sundet & Hjelset, 2010) would turn a large portion of animals in the group of the smaller legal-sized crabs into bycatch. Furthermore, as mentioned before, fishermen might sort out king crabs of both sexes even if they achieve the legal size in order to use their quota for large individuals that obtain higher prices per kg.

5.7 Large legal crabs

Large king crabs are known to be able to easily leave a pot by climbing through the entrance funnel (Stevens et al., 1993). Since the design of the entrance funnels were basically the same for all traps in our field work, it is unclear in how far eventual differences in the retention of those individuals are attributable to escape vents. The escape vents in our experiments should partly be too small to allow for egress of very big crabs. However, the way that escape vents influence entry and exit dynamics of smaller size classes might have exercised indirect effects on the entry and exit of the largest individuals as well, for example because of the density factor (Zhou & Kruse, 2000).

Our analysis did not identify any significant differences between any pairwise combination. Nevertheless, the average catches in this size group were higher for Control traps as well as small squared and round escape openings and lower for big squares and rectangles (compare figure 15), even though statistical significance at the 95 % confidence level was not achieved. In the case of the 170 mm escape openings (round and squared) as well as for the rectangular one, also large crabs might have used them to get out of the gear. A surprising result is the higher (though not significally higher) retention rate of the round escape vent compared to the 170 × 170 mm squared one since the square offers more surface for crabs of critical size.

5.8 Conclusion

The field work has been carried out in a specific area and in a specific season, and both of these factors as well as depth are very likely to influence age and sex structure of crabs present in the surrounding area of the trap chains and hence the catch composition. Younger king crab are known to form aggregations and the eventual presence of such aggregations has the potential of biasing the structure of catches.

Still, the results indicte that escape vents have played a role in influencing the catch dynamics of the employed pots. Rectangular escape openings of the tested dimension performed worst. They performed similar to all others in terms of bycatch reduction (in this work defined as a sex-neutral term that only refers to size), but retained less legal-sized individuals, most probably because large individuals climbing along the side panels had a comparatively easy time squeezing themselves sideways through the 300 mm long opening. Based on our findings, the use of rectangular escape vents is therefore not recommendable.

The only escape vent that performed significantly better than the rectangular one in at least one of the three major size groups was the 150 × 150 mm square. However, significant differences between it and the remaining two escape vents (round and 170 × 170 mm) could not be found, even though it tended to retain more of the smaller legal-sized crabs. In terms of large legal-sized crabs, round and small-squared escape vents seem to be superior to rectangular and large-squared ones, but statistical significance was again not obtained. In addition, the 150 × 150 mm squares were significantly superior to at least one other escape vent in the group of smaller legals (though this finding is to a certain point ambiguous, as discussed before) and were among the ones to obtain the highest averages in the group of larger legals, too. A possible general superiority of squared escape openings over round ones (of the same diameter) could not be derived from our findings. Differences between catches of round escape vents of 170 mm diameter and 170 × 170 mm squared ones were not significant for any size group, but while both types retained sublegals in comparable amounts, the round one caught more large legal crabs in a degree that was very close to statistical significance. Probably, crabs can squeeze themselves through squared escape vents easier than through round ones, but if this was the case in the experiments, then this effect applied strongest in the “wrong” size class for the selected diameter of 170 mm.

The results of this study point into the direction that rectangular escape openings are unfavorable, while 150 × 150 mm squared ones performed best. However, they are not convincingly superior to round escape rings (which have been most commonly used so far). The round vents in our experiments did not retain many undersized individuals, but the differences in bycatch reduction were far from being significant. On the other hand, they performed equally well in retaining crabs in the biggest size class.

Following the results of this work, our recommendation is that future research should rule out rectangular designs of such dimensions (side ratio 1 : 2) and focus on finding the optimal diameter of either round or squared escape vents, probably by conducting in situ observations in a laboratory tank or by carrying out similar research as in the fieldwork in order to obtain a wider picture and also larger data bases.

List of References

ADF&G (2015): 2015-2017 Commercial King and Tanner Crab Fishing Regulations. Alaska Department of Fish and Game, Juneau, Alaska.

Ahyong, S. (2015): *Paralithodes camtschaticus* (Tilesius, 1815). Accessed through: World Register of Marine Species at http://www.marinespecies.org/aphia.php?p=taxdetails&id=233889 (Accessed: 10th of March, 2016)

Alverson, D.L., Freeberg, M.H., Pope, J.G., Murawski, S.S. (1994): A Global Assessment of Fisheries Bycatch and Discards. FAO Fisheries Technical Paper. Food and Agriculture Organization of the United Nations, Rome, Italy, 223pp.

Anisimova, N., Berenboim, B., Gerasimova, O., Manushin, I., Pinchukov, M. (2005): On the effect of red king crab on some components of the Barents Sea ecosystem. Ecosystem dynamics and optimal long-term harvest in the Barents Sea Fisheries. Proceeding of the 11th Russian-Norwegian Symposium, Murmansk, 15–17 Aug 2005/ IMR/PINRO Joint Report Series 2 pp. 298–306

Anonymous (2007): Forvaltning av kongekrabbe [Management of the red king crab]. Parliament Whitepaper No. 40/2006-2007, Ministry of Fisheries and Coastal Affairs, Oslo, Norway, 144pp. [In Norwegian]

Anonymous (2015a): Evaluering av forvaltningen av kongekrabbe [Evaluation of the management of the red king crab]. Parliament Whitepaper No. 17/2014-2015, Ministry of Trade, Industry and Fishery, Oslo, Norway, 52pp. [In Norwegian]

Anonymous (2015b): ICES WGITMO Report 2015. Report of the Working Group on Introductions and Transfers of Marine Organisms (WGITMO), 18–20 March 2015, Bergen, Norway. ICES CM 2015/SSGEPI:10. 195 pp.

Anonymous (2015c): Forskrift om adgang til å delta i kystfiskefartøygruppens fiske for 2016 (deltakerforskriften) [Provision on access to participate in the fishery of the coastal vessel group for 2016 (participant regulation)]. Accessible at https://lovdata.no/dokument/SF/forskrift/2015-12-08-1418 (Accessed: 15th of March, 2016) [In Norwegian]

Anonymous (2016): J-27-2016: Forskrift om regulering av fangst av kongekrabbe i kvoteregulert område øst for 26°Ø mv. i 2016 [Provision on the regulation of catch of king crab in the quota-regulated area east of 26°E in 2016]. Accessible at http://www.fiskeridir.no/Yrkesfiske/Regelverk-og-reguleringer/Jmeldinger/Gjeldende-J-meldinger/J-27-2016 (Accessed: 5th of April, 2016) [In Norwegian]

Britayev, T.A., Rzhavsky, A.V., Pavlova, L.V., Dvoretskij, A.G. (2010): Studies on impact of the alien Red King Crab (*Paralithodes camtschaticus*) on the shallow water benthic communities of the Barents Sea. Journal of Applied Ichtyology 26 (Suppl.2) (2010), pp. 66-73

Chiasson, Y. V., Vienneau, R., DeGrâce, P., Campbell, R., Hébert, M., Moriyasu, M. (1993): Evaluation of catch selectivity of modified snow crab (*Chionoecetes opilio*) conical traps. Canadian Technical Report of Fisheries and Aquatic Sciences, Moncton, New Brunswick. Report No. 1930. 26pp.

Dew, C.B. (1990): Behavioral ecology of podding red king crab, *Paralithodes camtschatica*. Canadian Journal of Fisheries and Aquatic Sciences 47, pp. 1944-1958

Dew, C.B., McConnaughey, R.A. (2005): Did trawling on the brood stock contribute to the collapse of Alaska's king crab? Ecological Applications, 15(3), 2005, pp. 919-941

Dew, C.B. (2010): Podding Behavior of Adult King Crab and Its Effect on Abundance Estimate Precision. In: Kruse, G.H., Eckert, G.L., Foy, R.J., Lipcius, R.N., Sainte-Marie, B., Stram, D.L., Woodby, D. (eds.): Biology and Management of Exploited Crab Populations under Climate Change (pp. 129-151). Alaska Sea Grant, University of Alaska Fairbanks, Fairbanks.

Donaldson, W.E., Byersdorfer, S.C. (2005): Biological field techniques for lithodid crabs. Alaska Sea Grant College Program, University of Alaska Fairbanks, AK-SG-05-03

Dvoretsky, A.G., Dvoretsky, V.G. (2014): Red King Crab in Russia: Populations, Fisheries, and Symbionts. In: Stevens, B.G. (ed.): King Crabs of the World: Biology and Fisheries Management (pp. 501-518). New York, NY: CRC Press

Edwards, J.S. (1972): Limb loss and regeneration in two crabs: The king crab *Paralithodes camtschatica*, and the Tanner crab, *Chionoecetes bairdi*. Acta Zoologica 53: pp. 105-112

Eliasen, S.Q., Papadopoulou, K.-N., Vassilopoulou, V., Catchpole, T.L. (2014): Socio-economic and institutional incentives influencing fishers’ behaviour in relation to fishing practices and discard. ICES Journal of Marine Science (2014), 71(5), pp. 1298–1307

Faccia, I., Alyakrinsky, A., Bianchi, C.N. (2009): The crab that came from the cold: First record of *Paralithodes camtschaticus* (Tilesius, 1815) in the Mediterranean Sea. Aquatic invasions (2009) Vol.4, Issue 4: 715-718

Falk-Petersen, J., Renaud, P., Anisimova, N. (2011): Establishment and ecosystem effects of the alien invasive red king crab (*Paralithodes camtschaticus*) in the Barents Sea – a review. ICES Journal of Marine Science (2011), 68 (3), pp. 479-488

Godøy, H., Furevik, D., Løkkeborg (2003): Reduced bycatch of red king crab (*Paralithodes camtschaticus*) in the gillnet fishery for cod (*Gadus morhua*) in northern Norway. Fisheries Research 62 (2003): 377-384

Godøy, H., Furevik, D.M., Stiansen, S. (2003): Unaccounted mortality of red king crab (Paralithodes camtschaticus) in deliberately lost pots off Northern Norway. Fisheries Research 64 (2003): 171-177

Grant, W.S., Zelenina, D.A., Mugue, N.S. (2014): Phyleography of Red King Crab: Implications for Management and Stock Enhancement. In: Stevens, B.G. (ed.): King Crabs of the World: Biology and Fisheries Management (pp. 73-80). New York, NY: CRC Press

Guillory, V., Allemand, R., King, K., Bare, L. (2004): An Evaluation of 5.87-cm and 6.03-cm Escape Rings for Blue Crab *Callinectes sapidus* Traps. North American Journal of Fisheries Management, 24:4, 1431-1434

Hansen, T.H. (2002): Temperaturpreferanse hos kongekrabbe (*Paralithodes camtschaticus*) [Temperature preference of the king crab (*Paralithodes camtschaticus*)]. M.Sc. Thesis, University of Tromsø, 59pp. [In Norwegian]

Hauge, M., van der Meeren, G. (2012): Hvor viktig er størrelsen på hannen for krepsdyrhunnene? [How important is the male's size for crustacean females?] Institute of Marine Research, Bergen, Norway. Accessed online at: http://www.imr.no/temasider/skalldyr/hummer/europeisk_hummer/hvor_viktig_er_storrelsen_pa_hannen_for_krepsdyrhunnene/nn-no (Accessed: 27th of March, 2016) [In Norwegian]

High, W.L., Worlund, D.D. (1979): Escape of king crab (*Paralithodes camtschatica*) from derelict pots. US Department of Commerce, NOAA Technical Reports NMFS SSRF-374

Hjelset, A.M., Sundet, J.H., Nilssen, E.M. (2009): Size at sexual maturity in the female red king crab (Paralithodes camtschaticus) in a newly settled population in the Barents Sea, Norway. J. Northw. Atl. Fish. Sci., 41: 173–182

Hjelset, A.M. (2014): Fishery-induced changes in Norwegian red king crab (*Paralithodes camtschaticus*) reproductive potential. ICES Journal of Marine Science (2014), 71 (2): pp. 365-373

Ivanov, B.G. (2002): Red king crab (*Paralithodes camtschaticus*) in the eastern Okhotsk Sea: problems and stock management and research. In: Paul, A.J., Dawe, E.G., Elner, R., Jamieson, G.S., Kruse, G.H., Otto, R.S., Sainte-Marie, B., Shirley, T.C., Woodby, D. (eds.): Crabs in Cold Water Regions: Biology, Management, and Economics. Alaska Sea Grant College Program, University of Alaska Fairbanks, pp. 681-692

Jewett, S.C. and Feder, H.M. (1982): Food and feeding habits of the king crab *Paralithodes camtschatica* near Kodiak Island, Alaska. Mar. Biol. 66: pp. 243-250

Jørgensen, L.L. (2005): Impact scenario for an introduced decapod on Arctic benthic communities. Biological Invasions (2005) 7: pp. 949-957

Jørgensen, L.L., Manushin, I., Sundet, J.H., Birkely, S.-R. (2005): The intentional introduction of the marine red king crab *Paralithodes camtschaticus* into the Southern Barents Sea. ICES Cooperative Research Report No. 277, September 2005

Jørgensen, L.L. (2006): NOBANIS – Invasive Alien Species Fact Sheet – Paralithodes camtschaticus. Online Database of the North European and Baltic Network on Invasive Alien Species – NOBANIS. https://www.nobanis.org/globalassets/speciesinfo/p/paralithodes-camtschatica/paralithodes_camtschaticus.pdf (Accessed : 22th of February, 2016)

Jørgensen, L.L., Nilssen, E.M. (2011): The Invasive History, Impact and Management of the Red King Crab *Paralithodes camtschaticus* off the Coast of Norway. In: B.S. Galil et al. (eds.): In the Wrong Place – Alien Marine Crustaceans: Distribution, Biology and Impacts. Invading Nature – Springer Series in Invasion Ecology 6 sl.l: Springer Science + Business Media B.V. 2011, pp. 521-536

Juanes, F., Smith, L.D. (1995): The ecological consequences of limb damage and loss in decapod crustaceans: a review and prospectus. Journal of Experimental Marine Biology and Ecology 193: pp. 197–223

Jury, S.H., Howell, H., O'Grady, D.F., Watson, W.H. III (2001): Lobster trap video: In situ surveillance of the behavior of *Homarus americanus* in and around traps. Marine and Freshwater Research 52: pp. 1125-1132

Kuzmin, S., Olsen, S. (1994): BARENTS SEA CRAB (*Paralithodes camtschatica*) The transplantation experiments were successful. ICES Shellfish Committee C.M. 1994/K:12

Laerd Statistics (2015): Statistical tutorials and software guides. Retrieved from https://statistics.laerd.com/ (Accessed: 5th of May, 2016).

McLaughlin, P.A. (2014): Systematics of King Crabs. In: Stevens, B.G. (ed.): King Crabs of the World: Biology and Fisheries Management (pp. 31-46). New York, NY: CRC Press

Medby, A. (2016): Fant hundrevis av kongekrabber i Tromsø [Online]. Nordlys, Tromsø. Available: http://www.nordlys.no/kongekrabbe/fant-hundrevis-av-kongekrabber-i-tromso/s/5-34-363140 (Accessed: 24th of March, 2016) [In Norwegian]

Mikkelsen, N., Pedersen, T., (2012): Invasive red king crab affects lumpsucker recruitment by egg consumption. Marine Ecology Progress Series Vol. 469 (2012): pp. 87-99

Miller, R.J. (1990): Effectiveness of crab and lobster traps. Canadian Journal of Fisheries and Aquatic Sciences, 47: 1228-1251

Moen, F.E., Svensen, E. (2014): Dyreliv I havet - Nordeuropeisk marin fauna [Marine fish and invertebrates of Northern Europe], 6. utgave. Kom Forlag, pp. 312-313 [In Norwegian]

Nilssen, E.M., Sundet, J.H. (2006): The introduced red king crab (*Paralithodes camtschaticus*) in the Barents Sea II. Growth increments and moulting probability. Fisheries Research 82 (2006), pp. 319-326

Norges Råfisklag (2015): Prisdrøftelser kongekrabbe, snøkrabbe og reker [Price discussions king crab, snow crab and shrimps]. Accesible at http://www.rafisklaget.no/portal/page/portal/RafisklagetDokumenter/Markedstiltak/Markedsrapport_Kongekrabbe_2015.pdf (Accessed: 10th of May, 2016) [In Norwegian]

Orlov, Y.I., Ivanov, B.G. (1978): On the introduction of the Kamchatka King Crab *Paralithodes camtschatica* (Decapoda: Anomura: Lithodidae) into the Barents Sea. Marine Biology 48, pp. 373-375 (1978)

Oug, E., Cochrane, S.K.J., Sundet, J.H., Norling, K., Nilsson, H.C. (2011): Effects of the invasive red king crab (*Paralithodes camtschaticus*) on soft-bottom fauna in Varangerfjorden, northern Norway. Marine Biodiversity (2011) 41: pp. 467-479

Pavlova, L.V. (2009): Estimation of Foraging on the Sea Urchin *Strongylocentrotus droebachiensis* (Echinoidea: Echinoida) by the Red King Crab *Paralithodes camtschaticus* (Malacostraca: Decapoda) in Coastal Waters of the Barents Sea. Russian Journal of Marine Biology (2009) Vol. 35, No. 4, pp. 288–295

Pengilly, D., Tracy, D. (1998): Experimental Effects of Soak Time on Catch of Legal-Sized and Nonlegal Red King Crabs by Commercial Crab Pots. Alsaka Fishery Research Bulletin 5(2) (1998), pp. 81-87

Pinchukov, M.A., Sundet, J.H. (2011): Red king crab. In: Jakobsen, T., Ozhigin, V.K. (eds.): The Barents Sea. Ecosystem, Resources, Management. Half a century of Russian-Norwegian cooperation. Tapir Academic Press, Trondheim, Norway 2011, pp. 160-167

Powell, G. C., Nickerson, R.B. (1965): Aggregations among juvenile king crabs (*Paralithodes camatschatica*, Tilesius) Kodiak, Alaska. Animal Behaviour 13(2-3): pp. 374-380.

Rafter, I., Nilssen, E.M., Sundet, J.H. (1996): Stomach content, life history, maturation and morphometric parameters of red king crab, *Paralithodes camtschaticus*, from Varangerfjord area, North Norway. ICES C.M. 1996/K:10

Rittschof, D. (1992): Chemosensation in the Daily Life of Crabs. American Zoologist, 32: 363-369

Rotherham, D., Johnson, D.D., Macbeth, W.G., Gray, C.A. (2013): Escape Gaps as a Management Strategy for Reducing Bycatch in Net-Covered Traps for the Giant Mud Crab *Scylla serrata.* North American Journal of Fisheries Management 33 (2013): 307–317

Rose, C. S., Hammond, C.F., Stoner, A.W., Munk, J.E., Gauvin, J.R. (2013): Quantification and reduction of unobserved mortality rates of snow, Tanner and red king crabs (*Chionoecetes opilio*, *C. bairdi* and *Paralithodes camtschaticus*) after encounters with trawls on the seafloor. Fishery Bulletin 111: pp. 42-53

Salthaug, A., Furevik, D.M. (2004): Size selection of red king crabs, *Paralihodes camtschaticus*, in traps with escape openings. Sarsia 89: 184-189

Skinner, D.M. (1985): Molting and regeneration. In: Bliss, D.E. (ed.): The Biology of Crustacea, Vol. 9: Integument, Pigments and Hormonal Processes. Academic Press, Orlando, FL, pp. 43-146

Sparboe, M., Christiansen, J.S. (2008): Preliminary results from experimental studies of temperature preference and tolerance in Barents Sea red king crab (*Paralithodes camtschaticus*). In: Sundet, J.H., Berenboim, B. (eds.): Research on the red king crab (*Paralithodes camtschaticus*) fom the Barents Sea in 2005-2007. Joint Report Series. Institure of Marine Research (IMR) and Polar Research Institute of Marine Fisheries and Oceonography (PINRO).

Smolowitz, R., (1978): Trap design and ghost fishing: an overview. Marine Fisheries Review (40): 2–8

Stevens, B.G., Haaga, J.A., Donaldson, W.E. (1993): Underwater observations on behavior of red king crabs escaping from pots. Processed report, Report No. 93-06. NOAA/NMFS Alaska Fisheries Science Center, Seattle, WA

Stevens, B.G., Jewett, S.C. (2014): Growth, Molting and Feeding of King Crabs. In: Stevens, B.G. (ed.): King Crabs of the World: Biology and Fisheries Management (pp. 315-362). New York, NY: CRC Press

Stevens, B.G., Lovrich, G.A. (2014): King Crabs of the World: Species and Distribution. In: Stevens, B.G. (ed.): King Crabs of the World: Biology and Fisheries Management (pp. 1-30). New York, NY: CRC Press

Stevens, B.G. (2014): Development and Biology of King Crab Larvae. In: Stevens, B.G. (ed.): King Crabs of the World: Biology and Fisheries Management (pp. 233-260). New York, NY: CRC Press

Stevens, B.G. (2014b): Impact of Fishing on King Crabs: Bycatch, Injuries and Mortality. In: Stevens, B.G. (ed.): King Crabs of the World: Biology and Fisheries Management (pp. 363-402). New York, NY: CRC Press

Stiansen, S., Fernö, A., Furevik, D., Jørgensen, T., Løkkeberg, S. (2008): Efficiency and catch dynamics of collapsible square and conical pots used in the red king crab (*Paralithodes camtschaticus*) fishery. Fishery Bulletin 106 (2008): pp. 40-46

Sturdivant, S.K., Clark, K.L. (2011): An evaluation of the effects of blue crab (*Callinectes sapidus*) behavior on the efficacy of crab pots as a tool for estimating population abundance. Fishery Bulletin 109: pp. 48-55

Sundet, J.H., Hjelset, A.M. (2002): The Norwegian Red King Crab (*Paralithodes camtschaticus*) Fishery: Management and Bycatch Issues. In: Paul, A.J., Dawe, E.G., Elner, R., Jamieson, G.H., Kruse, G.H., Otto, R.S., Sainte-Marie, B., Shirley, T.C., and Woodby, D. (eds.): Crabs in Cold Water Regions: Biology, Management and Economics. Alaska Sea Grant College Program, University of Alaska Fairbanks, pp. 681-692

Sundet, J.H., Hjelset, A.M. (2010): Seasonal Depth Distribution of the Red King Crab (*Paralithodes camtschaticus*) in Varangerfjorden, Northern Norway. In: Kruse, G.H., Eckert, G.L., Foy, R.J., Lipcius, R.N., Sainte-Marie, B., Stram, D.L., Woodby, D. (eds.): Biology and Management of Exploited Crab Populations under Climate Change. Alaska Sea Grant, University of Alaska Fairbanks, pp. 403-411

Sundet, J.H. (2014a): Red King Crab in the Barents Sea. In: Stevens, B.G. (ed.): King Crabs of the World: Biology and Fisheries Management (pp. 485-500). New York, NY: CRC Press

Sundet, J. H. (2014b): The red king crab (Paralithodes camschaticus) in the Barents Sea. In: Vestergaard, N., Kaiser, B. and Fernandez, L. (eds.): Marine invasive species management in the Arctic. TemaNord, Nordic Council of Ministers, Copenhagen. Available at: www.vliz.be/imisdocs/publications/272394.pdf (Accessed: 10th of February, 2016)

Thomas, R.E., Rice, S.D. (1992): SALINITY TOLERANCE OF ADULT AND JUVENILE RED KING CRABS *PARALITHODES CAMTSCHATICA*. Camp. Biochem. Physiol. Vol. 103A, No. 3 (1992): pp. 433-437

Vienneau, R., Paulin, A. and Moriyasu, M., (1993): Evaluation of the catch mechanism of conventional conical snow crab (*Chionoecetes opilio*) traps by underwater video camera observations. Canadian Technical Reports in Fisheries and Aquatic Sciences, Moncton, New Brunswick. Report No. 1903. 15 pp.

Windsland, K. (2014): The invasive red king crab (Paralithodes camtschaticus): Mortality, individual growth and dispersal in Norwegian waters. Doctoral Thesis, University of Tromsø, 50 pp.

Winger, P.D., Walsh, P.J. (2011): Selectivity, efficiency, and underwater observations of modified trap designs for the snow crab (*Chionoecetes opilio*) fishery in Newfoundland and Labrador. Fisheries research 109 (2011): 107-113

Zelenina, D.A., Mugue, N.S., Volkov, A.A., Sokolov, V.I. (2008): Red King Crab (*Paralithodes camtschaticus*) in the Barents Sea: A Comparative Study of Introduced and Native Populations. Russian Journal of Genetics, 2008, Vol. 44 No.7, pp. 859-866

Zhou, S., Shirley, T.C. (1995): Effects of handling on feeding, activity and survival of red king crabs, *Paralithodes camtschaticus* (Tilesius, 1815). Journal of Shellfish Research Vol. 14, No.1, 173-177

Zhou, S., Shirley, T.C. (1996): Is Handling Responsible for the Decline of the Red King Crab Fishery? High Latitude Crabs: Biology, Management and Economics. Alaska Sea Grant College Programm AK-SG-96-02, 1996

Zhou, S., Shirley, T.C. (1997a): Behavioural responses of red king crabs to crab pots. Fisheries research 30 (1997): pp. 177-189

Zhou, S., Shirley, T.C. (1997b): Chemoreception and feeding responses of red king crabs to potential bait extracts. Crustacean research, No. 26: pp. 1-15

Zhou, S., Shirley, T.C. (1997c): Performance of two red king crab pot designs. Canadian Journal of Fisheries and Aquatic Sciences 54: pp. 1858-1864

Zhou, S., Kruse, G.H. (2000): Capture Efficiency and Size Selectivity of Two Types of Pots for Red King Crabs in the Bering Sea. Alaska Fishery Research Bulletin 6(2): pp. 94-103

Appendix

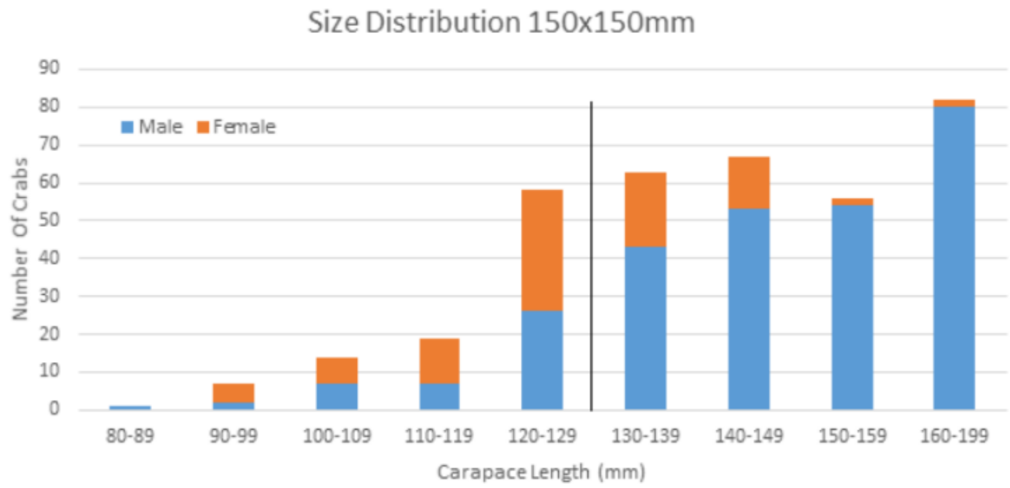

Figure A1 *Size distribution of all retained king crabs from pots with small squared escape vents (all five experiments).*

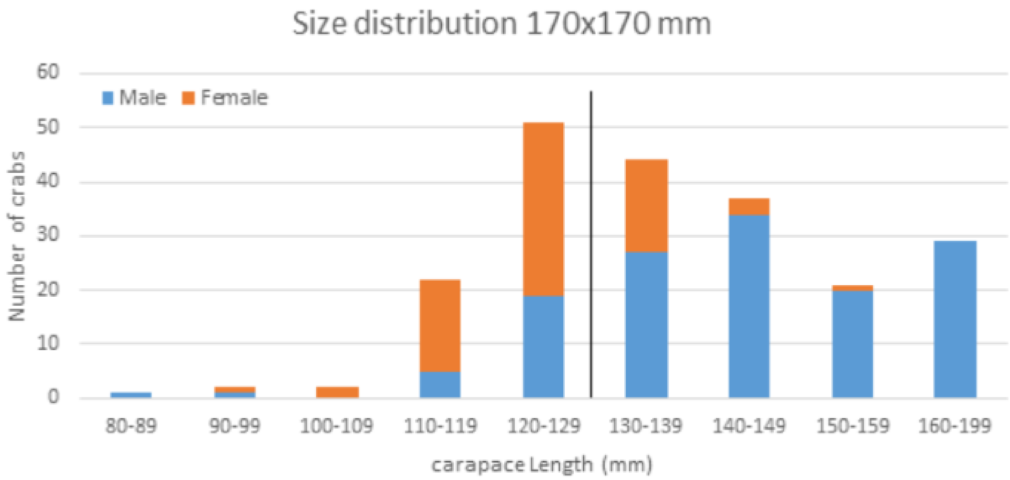

Figure A2 *Size distribution of all retained king crabs from pots with large squared escape vents (all five experiments).*

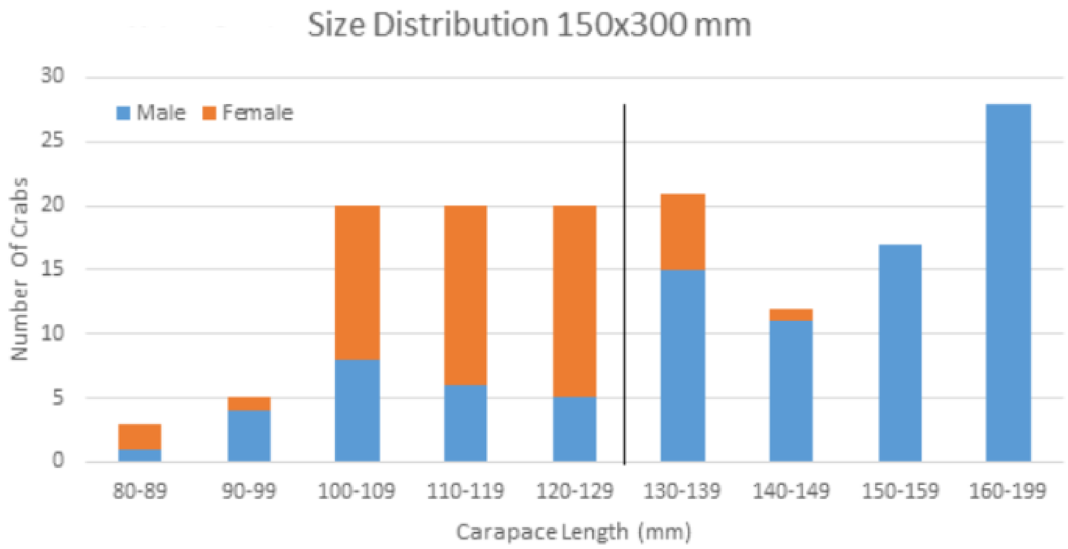

Figure A3 *Size distribution of all retained king crabs from pots with rectangular escape vents (all five experiments).*

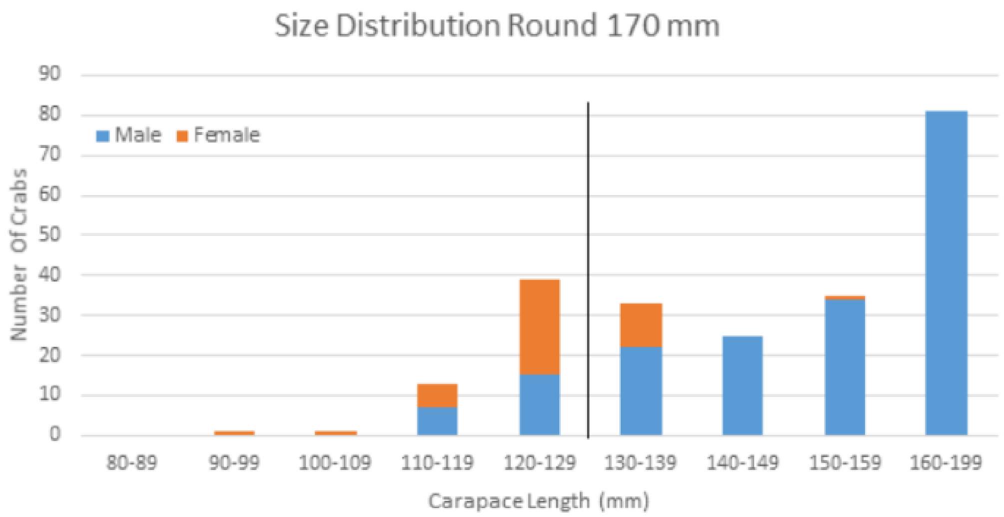

Figure A4 *Size distribution of all retained king crabs from pots with round escape vents (all five experiments).*

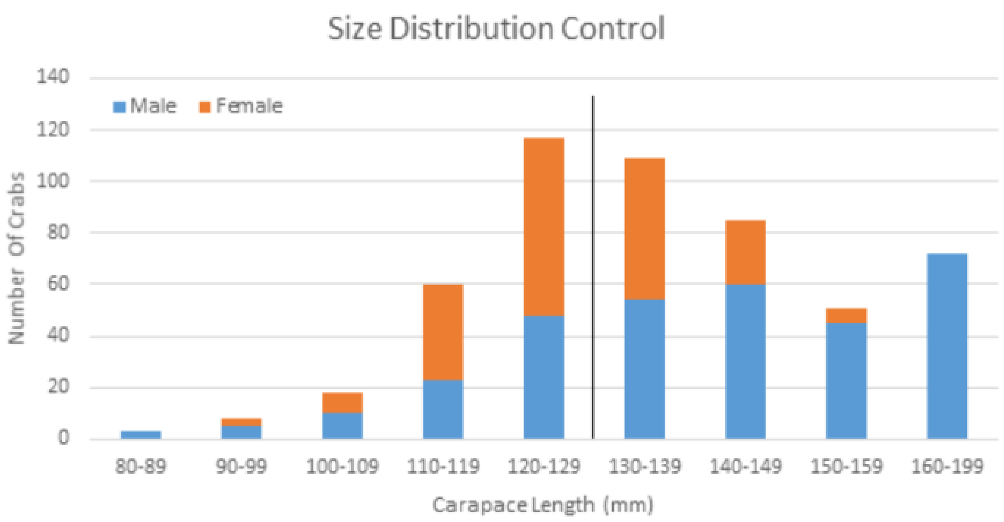

Figure A5 *Size distribution of all retained king crabs from control pots (all five experiments).*

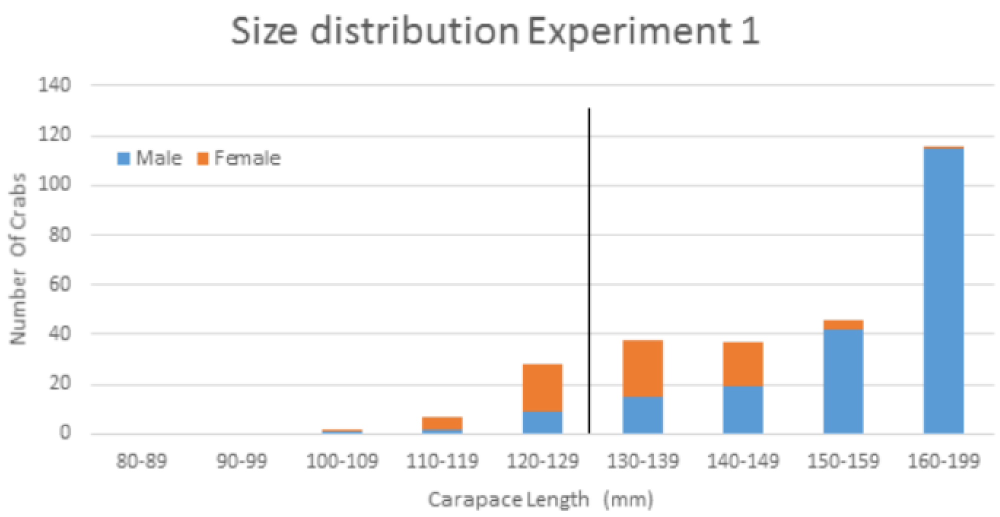

Figure A6 *Size distribution of all retained king crabs during experiment 1 (all five pot types).*

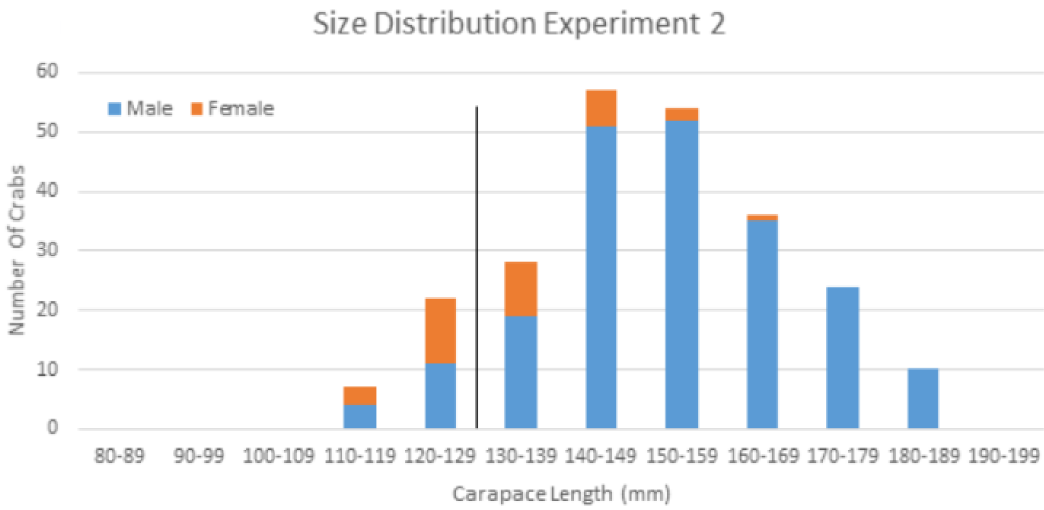

Figure A7 *Size distribution of all retained king crabs during experiment 2 (all five pot types).*

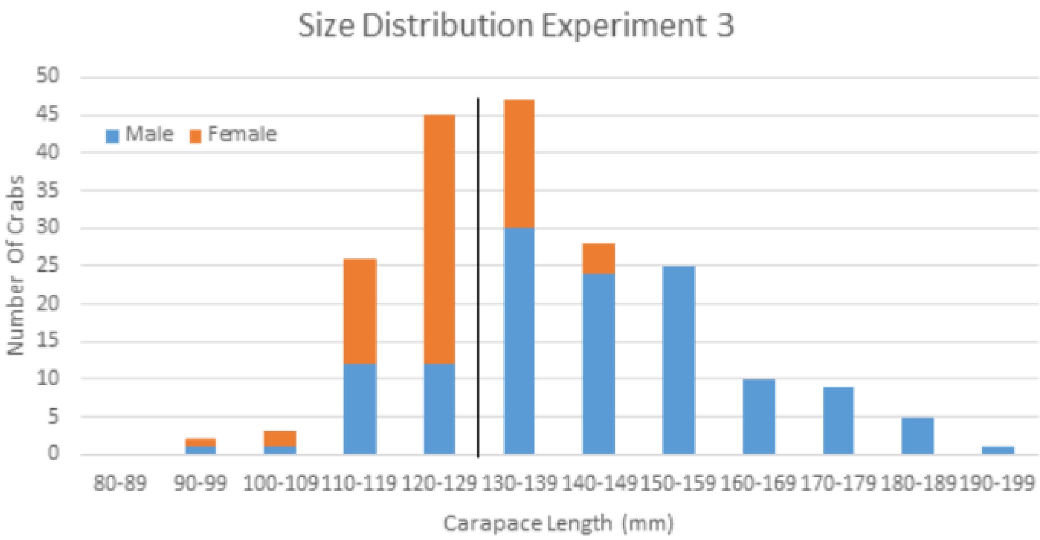

Figure A8 *Size distribution of all retained king crabs during experiment 3 (all five pot types).*

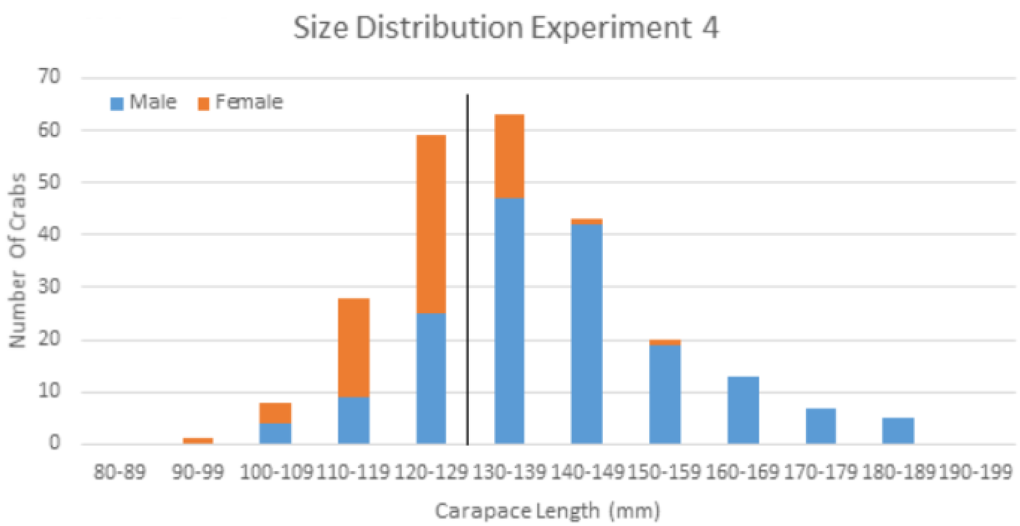

Figure A9 *Size distribution of all retained king crabs during experiment 4 (all five pot types).*

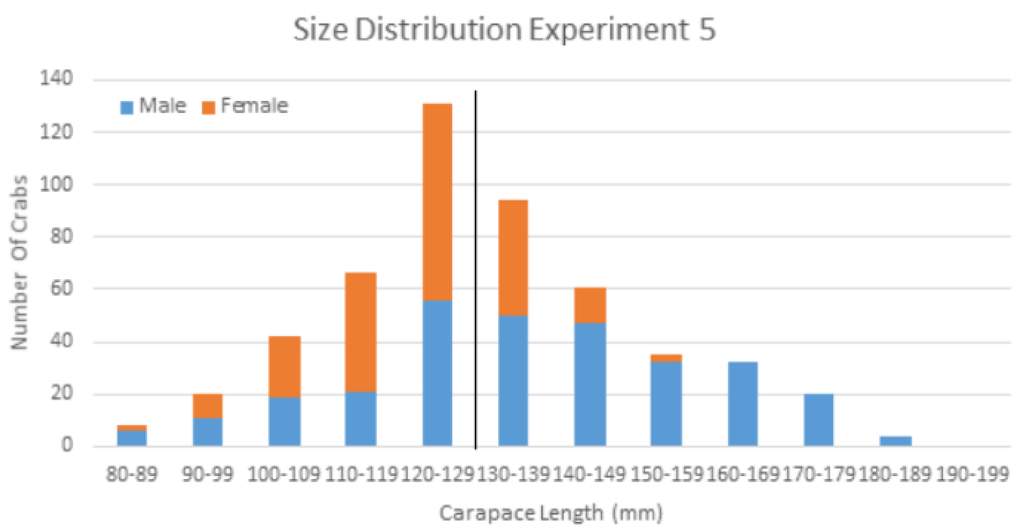

Figure A10 *Size distribution of all retained king crabs during experiment 5 (all five pot types).*

Exp.	Trap position	Escape vent	Crabs total	Males	Females	Sub-legals	Small legals	Large legals	Injured crabs	Molting crabs
1	String 1, Pos. 4	None (Control)	6	3	3	0	4	2	1	0
2	String 1, Pos. 4	None (Control)	0	0	0	0	0	0	0	0
3	String 1, Pos. 4	None (Control)	4	4	0	1	1	2	3	1
4	String 1, Pos. 4	None (Control)	9	4	5	4	5	0	2	3
5	String 1, Pos. 4	None (Control)	52	31	21	23	23	6	15	21
1	String 2, Pos. 1	None (Control)	48	34	14	11	21	16	13	1
2	String 2, Pos. 1	None (Control)	37	27	10	6	17	14	10	13
3	String 2, Pos. 1	None (Control)	22	10	12	14	6	2	3	6
4	String 2, Pos. 1	None (Control)	33	27	6	9	18	6	11	13
5	String 2, Pos. 1	None (Control)	54	37	17	21	27	6	11	40
1	String 3, Pos. 4	None (Control)	44	30	14	9	22	13	10	4
2	String 3, Pos. 4	None (Control)	28	23	5	9	18	1	13	6
3	String 3, Pos. 4	None (Control)	24	16	8	10	14	0	5	13
4	String 3, Pos. 4	None (Control)	63	39	24	34	26	3	11	44
5	String 3, Pos. 4	None (Control)	99	35	64	55	43	1	29	33

Table A1 *Total number of crabs as well as number of males, females, sublegals (< 130 mm CL), small legals (≥ 130 mm CL and < 160 mm CL), large legals (≥ 160 mm CL), injured crabs and molting crabs for each of the 15 hauls of control traps. Number of experiment and position of trap are stated.*

Exp.	Trap position	Escape vent	Crabs total	Males	Females	Sub-legals	Small legals	Large legals	Injured crabs	Molting crabs
1	String 1, Pos. 5	Round (⌀ 170 mm)	3	3	0	0	1	2	3	0
2	String 1, Pos. 5	Round (⌀ 170 mm)	14	13	1	1	7	6	7	2
3	String 1, Pos. 5	Round (⌀ 170 mm)	2	2	0	0	0	2	0	1
4	String 1, Pos. 5	Round (⌀ 170 mm)	9	6	3	2	7	0	3	1
5	String 1, Pos. 5	Round (⌀ 170 mm)	32	22	10	14	13	5	8	13
1	String 2, Pos. 2	Round (⌀ 170 mm)	23	22	1	0	4	19	7	2
2	String 2, Pos. 2	Round (⌀ 170 mm)	21	21	0	0	13	8	5	5
3	String 2, Pos. 2	Round (⌀ 170 mm)	21	9	12	13	8	0	5	7
4	String 2, Pos. 2	Round (⌀ 170 mm)	5	4	1	2	1	2	2	2
5	String 2, Pos. 2	Round (⌀ 170 mm)	13	11	2	2	6	5	11	8
1	String 3, Pos. 3	Round (⌀ 170 mm)	27	25	2	4	10	13	9	0
2	String 3, Pos. 3	Round (⌀ 170 mm)	11	10	1	0	2	9	1	1
3	String 3, Pos. 3	Round (⌀ 170 mm)	18	13	5	6	10	2	4	15
4	String 3, Pos. 3	Round (⌀ 170 mm)	22	16	6	10	10	2	6	17
5	String 3, Pos. 3	Round (⌀ 170 mm)	7	7	0	0	1	6	3	2

Table A2 *Total number of crabs as well as number of males, females, sublegals (< 130 mm CL), small legals (≥ 130 mm CL and < 160 mm CL), large legals (≥ 160 mm CL), injured crabs and molting crabs for each of the 15 hauls of traps equipped with round escape openings of 170 mm diameter. Number of experiment and position of trap are stated.*

Exp.	Trap position	Escape vent	Crabs total	Males	Females	Sub-legals	Small legals	Large legals	Injured crabs	Molting crabs
1	String 1, Pos. 2	150 × 300 mm	3	3	0	0	2	1	2	0
2	String 1, Pos. 2	150 × 300 mm	0	0	0	0	0	0	0	0
3	String 1, Pos. 2	150 × 300 mm	13	9	4	3	8	2	6	0
4	String 1, Pos. 2	150 × 300 mm	8	7	1	1	3	4	5	2
5	String 1, Pos. 2	150 × 300 mm	14	11	3	3	9	2	4	7
1	String 2, Pos. 3	150 × 300 mm	0	0	0	0	0	0	0	0
2	String 2, Pos. 3	150 × 300 mm	6	5	1	1	4	1	0	0
3	String 2, Pos. 3	150 × 300 mm	5	5	0	0	3	2	1	1
4	String 2, Pos. 3	150 × 300 mm	14	7	7	7	6	1	1	7
5	String 2, Pos. 3	150 × 300 mm	10	4	6	6	1	3	3	6
1	String 3, Pos. 5	150 × 300 mm	12	8	4	5	3	4	4	1
2	String 3, Pos. 5	150 × 300 mm	9	8	1	2	6	1	4	4
3	String 3, Pos. 5	150 × 300 mm	6	6	0	3	2	1	2	6
4	String 3, Pos. 5	150 × 300 mm	7	5	2	3	2	2	2	5
5	String 3, Pos. 5	150 × 300 mm	39	17	22	34	1	4	10	29

Table A3 *Total number of crabs as well as number of males, females, sublegals (< 130 mm CL), small legals (≥ 130 mm CL and < 160 mm CL), large legals (≥ 160 mm CL), injured crabs and molting crabs for each of the 15 hauls of traps equipped with rectangular (150 × 300 mm) escape openings. Number of experiment and position of trap are stated.*

Exp.	Trap position	Escape vent	Crabs total	Males	Females	Sub-legals	Small legals	Large legals	Injured crabs	Molting crabs
1	String 1, Pos. 3	170 × 170 mm	19	13	6	1	8	10	7	0
2	String 1, Pos. 3	170 × 170 mm	24	21	3	4	17	3	11	3
3	String 1, Pos. 3	170 × 170 mm	25	16	9	8	15	2	7	6
4	String 1, Pos. 3	170 × 170 mm	16	14	2	1	13	2	6	6
5	String 1, Pos. 3	170 × 170 mm	25	9	16	20	5	0	6	15
1	String 2, Pos. 5	170 × 170 mm	2	2	0	0	1	1	1	0
2	String 2, Pos. 5	170 × 170 mm	3	2	1	0	1	2	1	1
3	String 2, Pos. 5	170 × 170 mm	2	2	0	0	0	2	2	0
4	String 2, Pos. 5	170 × 170 mm	1	0	1	0	1	0	1	0
5	String 2, Pos. 5	170 × 170 mm	6	4	2	2	3	1	3	6
1	String 3, Pos. 1	170 × 170 mm	15	12	3	4	9	2	4	3
2	String 3, Pos. 1	170 × 170 mm	4	4	0	0	2	2	2	0
3	String 3, Pos. 1	170 × 170 mm	29	15	14	15	13	1	10	8
4	String 3, Pos. 1	170 × 170 mm	26	16	10	13	12	1	5	11
5	String 3, Pos. 1	170 × 170 mm	12	5	7	10	2	0	3	3

Table A4 *Total number of crabs as well as number of males, females, sublegals (< 130 mm CL), small legals (≥ 130 mm CL and < 160 mm CL), large legals (≥ 160 mm CL), injured crabs and molting crabs for each of the 15 hauls of traps equipped with squared (150 × 150 mm) escape openings. Number of experiment and position of trap are stated.*

Exp.	Trap position	Escape vent	Crabs total	Males	Females	Sub-legals	Small legals	Large legals	Injured crabs	Molting crabs
1	String 1, Pos. 1	150 × 150 mm	36	15	21	3	23	10	10	11
2	String 1, Pos. 1	150 × 150 mm	42	37	5	2	27	13	16	5
3	String 1, Pos. 1	150 × 150 mm	16	11	5	2	11	3	8	3
4	String 1, Pos. 1	150 × 150 mm	7	6	1	2	3	2	4	4
5	String 1, Pos. 1	150 × 150 mm	61	36	25	38	19	4	15	30
1	String 2, Pos. 4	150 × 150 mm	13	13	0	0	2	11	4	2
2	String 2, Pos. 4	150 × 150 mm	25	22	3	2	17	6	6	6
3	String 2, Pos. 4	150 × 150 mm	3	3	0	0	1	2	0	2
4	String 2., Pos. 4	150 × 150 mm	12	8	4	4	8	0	4	5
5	String 2., Pos. 4	150 × 150 mm	63	52	11	25	30	8	16	49
1	String 3, Pos. 2	150 × 150 mm	23	20	3	0	11	12	3	0
2	String 3, Pos. 2	150 × 150 mm	14	13	1	2	8	4	2	5
3	String 3, Pos. 2	150 × 150 mm	11	9	2	1	8	2	6	3
4	String 3, Pos. 2	150 × 150 mm	15	11	4	4	11	0	4	7
5	String 3, Pos. 2	150 × 150 mm	26	17	9	14	7	5	7	13

Table A5 *Total number of crabs as well as number of males, females, sublegals (< 130 mm CL), small legals (≥ 130 mm CL and < 160 mm CL), large legals (≥ 160 mm CL), injured crabs and molting crabs for each of the 15 hauls of traps equipped with squared (170 × 170 mm) escape openings. Number of experiment and position of trap are stated.*