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Snow crab (*Chionoecetes opilio*) in the Barents Sea.

Possibility of harvesting a new species by the Russian fleet.

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Contents

Introduction

Snow crab (*Chionoecetes opilio*) is a species naturally occurring in the Northwestern Atlantic Ocean and in the Northern Pacific Ocean where it is subject to a valuable large scale exploitation (Comeau *et al*, 1998). Recently, however, this species was also detected in the north-eastern region of the Atlantic Ocean, in the Barents Sea. There are several possible explanations for its sudden appearance. Some scientists suggest that it was transported with ballast water of ships (Agnalt *et al*, 2011; Jørstad *et al*, no date). It has also been suggested that it crawled across the Atlantic Ocean from its native area. The actual mode of dispersal, by natural locomotion or by anthropogenic transport, can give it a characteristic status, as a naturally invasive species or as an introduced exotic, respectively (Pavlov and Sokolov, 2003). This has consequences with respect to the appropriate management regime of the new population: is it a new resource to exploit sustainably, keeping the stock at appropriate precautionary levels, or is it a population to exterminate, possibly by intentional over-exploitation? Nowadays snow crab is exploited in the Barents Sea by two vessels – one Spanish and one Norwegian, but in the lack of a regulatory regime it may be that other interests claim the rights to fish.

There are numerous studies about invasive species and their impact on their new environments. Biologists and ecologists do researches in this field all over the world. Snow crab in the Barents Sea is not an exception (Pavlov, 2005). Scientists have investigated possible effects of the invasion, and harvesters estimate the ways of taking an advantage and derive benefit from it. In the thesis, I try to represent interests of managers, and suggest possible management regime of the snow crab fishery in the Barents Sea from an utilitarian perspective.

The structure of the thesis is as follows. The first chapter covers snow crab biology including its main characteristics, such as the size and growth, diet, and distribution. The description of the snow crab biology is aimed at the evaluation of the new environment. The section on king crab (*Paralithodes camtschaticus*) describes the species' establishment in the Barents Sea and specifies possible consequences of this introduction. This parallel case-study suggests what actions and measures might be taken by the States applied in case a new species appears and what kind of difficulties occur altogether with such invasion. Next chapter is a short description of the Barents Sea. This section illustrates the new conditions for snow crab, its similarities with the traditional area of occurrence, and the likelihood of permanent settlement in the new grounds. The management section identifies different and common moments in the snow crab fisheries management systems in Alaska and Canada. In addition, the snow crab fishery in Russia exemplifies the main difficulties of the industry and management in the Far East. The discussion chapter covers the recommendations for setting management rules and measures in order to sustain the future snow crab fishery in the Barents Sea from the Russian side. The last section identifies the main conclusion.

Initially, the current thesis was meant to evaluate the possibility of snow crab harvesting in the Barents Sea by Russia. However, while I was writing the paper, it was reported that the Russians together with the Norwegians decided to open the snow crab fishery since 2014.

They have already set a catch quota (The Committee on the Fisheries Industry, 2013). Due to the above-mentioned news, it is useless to discuss the possibility of snow crab harvesting. Now the question about the proposed management regime becomes more relevant.

Thus, is I compare management regimes in the snow crab fisheries in Canada, Alaska and Russia. This action is aimed at discovery of necessary measures and restrictions, which provide sustainable snow crab fishery in the Barents Sea from the Russian side. The main goal of the thesis is to provide recommendations for the future snow crab fishery in the Murmansk region.

Materials and methods

The thesis is mostly based on a review of scientific literature. Reviewed sources represent different disciplines, including biology, fishing technology, law, and management. Articles, reports, conference materials, laws and rules of the regulatory system, make the list of used literature. Some retrospective articles are studied as they are related to the theme. In addition, attempts were made to recover some “grey literature”, including articles from non-scientific journals. Scoping search on selected databases such as Google Scholar, Springer Link, Alaska Department of Fish and Game, NOAA Fisheries (National Oceanic and Atmospheric Administration), NPFMC (North Pacific Fisheries Management Council) – was performed. Key words used for the search were “snow crab fisheries”, “snow crab in Alaska”, “snow crab in Canada”, “Chionoecetes opilio”. The search included literature in English and Russian languages.

Results

1. Snow crab biology

1.1 Taxonomy

The taxonomical standing of snow crab is considered presently a crustacean and its scientific classification is mentioned below.

Kingdom: Animalia

Phylum: Arthropoda

Subphylum: Crustacea

Class: Malacostraca

Order: Decapoda

Infraorder: Brachyura

Family: Oregoniidae

Genus: Chionoecetes

Snow crab *(Chionoecetes opilio)* is a true crab of a high commercial value, with highly appreciated and nutritious meat (Jensen, no date). In the global market, it is a popular marine product. As a rule, snow crab is sold frozen in limb sections or as separate meat (NOAA FishWatch). The first hand price varies depending on a price for the exported snow crab, on the currency rate, meat quality and economic situations of the importing countries (Report on the snow crab industry in the Atlantic Provinces and Quebec, 2011).

Snow crab is a long-living species. At the age of 15, it reaches the size of 80-90 mm in a carapace width (CW), and weighs approximately 1.3 kg (Agriculture and Agri-Food Canada). The maximum size of the male snow crab is 178 mm CW, and it was registered in the Russian Far East (Grigoryeva, 2010). The body has a slightly rounded shape, and the crab has five pairs of legs.

Figure 1. Snow crab male and female. Resource: National Marine Fisheries Service, Alaska Fisheries Science Center.

1.1 Distribution

Snow crab is a stenothermal species and the normal temperature range for it is from -1 to 4 °C (Chabot *et al*, 2008). It can be found in waters with temperature of more than 7.2 °C, too. This species is distributed in the Atlantic Ocean from the Gulf of Maine in the south to Greenland in the north (Foyle *et al*, 1989). In addition, snow crab dwells in the northern part of the Pacific Ocean, mainly in the Sea of Okhotsk, in the Bering Sea and in the Sea of Japan (Orensanz *et al*, 2004). Snow crab can be found at depths of 60-400 m (Elner, 1995), but its usual distribution ranges between 200 and 300 m (Bakanev, 2010). In the northern part of the Pacific Ocean, the migrations of snow crab are of a short range, and are relatively independent of the season. Mature individuals do not perform notable spawning migrations (Grigoryeva, 2010). Dispersal of the species is made mainly by larval drift. Possible reason of the snow crab migration might be its preference of colder water (Kruse *et al*, 1999).

1.2 Reproduction

The reproduction season begins approximately in early spring. For more than half of the year males are separated from females. Usually males stay on muddy bottoms of deep waters, while females dwell on rock bedding and sand-pebble round-stone bottom (Pavlov, 2006). The rest of the year males and females stay together on the muddy bottoms.

Females are able to carry from 6,000 to 140,000 eggs for up to two years, and after that the eggs are released into water. They are spread by currents and float for 2-8 months. During this time, larvae hatch out. The eggs drift until the carapace becomes 3 mm wide. After that, they settle on the sea bottom and live for the next seven to 15 years (NOAA Fisheries Service, 2010).

1.2 Moulting and shell condition

Snow crab undergoes a number of moults while it grows. During moulting crab gets a new shell, and it takes 8-10 months for it to become hard. At this stage, the individual is called "white crab", or a soft-shell crab. During this period, snow crab is an easy prey. As for the commercial value, the species does not present any marketable weight (Rugolo *et al*, 2001).

All crabs can be divided into several groups according to the shell condition. These groups are organised mainly due to the colour fading of the exo-skeleton. The following categories are:

- *Moulting* (the species is in the process of moulting or will be in this process in few days);

- *Soft-shell* (the species has moulted in a couple of weeks and more, this stage is presented by a soft carapace);

- *New hard-shell* (the species has already been in the moulting process for about one year, the carapace has become hard);

- *Old-shell* (more than likely that the species has not been in the moulting process for the previous year, the carapace might get the colour which is different from that one of the previous stage);

- *Very old-shell* (the species was in the moulting process for more than one year ago, although it is not precisely defined; down sides of limbs are discoloured to yellow; the significant scratches and speckles appear; spines and claws become very rubbed; encrusting species are constantly located on the surface and, as a rule, they are numerous);

- *Very, very old-shell* (hard to define when the previous moulting process has been done; shells are widely marked with spots and often with a great number of encrusting organisms) (Rugolo *et al*, 2001).

1.3 Feeding

In every life-stage, snow crab feeds differently. In a larval stage, it feeds on phytoplankton. Later, as juveniles and adults they become generalists, feeding on gastropods, bivalves, shrimps, polychaete worms and even snow crabs (Pinfold, 2006). There exist many reports about cannibalism. Such conclusions have been made due to observations of the snow crab stomachs for the presence of crab parts (Lovrich, 1997).

1.4 Predators

During the observation of the stock in Alaska in the period from 1974 until 1976, the fish stomachs were investigated. Thus, the scientists concluded that such kinds of fish as Pacific Cod (*Gadus macrocephalus*), Pacific Halibut (*Hippoglossus stenolepsis*) and Tom Cod (*Microgadus proximus*) feed on snow crab at its early stages when the carapace is soft and the individuals have an average size of 3.4 mm CW (Donaldson *et al*, 1981). Skates feed on snow crab, too, in its native areal (Jensen, no date). Snow crab does not have sharp horns on the carapace. That is why the predators – cod, gobies, halibut, pollack, easily follow juveniles (FAO, 2009).

1.5 Parasites

Snow crab is a flatworm's host. Scientific investigations found out that such kinds as *Ectocotyla hirudo* (Levinsen, 1879), *E. multitesticulata*, and P*eraclistus oophagus* parasitize the species most of all. In addition, barnacles, bryozoans and serpulidae worms present the epifauna on the carapace of the adult crabs (Jensen, no date).

2. Snow crab in the Barents Sea

In the past years, the commercial importance of this type of crab has grown. In the world market it competes with red king crab (*Paralithodes camtschaticus*) and blue king crab (*Paralithodes platypus*) (Selin, 2002; Perveeva, 2007). Snow crab was found in the late 1990s and presents a new species in the Barents Sea. At first, it was caught as a bycatch in shrimp and demersal fish harvesting. In addition, it was found in the process of trawl-acoustic surveys, which were performed by research vessels (Pavlov and Sokolov, 2003). According to Pavlov's study (2007), snow crabs are found in the northern part of the Kanin-Kolguev shallow waters, southern part of the Goose Bank, western part of the northern slope of the Goose Bank and northern part of the Novaya Zemlya shallow waters. Agnalt *et al* (2011) mark main areas of the snow crab abundance, which are presented in the Figure below.

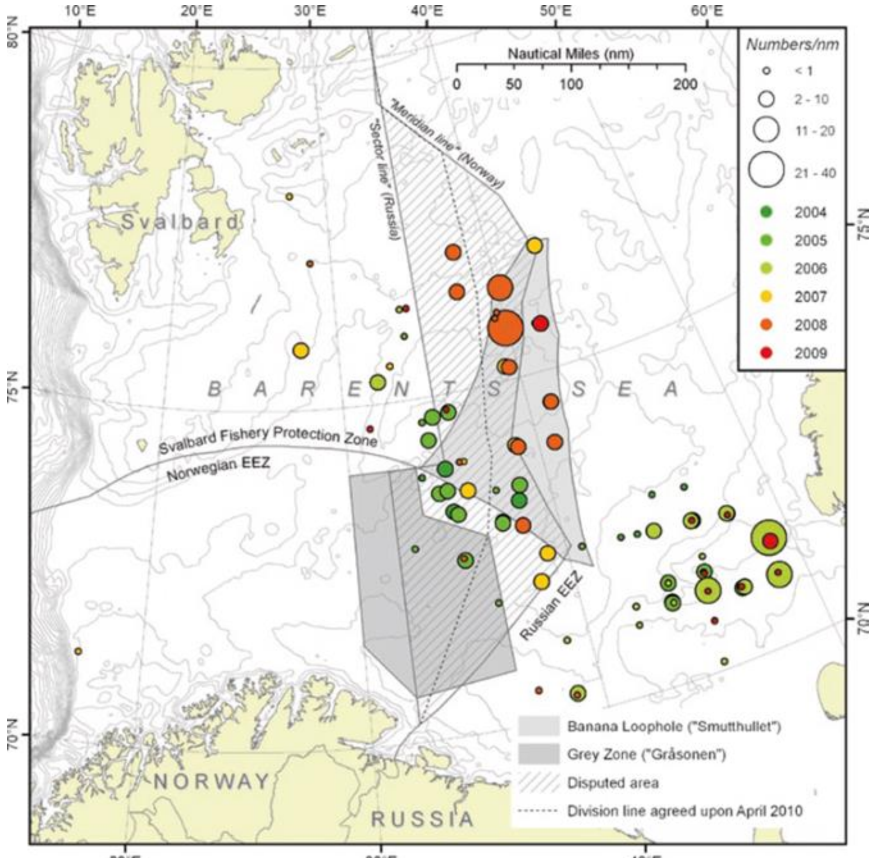

Figure 2. Abundance of snow crab (*Chionoecetes opilio*) in the Barents Sea estimated during the Norwegian bottom-trawl surveys 2004–2009 (Agnalt *et al*, 2011).

The smallest juvenile observed in the Barents Sea was 7 mm CW; it was found in 2004 in the east of the Barents Sea at a depth of 76 m. The biggest male was 166 mm CW, and it was found in 2005 at a depth of 200 m. As for the females, the biggest one was 76 mm, however, more than likely that it did not reach its maximum size (Pavlov and Sokolov, 2003). Most of females were caught in the Goose Bank and neighbouring zones. Since 2003, the females' distribution zone has broadened towards the north-west of the Barents Sea. All snow crab females were caught at the depth of 100-317 m, while the majority was found at depths of 201-250 m (Pavlov, 2005). During their exploration the PINRO scientists found out the proportion of males and females in the catches; it appeared to be 7.5:1. Such a low amount of females might be explained by their small size and their ability to burrow in the mud. That is why, females become invisible and unavailable to bottom trawls (Perveeva, 2009).

The PINRO scientists make their researches annually in the period from October to December. The snow crabs sampled are then analysed in order to obtain biological information. During routine scientific surveys in the Barents Sea, the following information is collected from the individuals sampled: the size in CW (mm), shell condition, gender, maturity, and state of the egg mass (colour) (Pavlov and Sokolov, 2003). Existing data allows to claim that snow crab found in the Barents Sea is alike the one from traditional grounds, although there is a lack of data about the species behaviour in the new environment.

3. Barents Sea

3.1 Location

The Barents Sea takes up the most northern position among all Arctic seas, which sweep the Russian coast. It is located between the northern coast of Europe and the island Vaigach, the Novaya Zemlya archipelago, the Frantz Josef Land, Spitsbergen, and the Bear Island. It is also connected to the warm Norwegian Sea and the cold Arctic Basin, as well as to the White and the Kara Seas (Eldholm and Talwani, 1977). The Barents Sea is a typical submerged margin sea, which is located completely on the shelf of the Arctic Ocean. The latter is more deep-dwelling within the Barents Sea area in comparison with other Arctic seas. The Barents Sea is 1405 sq. km in area (Frolov *et al*, 2008).

3.2 Depth and bottom characteristics

The average depth of the sea is 200 m. Most part of the sea has a depth range of 300-400 m (Elverhøi and Solheim, 1983). Coastal shallow waters with the depth less than 50 m occupy a significant area only in the southeastern and northwestern parts. Bottom configuration has one more property – it has a great roughness, and the depth ranges between 50 and 100 m. The southern part of the bottom has depths less than 200 m and it is distinguished by a flattened character. Abyssal depths are located in the western part of the sea (Vorren *et al*, 1989).

The geological history of the sea and hydrological elements form numerous small irregularities on the sea bottom (Gudlaugsson, 1993). Most part of the Barents Sea is covered with sandy silt. Coastal slopes, slopes of Murmanskaya and Rybachiya Banks, and Central highland are covered with silty sand (Eldholm and Ewing, 1971). In the southwestern part of the sea silt deposits occur (Solheim and Elverhøi, 1993). The latter is explained by weak dynamics of waters in this area and migration of fine materials by rivers and ice (Slagstad *et al*, 1990).

3.3 Climate and currents

The climate of the sea is polar marine; high air temperatures, mild winters and a great amount of precipitation introduce it (Hibler, 1979). One of the characteristics of the Barents Sea hydrology is its good mixing of waters. The seawaters are properly aerated; the oxygen concentration in the water column in the entire area is close to saturation (Frolov *et al*, 2008).

The current system in the Barents Sea combines into a quite complicated formation of surface and deep-sea currents. The Nordcape current with its numerous streams is the most significant in this system. Cold waters, which come from the Arctic Basin and the Kara Sea, influence this current system, too (Frolov *et al*, 2008), (Ingvaldsen *et al*, 2002).

3.4 Water temperature and salinity

The Barents Sea is considered as one of the Ice seas. ¾ of its surface is annually covered with the ice, but it never freezes up totally (Landvik *et al*, 1998; Sorteberg and Kvingedal, 2006). Atlantic waters prevent cooling of the surface up to the freezing point. Thus, this inflow explains the “warm” Barents Sea effect (Hamre, 1994; Frolov *et al*, 2008).

Table 1. Surface temperature in the Barents Sea (Dobrovolskii and Zalogin, 1982).

Area	Winter	Summer
South, south-west	4-5 °C	8-9 °C
Central	3-0 °C	3-5 °C
North, north-east	Negative, close to the freezing point within given salinity	Declines till negative point

As for the bottom temperatures, several characteristics influence temperature distribution in water column, such as winter cooling, bottom contour and ingress of the warm Atlantic waters (Ottersen and Stenseth, 2001). The south-west of the Barents Sea is subjected mostly to the influence of the Atlantic waters. In this area, the temperature goes down with the depth in a flowing manner and within small limits, at the same time staying positive down the seabed (Sakshaug, 1997). In summer the sea surface does not have a high temperature. It goes down rapidly up to the depth of 20-50 m and remains low (-1.5 °C). Within the depth of 50-100 m, a cold interfacial layer is presented. The temperature of the water column in winter is negative: -1 °C.

The Barents Sea salinity is defined by the intensity of water exchange with the surrounding basins. The Atlantic waters have a great influence on this process, as ⅔ of the basin has the salinity on the surface higher than 34 ‰. High salinity mostly occurs in the southwestern part of the sea. In all other areas of the basin, the salinity ranges between 32 and 34 ‰. The biggest volume of the freshened water is situated in the southeast of the sea, where the freshened waters of the White Sea are flowed (Sakshaug *et al*, 1994; Schauer and Fahrback, 1999). Northward and southward the salinity declines up to 34.5 ‰ due to the ice melt. As for the bottom salinity, in major areas of the Barents Sea it reaches 35.1 ‰ due to bottom contour characteristics (Swift *et al*, 1983).

4. King crab invasion in the Barents Sea

4.1 Introduction and distribution

King crab was introduced into the Barents Sea in the 1960s, where it successfully naturalized itself (Jørgensen and Nilssen, 2011). By the present times it has organised a self-replicating population in the basin from Lofoten Islands in the west to the Novaya Zemlya archipelago in the east (Gudimova, 2002), and off the coast of the Kolguev Island (Mikkelsen and Pedersen, 2012). At that time, this introduction was supposed to improve and develop the crab harvesting in the Northern Atlantic Ocean (Orlov and Ivanov, 1978).

According to the Convention of Biodiversity, any new species must be destroyed (Convention on Biological Diversity of 1992). At the same time, one might observe the alien behaviour and preserve the species for further investigations. There is a great amount of invasive species in the world, and as a rule, they harm native species, and a risk of balance destruction in the new environment appears (Alien species in Norway – with the Norwegian Black List 2012). It is a rare case of the invasion with the one relatively positive consequence. King crab in the Barents Sea naturalized itself rapidly; it’s advantage is that it helped to make a profit on this introduction.

In the main introduction period in 1961-1969, approximately 3,000 individuals were released into the Barents Sea at the age of 6-15, about 10,000 of juveniles and 1.6 million of larvae (Agnalt *et al*, 2011). The first adult king crab was caught in the Kola Bay in 1974. Starting in 1977 king crabs were sporadically caught by the fishermen off the Norwegian coast. Later, since 1992 numerous concentrations of crab have started to appear (Pavlova *et.al*, 2005).

4.2 Impacts of establishment and risks

The Murmansk Marine Biological Institute (MMBI) regularly assesses the impact of the king crab invasion. It is the coastal marine communities of the Barents Sea that are subject to higher risk (Matishov, 2008). There are two main groups of risks – ecological (consequences for the environment and its organisms, which traditionally inhabit it); and economical (consequences for traditional harvesting and mariculture). The appearance of king crab in the Barents Sea raises several issues. On the one hand, the species has a commercial value, and it is a new commodity in the region. Another positive aspect is the increase of biological resources of the sea, its biodiversity and productiveness (Gudimova, 2002). On the other hand, this species is more likely to compete with some target fish, and it may lead to decline in abundance of the latter (Falk-Petersen and Armstrong, 2013). At the same time, there might be a decrease in profit of the bottom fish harvesting (Pavlova *et al*, 2005). In addition, the introduction leads to an increase in competition among other types of aquatic organisms for food and breeding places, transformation of the environment itself, decline in biodiversity, and changes in trophic chains (Gudimova, 2002). An important issue is the risk of predation by crab and the introduction of new diseases.

King crab as well as bottom-feeding fish, consume benthos a lot. Here possible food competitors are mainly: the Haddock (*Melanogrammus aeglefinus*), the Long rough dab (*Hippoglossoides platessoides*), the Plaice (*Pleuronectes platessa*), and the Starry skate (*Raja radiate*). In the present times, king crab is able to present a serious competition with the bottom-feeding fish in the areas of the crab's maximum concentration. However, the total amount of benthos consumed by the king crab population in 2006 does not exceed the consumption by the dominant bottom-feeding fish species in the Russian Barents Sea (Bakanev, 2009). At the same time, in the Varangerfjord (Northern Norway) the king crab abundance is high. Moreover, red king crab is considered as an alien species in Norway (Elven *et al*, 2012). It was found there, that the decrease of bottom organisms such as mud sea star, brittle star, bivalves and bristle worms coincided in time with the increase of crab number. Thereby, scientists concluded that benthos decline was related to consumption by red king crab (Oug and Sundet, 2008).

During various investigations of king crabs for parasites occurrence, some species as Nematodes, thorny-headed worms and fish leech were found. After investigations, the conclusion was made that no parasites invaded when the red king crab was introduced.

4.3 Harvesting

In the Barents Sea, the Norwegian and Russian scientists investigate the king crab stock. Therefore, these countries perform the most part of all research activities. The Joint Norwegian-Russian Commission performs the management and establishes the TAC, which is shared between Norway and Russia (Jørgensen *et.al*, 2005). This Commission provides the protection of the marine environment. The main idea of the Joint Norwegian-Russian Fisheries Commission is to investigate the Barents Sea environment. It is important to establish the joint work as cooperation leads to positive results in any kind of industry especially if it concerns the fisheries of invasive species.

According to the decision of the 22nd Collaborative Russian-Norwegian Fisheries Commission, the experimental harvesting of the king crab in the Barents Sea started in 1994. In 2004, industrial fishing began in the Russian waters. The history of the Russian harvesting of the crab in the Barents Sea can be divided into three main periods:

1994 – 1997: the initial period;

1998 – 2003: the transition period;

From 2004: the industrial fishing period.

In the initial period, the harvesting took place with the help of Japanese conical pots and bottom trawls. The fishing was held within 4 months – from September to December. Few vessels were used at that time, including coastal motor boats and medium fishing trawlers. The annual yield did not exceed 20,000 crabs. The main harvest area was in the Western Murman, which extended from the Varangerfjord to the Kildinskaya Bank.

The usage of American pots-processors began in 1998. The harvesting was held primarily with the Japanese conical pots and American rectangular pots. The annual catch rose up from 20,000 in 1998 to 60,000 crabs in 2003. The fishing area expanded towards the Eastern Murman basin (Eastern and Western Coasts, Murmansk shallow waters). This fact was given a bad press, as the Russian media worried about the uncontrolled fishing of king crab in the Barents Sea. According to the oral reports of the observers, the amount of unaccounted crab was about 50-80 % of the unloaded cargo on the vessels.

Since 2002, the king crab fishery in the Barents Sea has become commercial; it targets to harvest crab at a maximum economic yield. In 2004, the Norwegian authorities implemented an open access fishery in order to regulate the stock and control the abundance of the species (Falk-Petersen *et al*, 2011). Commercial king crab fisheries are performed in a particular territory, while the open fishing is held outside this area in order to control the species distribution.

The industrial fishing period was characterised by a significant increase of the industrial effort in 2005-2006. The number of vessels was up by three units. The main basin of the harvest is Eastern Murman. Measured actual catch was around 3-5 millions of crabs during these two years.

Thus, there is a need in suitable and adequate data of the aliens' migrations. Information about recruitment of the invasive species should be provided, too. These actions are aimed at predictions of the immigrant behaviour (Science Poles, 2013).

5. Snow crab fisheries in Canada and Alaska

5.1 Snow crab fisheries in Canada

5.1.1 Distribution of snow crab in the Canadian waters

In Canada snow crab is caught in the Gulf of Saint Lawrence, Newfoundland and Labrador (Moriyasu and Lanteigne, 1998); it is also fished on the Scotian Shelf (RSCFO, 2011), and off the Cape Breton, too (Tremblay, 1997). Main areas of its distribution are shown in the figure below.

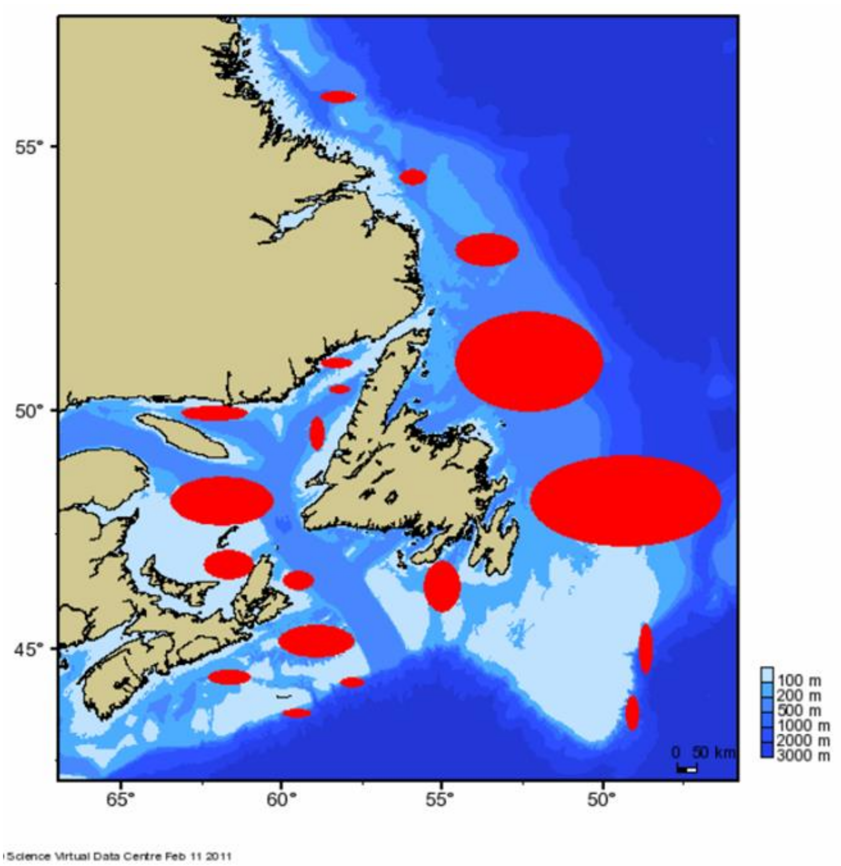

Figure 3. Distribution of the snow crab stocks in Atlantic Canada. The map features the ocean depths. Circles define main fishing areas: the Labrador Shelf, the Gulf of St. Lawrence, on the Scotian Shelf, off Newfoundland, around Cape Breton Island and the Estuary. Data of 2011. Resource: Fisheries and Oceans Canada, 2013.

Data on snow crab landings in Canada provided by the DFO is presented in the table below.

Table 2. Snow crab fisheries in Atlantic Canada and Quebec in the period of 2003-2009. Landings per Region of the Department of Fisheries and Oceans (DFO) and per Year.

DFO Region	2003	2004	2005	2006	2007	2008	2009
	(metric tonnes)						
Maritimes	10.779	9.924	8.149	5.343	5.396	8.869	11.219
Gulf	15.158	22.485	27.023	21.531	19.932	18.527	16.871
Quebec	12.606	15.289	16.219	15.270	14.736	13.463	15.018
Newfoundland & Labrador	58.355	55.656	43.957	47.238	50.208	52.748	53.446
Total	96.898	103.354	95.348	89.382	90.272	93.607	96.554

Source: DFO Statistics (Commercial Fisheries, Seafisheries, Landings; and Year-End Quota Report for 2009).

The table below identifies landings of snow crab in Canada in the period of 1990-2008, and the price dynamics. Source: Government of Canada.

Landings, Landed Value & Price

Year	Landings (MT)	Landed Value ($M 000's)	Average Landed Price	
			$/kgm	$/lb
1990	11,053	$13,159	$1.19	$0.54
1991	16,276	$19,989	$1.23	$0.56
1992	16,441	$12,973	$0.79	$0.36
1993	22,922	$31,729	$1.38	$0.63
1994	27,922	$87,197	$3.12	$1.42
1995	32,343	$176,213	$5.45	$2.47
1996	37,970	$96,832	$2.55	$1.16
1997	45,746	$91,809	$2.01	$0.91
1998	52,672	$102,214	$1.94	$0.88
1999	69,131	$236,234	$3.42	$1.55
2000	55,434	$267,639	$4.83	$2.19
2001	56,721	$218,831	$3.86	$1.75
2002	59,417	$229,240	$3.86	$1.75
2003	58,356	$263,583	$4.52	$2.05
2004	55,675	$300,670	$5.40	$2.45
2005	43,957	$140,254	$3.19	$1.45
2006	47,238	$100,683	$2.13	$0.97
2007	50,208	$177,456	$3.53	$1.60
2008	52,746	$179,503	$3.40	$1.54

5.1.2 History of the Canadian snow crab harvesting

The snow crab harvesting started in the 1960s in the Gulf of Saint Lawrence. By the 1980s, it increased, and in 1982 the highest level of the caught crab was reached – 31,500 t (Hebert *et al*, 2000). The first landings took place as bycatches in gillnets. From the beginning the management system was directed to the sustainable fisheries, although in 1987 there was a sharp decline in the crab abundance. After two years, the fishery was closed for a short period due to a high number of white crabs (Comeau *et al*, 1998). Annual trawl surveys started from the 1950s on the Scotian Shelf. Normal recordings of the snow crab catches began only in 1980 (Tremblay, 1997). The species population has been regularly observed since 1988; for this purpose a beam-trawl has been used (Sainte-Marie *et al*, 1996). The main steps of the Canadian snow crab fishery are given in the table below.

Table 3. Main periods of establishment of the Canadian snow crab fishery.

Steps	Period	What happened
I	1965 – 1975	Initial exploration
II	Until 1982	Sharp rise in landings
III	1983 – 1986	Period of increased harvests
IV	1987 – 1990	Collapse in the fishery
V	Until 1994	Great amount of landings

In the southern Gulf of St. Lawrence all landings are presented on the chart below. Numbers identify the particular areas of fisheries. They are shown in the figure 4.

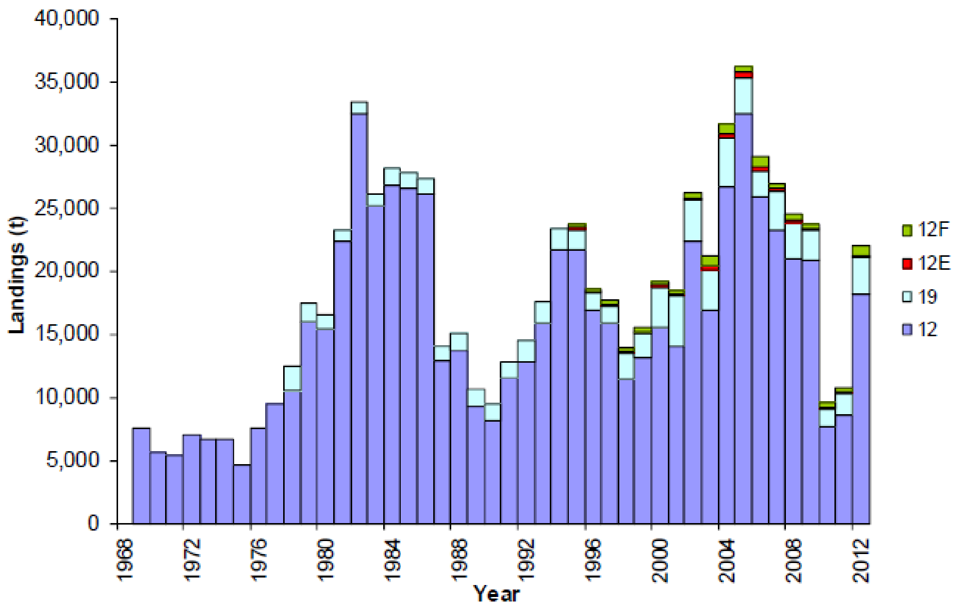

Figure 4. Chart of the snow crab landings in the Gulf of St. Lawrence. Source: Assessment of snow crab in the southern gulf of St. Lawrence (areas 12, 19, 12e and 12f) and advice for the 2013 fishery.

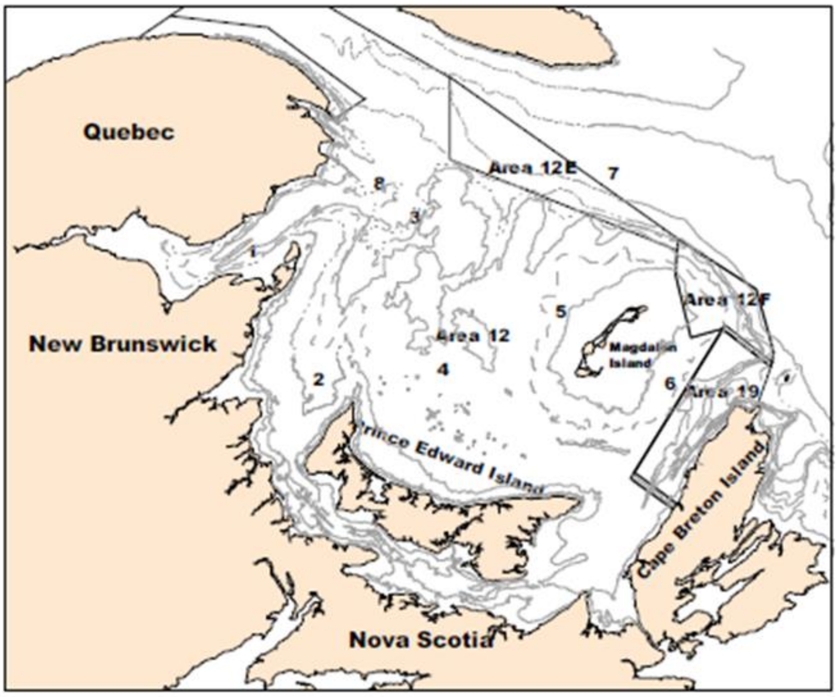

Figure 5. Southern Gulf of St. Lawrence with crab fishing areas. The numbers identify the zones: 1-Chaleur Bay, 2-Shediac Valley, 3-Orphan Bank, 4-Bradelle Bank, 5-Magdalen Channel, 6-Cape Breton Corridor, 7-Laurentian Channel, 8-American Bank. Source: Assessment of snow crab in the southern gulf of St. Lawrence (areas 12, 19, 12e and 12f) and advice for the 2013 fishery.

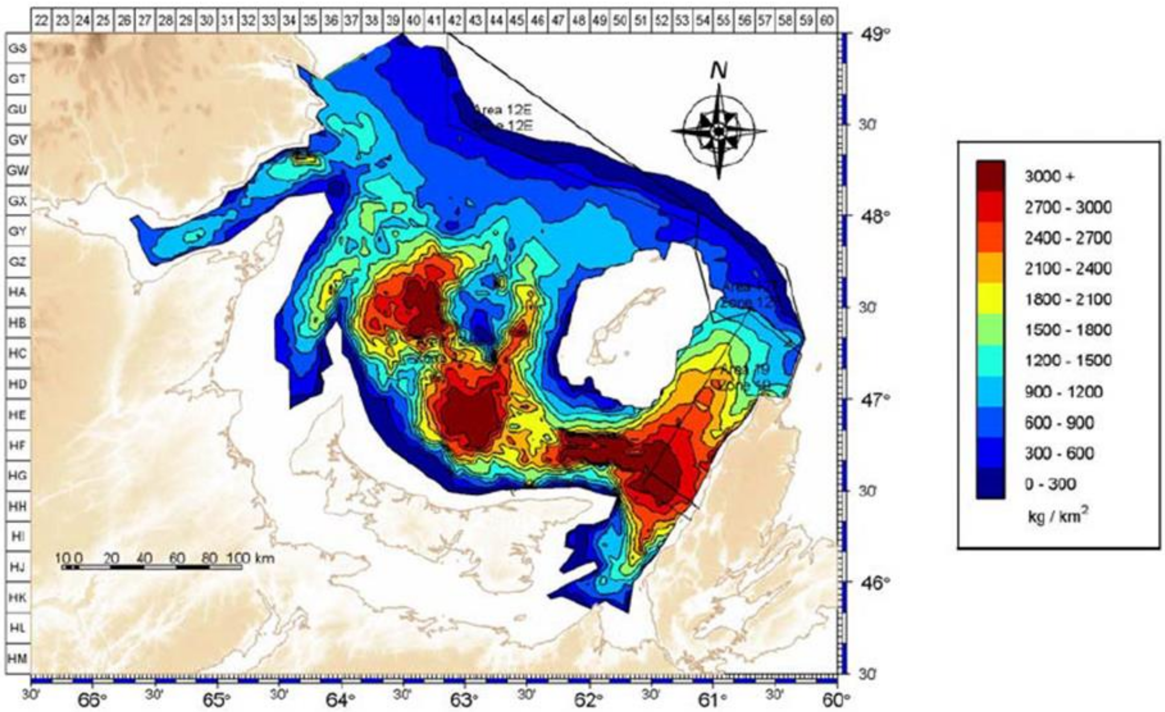

Figure 6. Density (kg per sq.km) of the adult snow crab with CW > 95 mm. Southern Gulf of St. Lawrence in 2012. Source: Assessment of snow crab in the southern gulf of St. Lawrence (areas 12, 19, 12e and 12f) and advice for the 2013 fishery.

5.1.3 Fishing process

The fishing process is held with the use of baited crab traps – pyramidal, rectangular and conical. Herring, squid or mackerel are used as baits. Fishermen prefer using the conical traps as they are the most efficient in catches and easy in transportation (Hebert *et al*, 2000). Wood and steel are used in their construction (Tremblay, 1997).

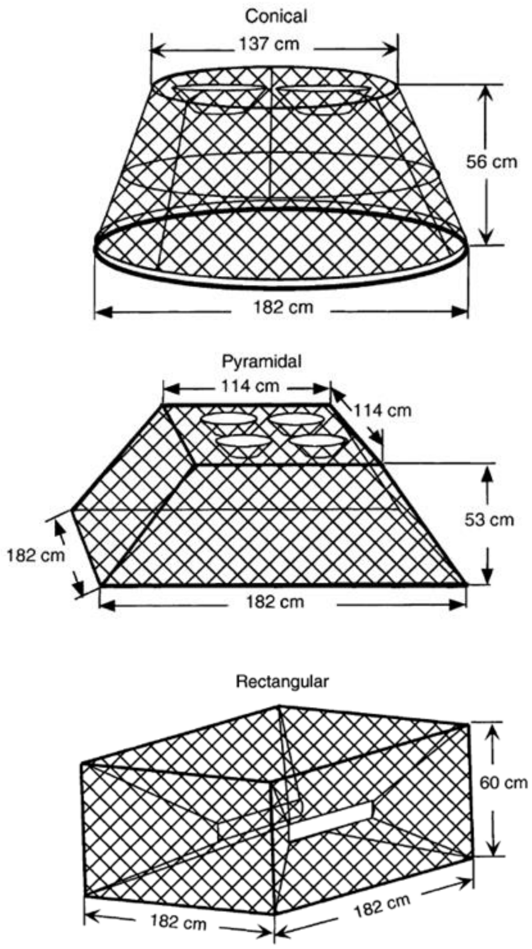

Figure 7. Three types of traps: conical, pyramidal, and rectangular (Hebert *et al*, 2001).

As a rule, the fishing season begins at the end of April or at the beginning of May, and lasts for about three months (Hebert *et al*, 2000), but it depends on a particular territory. However, it does not mean that the harvesting lasts through the whole period. In some areas, the fishing period is quite short; moreover, a lot depends on weather conditions (Pinfold, 2006).

5.1.4 Management system and restrictions

From the history of Canadian restrictions, the first management measure appeared in 1978. At that time, there was a necessity to limit the fishing effort. From the beginning of the harvesting in eastern Canada, the restrictions were introduced in order to preserve the stock (Sainte-Marie *et al*, 1996). Since the early 1960s, some of these measures have become main conservation methods (Alunno-Bruscia and Sainte-Marie, 1998):

- A minimum legal size of 95 mm in carapace width (CW);

- Forbiddance of fishing females;
- Total allowable catch (TAC);
- A limited number of “white crabs” in the harvest, or soft-shelled Protocols (Siddeek *et al*, 2009; DFO, 2011). The soft-shelled protocol was initiated in 2004. Its activity results in closure of particular territory where the number of white crabs exceeds 20 % of all adult crabs caught during the fishing. Every fishery district is able to regulate the percentage of the white crabs in the catch, so in 2009 there was implemented a 15 % limit in 3L (Orphan Bank) snow crab Fishery.

Over time, some more important factors have been introduced into the Canadian fisheries management:

- Regulating the license number, traps number and the mesh size, and fishing seasons;
- Quotas.

As for the management system in general, it includes several important conditions for the efficient crab fishery (Atlantic Canada Export, 2011).

Planning

Science as an important source of making a decision

Regulating of the environmental effects

Implementation of the restrictions and rules

Control of the results

5.2 Snow crab fisheries in Alaska

5.2.1 Snow crab distribution

In the Eastern Bering Sea snow crab is distributed mainly by the St. Matthew and Pribilof Islands (Ernst *et al*, 2005). Here the species is found off the coastal waters in the north. Snow crab is distributed towards the deep waters with a high abundance, as the temperature decreases on the bottom and the inflow of fresh water is weak (Orensanz *et al*, 1998). The basic current that flows from the Gulf of Alaska to Unimak Pass, is the Alaskan Coastal Current, and it goes by the Aleutian Islands. This current creates special conditions for the snow crab larvae. As water density and salinity change in the period of active snow melting, it possibly effects the larvae distribution (Ernst *et al*, 2005).

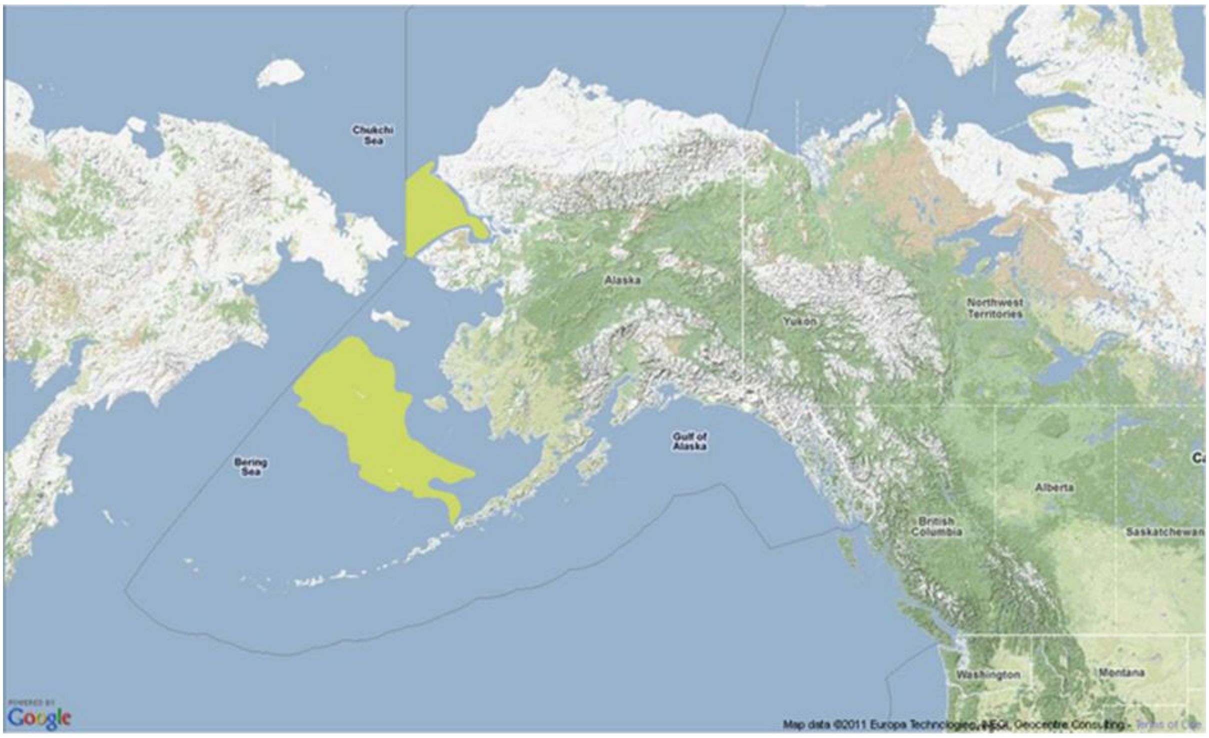

Figure 8. Snow crab distribution in Alaska. The species is found mainly in the Bering Sea, the Beaufort Sea, and the Chukchi Sea. The mentioned area is accessed by the USA. Resource: NOAA FishWatch, US Seafood facts.

5.2.2 History of the snow crab fishery

In the Alaska Peninsula, the snow crab fishery started in 1967. In the beginning the industry was a small-scale fishery oriented to the domestic consumption. The first areas of the harvesting were Kodiak and the southern part of the Alaska Peninsula. It is known that since 1978 the stock investigation has been held with the specially designed trawls. Their sizes allow surveying a greater territory than before. Thus, the data becomes more complete and the stock is represented better (Kruse *et al*, 1999). The biggest catches occurred in Kodiak in the period from 1969 to 1994. At the beginning of the 1980s, the fishing effort was at its highest point (Orensanz *et al*, 1998).

The US fishermen have used crab pots as fishing gears for snow crab from the beginning of the industry. Initially the fishery was very active and effortful, thus by the 1990s the catches had reached a high level, but later, in the 2000s the fishery collapsed. A graph of snow crab catches in Alaska is presented below.

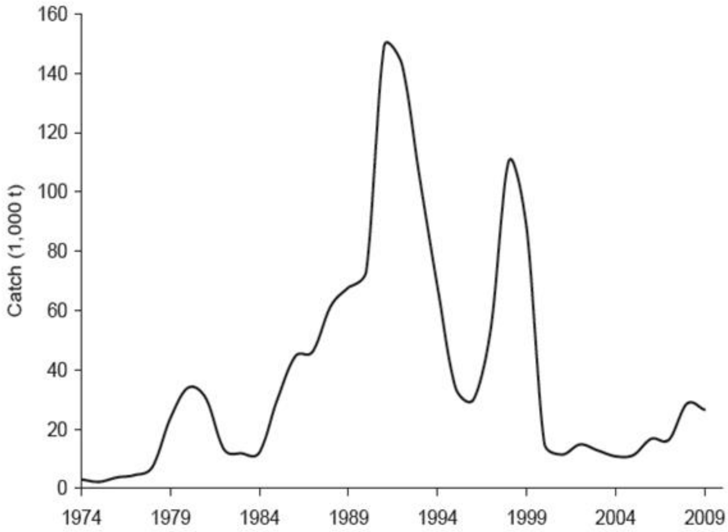

Figure 9. Catch (in tonnes) per year in Alaska snow crab fishery. Resource: Alaska Fisheries Science Center.

For a long time snow crab catches were not taken into account as they represented bycatches in the Tanner crab (*Chionoecetes bairdi*) harvesting. This delay of the scientific information influenced future fisheries. Due to lack of information about landing statistics of snow crab, no market models were created which could be considered important (Greenberg *et al*, 1995).

The Alaskan scientists control the snow crab stock paying much attention to the recruitment status. In this case, they mainly use reproductive properties of the snow crab females, estimating the clutch size and its changes with the time (Orensanz *et al*, 1998).

Depending on a type and goals of research, scientists collect data by trawling; sometimes scuba divers participate (Donaldson *et al*, 1981). In order to define the stock status and its abundance scientists use an area-swept method annually.

While the fisheries managers try to sustain the industry contacting with the science and controlling the effort, the harvesters follow their own goal of reaching a quota size as soon as possible (Paulin, 2012). The restrictions force them to return all caught females into the sea. Unfortunately, not every fisherman pays attention to the catches and sorts males from females. Here a human factor exists and it influences the fishery. It is necessary to regulate natural resources, but at the same time, harvesters need a strict control, too (ADFG, Commercial Fisheries).

5.2.3 Fishing process

In Alaska, harvesters use baited crab pots in the snow crab fishing. The bottom areas where snow crab dwells are of a soft structure. As muddy and silty sediments are hard to destroy or damage, crab pots are preferable in this industry, in comparison with trawls. However, there is a risk of getting a bycatch when using crab pots. Crabs of inappropriate size or non-targeted species may be caught accidentally. In order to prevent bycatches, managers force the harvesters to install different kinds of gadgets, such as escape panels or rings on the pots (NPFMC, 2011; SeaFoodSource, 2012). As for the ghost fishing, which also occurs, the Alaska Bering Sea Crabbers suppose they have solved this problem. The fishermen have to use a special cord which is destroyed in due course if the pot is left in the sea. In this case, the species, which are accidentally caught, are able to escape unharmed (IntraFish, 2012).

Snow crab managers in Alaska pay much attention to the commercial value of the product. A high quality of the snow crabmeat is possible if appropriate conditions of delivery are applied. It is provided with the specially equipped vessels. In order to keep the crabs fresh, these vessels use a system of a salt-water circulation. In addition, tanks with ice allow to preserve a good state and quality of the harvest during long trips before the product reaches the market (Pinfold, 2006).

5.2.4 Management system

There are many management programs in the Alaskan management system, directed to different sides of the fisheries industry. *The Sustainable Fisheries Division* (SFD) defines goals of *the North Pacific Fishery Management Council*. Together with *the NOAA Fisheries* and *the State of Alaska*, they develop fisheries from the management side, creating programs for collecting information. The above-mentioned programs are coordinated with *the Magnuson-Stevens Act* and some other laws (NMFS).

National Marine Fisheries Service (NMFS) is an organisation, which provides data on the snow crab population. This data is used in a "length-based stock assessment model" (Alaska Fisheries Science Center). This model was established in order to define the stock state and its abundance. The latter is estimated by NMFS in cooperation with the *Alaska Department of Fish and Game* (ADFG), which uses data for setting a maximum level of fishing and publishes information after collecting it (Orensanz *et al*, 1998; Gavel et al., 2006). In addition, the ADFG controls management regimes and preservation system (IntraFish, 2012).

Fisheries Management Plan (FMP) provides various restrictions, such as minimum size limits, closed seasons and gender restrictions. However, it envisages the opportunity of experimental catching of the females, when their abundance is definitely available (FMP for BSAI King and Tanner Crabs, 2011). According to the Magnuson-Stevens Act, if snow crab is overfished the FMP should provide a rebuilding plan, oriented to the preservation of the stock and its recover (FMP for BSAI King and Tanner Crabs, 2011).

5.2.5 Programs

In 2005, *the Crab Rationalisation Program* (CRP) was created and introduced as a resolution to some specific issues, such as environmental and economic questions, and secure fishing. Under this program, the system of *Individual Fishing Quotas* (IFQ) has started its work (Alaska Fisheries Science Center). The CRP contains a *Community Development Quota* (CDQ), and the latter allows communities to follow their interests by getting 10 % of the harvested snow crab (Alaska Snow Crab, 2012). This program shares the harvest among 65 agricultural groups from the Western part of Alaska, and the list includes Native Alaskans (Fina, 2005). In addition, the CDQ provides an economic development, decrease in poverty, and gives social welfares to the habitants (NOAA Fisheries, CDQ). For example, for 2013-

2014 snow crab fishery in the Bering Sea District is 53.983 million pounds, while the IFQ is 48,584,700 pounds, and CDQ is 5,398,300 pounds (Fitch, 2013).

In order to control and protect the processors investments into the fishery, a special *Individual Processing Quota* (IPQ) has been implemented. It provides 10 % of the catch into the processing sector. When the overcapacity occurs, the economists advice methods of decreasing the effort, such as IFQ or *Individual Transferable Quota* (ITQ) (ADFG, Commercial Fisheries).

A *License Limitation Program* (LLP) regulates crab fisheries in the USA. The licenses are distributed among participants according to their historical involvement into the fishing process. *Vessel Monitoring System* (VMS) controls and inspects a fishing vessel. It monitors the intensity of the fishing process, its direction and duration (Mills *et al*, 2007). When the vessel owner is not able to control the ship, the VMS performs inspection and reports corresponding information about the vessel's state (Patent #US6687583). In addition, all fishermen should be licensed, as well as their vessels (Barnard and Burt, 2007; NOAA Fisheries, VMS, 2010).

5.3 Snow crab harvesting in Russia (Far East).

5.3.1 History

In Russia, the snow crab fishery started in 1985 off the coast of Sakhalin. In the Kamchatka waters, first catches took place earlier – in 1973 (Baharev and Krasnikov, 2003). Within the period of 1992-1996, the snow crab catches reached their maximum rates. In 1998-2001, the harvesting is characterised by stable landings. However, by 2002-2003 a sharp decline in crab catches occurred.

The decline in snow crab abundance led to the fisheries closure. Decrease in population is connected with snow crab exploitation during last 20 years. In the period of intensive harvesting in 1988-2005, the commercial stock declined. At the same time, biological characteristics of snow crab worsened, such as the average size and amount of matured individuals in traps. The increased poaching during a long period and illegal fishing are supposed to be the main reasons. Nevertheless, the period of 2005-2009 was characterised by positive dynamics in the fisheries and increase in catches (Badmakhalgaev, 2012).

5.3.2 Problems

One of the main problems in the Russian Far-Eastern fisheries is a lack of fishing vessels and expiration of their working period. Another problem is the above-mentioned poaching and illegal fishing. The absence or lack of licenses for acceptance and transporting of the catches has a negative influence on the fisheries. The existing control over vessels is not enough. Scientific research is almost absent due to financial strain (Larichev, 2009). The regulatory system has been constantly changed and numerous loopholes and contradictions can be found there (Rodina, 2004). There is a great loss of crab traps during the harvest process with obvious economic consequences (Baharev, 2003). Another concern is a possible ghost fishing. The utilisation of escape windows in the traps, which is mandatory to the crab traps in Alaska, Canada and Russia, does not seem to solve the problem totally.

Discussion

Snow crab biology

Snow crab biology was studied in order to learn the species behavioural characteristics, its migration and distribution properties. Snow crab is an important bio resource, and it is necessary to have an appropriate knowledge about the species, as its biology has a direct connection to the sustainable industry. The discussion about the dispersal and establishment of snow crab is still greatly hampered by the lack of biological data on snow crab in the Barents Sea (Dahle *et al*, 2012). We know much about the species' behaviour and ecology in the native areas, but too little about the snow crab's behaviour in the new environment. First of all, it concerns the diet and migrations. It is necessary to perform more scientific surveys in order to get additional information. Knowledge of the biological data, such as reproductive potential plays a significant role in management planning of the sustainable fisheries.

The Barents Sea

The Barents Sea has a lot in common with the native area of snow crab in the Northwestern Atlantic and Northern Pacific Oceans. It allows to explain a wide and fast distribution of snow crab in the Barents Sea basin and its rapid acclimatisation. Basic characteristics of the Barents Sea and traditional snow crab habitats are compared in the table below.

Table 4. Comparison of snow crab habitats.

Parameter	Barents Sea	Native habitat of snow crab
Temperature (bottom)	-1.5 °C	-1…4 °C; up to 7.2 °C
Salinity	32-34 ‰; bottom – 35.1‰	32-34 ‰
Depth	Average 200 m; mostly 300-400 m	200-300 m, can be found at 60-400 m
Bottom type	Sandy silt, silty sand, silt deposits	Muddy bottoms; rock beddings, sand-pebble round-stone bottom

King crab in the Barents Sea

The king crab introduction in the Barents Sea was aimed at developing of the crab fisheries in the north-eastern part of the Atlantic Ocean (Jensen, no date). Estimating of this issue was oriented to investigation of the state activities forwarded to the new species.

The Convention on Biological Diversity (CBD) of 1992 provided a special rule for the immigrants – Article 8 In-situ Conservation. The CBD is an international agreement and its goals are to preserve biological diversity and perform a sustainable usage of its components.

States, which have signed the Convention, are to follow its requirements (Convention on Biological Diversity, 1992).

A parallel case study of a well regulated fishery targeting an exotic species is that of the red king crab. Although red king crab is an alien species, it represents a commercially valuable marine species. That is why the Norwegian government set a limited territory of the king crab fishery from the North Cape to the Russian border. At the same time the Norwegian authorities suppose the species abundance should be decreased, and its distribution should be regulated (Sundet, 2008; Elven *et al*, 2012). These are measures aimed at the preservation of the native communities. According to Hjelset (2012), in Norway, the regulations concerning red king crab are performed in accordance with a White Paper. The Norwegian Parliament created this document. An area where the tightly regulated fishery takes place is controlled by quotas; regulations of the outside territory are oriented to preservation of the minimum number of individuals so that the stock is not able to disperse and to harm native species.

The Norwegian scientists have found out a great decrease in native bottom organisms with the king crab appearance in the Barents Sea. Although there is no direct evidence of the crab harm, the species is considered as an alien with a severe impact on the environment (Alien species in Norway – with the Norwegian Black List 2012). Thus, more research on the distribution potential and ecological influence is expected (Elven *et al*, 2012). As the red king crab invasion has both negative and positive outcomes, it is necessary to develop the positive consequences and hedge the negative ones (Gudimova, 2002). Thus, in the Norwegian waters harvesting follows two approaches – to fish in a particular territory and thus maintain sustainable fisheries, and provide an open fishing in order to limit the spreading area of the species (Hjelset, 2009).

If talking about invasive species such as snow crab in the Barents Sea ecosystem, it should be destroyed according to the CBD. However, in the interview to a newspaper, Russian scientists argue that such measures would be useless owing to the wide distribution of snow crab in the Barents Sea basin (The Fishermen Newspaper, 2009). My personal view against this background is that the best way to control the spread of the snow crab even further is to open a well regulated fishery.

Management measures and restrictions

Observation of the management process in Alaska and Canada gives an example of well-organised industry and provides an opportunity to analyse the regulatory system. One sees good and bad results in their experiences. When collapse occurs, the management plan implements activities which help to recover the stock. Thus, main aims of any type of fisheries are achieved – to preserve the stock and sustain the industry. I have found interesting methods of obtaining these results. The usage of escape mechanisms, for instance, is a good way to avoid the ghost fishing.

The sustainable snow crab fishery is provided with a well-organised management regime, where appropriate (necessary) restrictions and measures are applied.

Probably almost every fishery starts with the by-catches, and so the snow crab fisheries in Alaska and Canada did. Not long after the beginning of exploitation, harvesters set the main aims of the sustainable fisheries.

The following goals were set, which were considered the most important and basic:

- To sustain the spawning stock and its recruitment (preservation of females and juveniles);
- To get crabs of a high commercial quality (high meat content).

Apart from goals and strict planning, a number of restrictions was implemented. They are summarised in the table below.

Table 5. Comparison of management restrictions in similar crab fisheries

Regulations	Alaska	Canada	Russia (king crab in the Barents Sea)	Russian snow crab fishery (Far East)
Size	78 mm (preferable 95>)	95 mm (preferable 101>)	V	V
Gender	V	V	V	V
TAC	V	V	V	V
Pots only	V	V	V	V
Season	V	V	V	V
Quotas	V	V	V	V
License number	V	V		
Limited traps number	V	V		
Min number of “white crabs”	V	20 % of the catch		
Fishing areas	V	V		V
Escape mechanisms	V	V		V
VMS	V	V	V	V

Above all, three basic measures are used in the mentioned fisheries: minimum carapace size, restriction on capturing males and closed seasons during moulting. These factors are common in the harvesting of any type of crab. Other limitations such as regulation of traps' number are aimed at control of the fishing effort. Measures, which include TAC and mesh trap size, are mandatory when it is necessary to regulate the harvest and avoid the overfishing.

An important contribution to the maintenance of good recruitment levels to the crab stock is avoidance of fishing during mating and moulting periods. Harvesting should be strictly held within appropriate and approved time periods. If the start of the season is delayed, there is a risk of catching a great amount of soft-shelled crabs.

To orient the managers of the new resource it is useful to illustrate the normal trends observed in a non-regulated fishery for snow crab. Examples of historical trends and control regulations are available from the histories of the Alaskan, Canadian and Russian fisheries managements. The development of the industry in both Alaska and in Canada had similarities. Some analogy appears in comparing the above-mentioned fisheries with the Russian king crab fishery in the Far East. For convenience, these time lines are tabulated.

Table 6. Main periods in snow crab harvesting in Canada, Alaska and Russia.

Period	Canada	Alaska	Russia
I	Exploration	Exploration	Exploration
II	Sharp rise in landings	Sharp rise in landings	Sharp rise in landings
III	Stable high catches	Stable high catches	Stable landings
IV	Collapse	Periodicity in landings	Sharp decline
V	High landings	Collapse	Risk of collapse => Closure of the fishery

The first period is characterised by the start of the exploration. As for the second period, scientists are inclined to believe that the first sharp increase in fishing is connected with a great abundance of snow crab. To avoid such situations controlling of the fishing effort is an appropriate measure. The third period shows increased harvests which lead to overfishing. It is followed by collapse in the Canadian fisheries. In Alaska the fourth period is characterised by periodicity in landings, i.e. the decrease in landing follows the increase, and this process repeats from time to time. In Russia sharp decline in crab catches occurred in the fourth period. The last period slightly differs in these fisheries. In Canada, high landings may be explained by rapid recovery of the stock, while the Alaska collapse is connected with the high intensity of harvesting. The Russian fishery is characterised by the risk of collapse due to low snow crab abundance and worsened biological characteristics. However, nowadays the fishery is characterised by quite stable landings (Duplyakov, 2013).

Russian snow crab fishery in the Far East

It is impossible to avoid the Russian experience in the snow crab fisheries. Although this experience seems to be relatively insignificant in comparison with the Alaskan and Canadian ones, it helps to estimate the current situation of the Russian fisheries. If Alaskan and Canadian experience was studied in order to learn about strong sides and ways of development of the industry, then the Russian one provides knowledge about the weak sides. One of the main negative moments in the Russian snow crab fisheries is a lack of the governmental support, which includes low financial investments; also, there is a lack of appropriate conditions for the maintenance of the industry. At the same time, I would like to notice that this situation changes gradually.

In the Far East in 2011 the results of snow crab catches showed, that 80 % of the TAC was exploited, and the quota exploitation counted 71.48 %. In 2012, the TAC decreased and the catches were 96.57 % of the TAC. At the same time quota increased and it was exploited by 89.03 %. Some insignificant declines in the total catches of 2012 in comparison with 2011 occurred due to a decrease of the TAC. However, in his interview, Aleksandr Duplyakov – a president of the Association of the Far Eastern crabbers, claims that there is a relatively positive dynamics in the present catches of snow crab in the Far Eastern Basin (FishNews, 2013).

Recommendations for the Russian fisheries

Effort control is one of the most difficult and important tasks in the fisheries management. To control the effort means to forbid some actions of the fishing companies or reallocate quotas among them. Various limitations are considered as measures of effort control, such as limitation of the vessels' number in the fishery, reduction of the fishing season.

The Russian fisheries encounter many problems, and one of them is the above-mentioned weak control over fishing vessels. The system, which controls vessels' position, is a way to control the fishing effort. The limitation of the fishing days might be an effective management measure aimed at controlling of vessels' position in the sea. As poaching is widely spread in the Russian fisheries, the actions aimed at combating illegal catches should be applied. The limitation of the number of vessels is connected with illegal fishing. As a rule, unaccounted harvesting is carried out by vessels that have official fishing permits and exceed their volumes of production (Larichev, 2009). Under-reporting of the number of the processed pots per day is one of the most harmful forms of poaching. It makes difficult to define the level of the crab exploitation. Moreover, the lack of records leads to under-estimations of the stock size and the productivity. Recommendations based on such observations influence the effectiveness of the stock control. If one knows the number of vessels, their approximate efficiency, and the amount of operations per time unit, it is possible to estimate the approximate harvest and the total amount of the fishing effort per season. At the same time, technical measures oriented to controlling the biological parameters of the population, and a number of administrative and economic considerations should be implemented. In addition, there is a need of a strong facilitation of the bureaucratic procedures, as well as a gradual decline in customs duties on imports and exports of fish products (Bakanev, 2009). Above all, it is necessary to develop a governance system that leads the industry to some form of auto-regulation. Making the industry appreciate and discuss the control measures implemented in Canada and Alaska may be a first step to their acceptance.

Fishery participants should be educated to the tools of fisheries management, at least partially. Information is one of the basic steps in motivating, as all stakeholders must be informed about the benefits of the process (Miller, 1976).

Barents Sea snow crab

According to the PINRO scientists, the intensive growth of the snow crab stock in the Barents Sea allows of the commercial fisheries. However, an additional analysis of the current stock state should be done.

Table 7. Ecosystem survey in the Barents Sea during 2003-2012 (Goryanina *et al*, 2013).

Year	Basin of the survey, millions of sq.km	Number of trawling	Number of trawling with crab	Number of crabs, individuals	Bio analysis, individuals
2003	1,178	379	0	0	0
2004	1,439	473	1	1	1
2005	1,416	358	11	14	14
2006	1,289	365	29	61	61
2007	1,463	383	56	134	126
2008	1,331	367	77	670	582
2009	1,538	379	66	284	279
2010	1,470	473	58	400	381
2011	1,715	401	84	6657	1182
2012	1,377	448	128	37780	1970

Concerning the possible snow crab fishery in the Barents Sea, the PINRO scientists recommend the usage of the crab pots as main fishing gears, as they are of high selectivity. Results of the joint Russian-Norwegian surveys show that there is a good perspective of the fishery development in the nearest future. The allowable crab size is suggested to be of 100 mm in CW. As for the fishing season and the areas of harvesting, there is a need in further investigations, as in the Alaskan and Canadian snow crab fisheries it is strongly recommended to avoid the moulting and mating periods in order to preserve the stock. In addition, it is reported that the negative air temperature aids to a mass scale limb autotomy. That is why, it is useful to avoid periods of low air temperatures during harvesting, as it leads to a reduced market value. A period between November and March is considered to be an undesirable time for snow crab harvesting in the Barents Sea (Goryanina *et al*, 2013).

As the commercial interest for the snow crab in the Barents Sea develops, it is interesting to give a further look at the present state of the Russian fishery sector in the Northeast Atlantic. According to the data provided by the Committee on the Fisheries Industry in the Murmansk region (2013), the main problems of the Murmansk fisheries are:

- A high degree of degradation of the fishing fleet and coastal fish-processing infrastructure;
- Insufficient governmental support in introduction of new technics;
- Volatile business environment in the global fish market.

A Program for Fisheries Development in the Murmansk region (further: "Program") has been approved. Its main goals are:

- Rationale usage of marine bio resources;
- Introduction of new technics;
- Ability to participate in a global market competition.

The "Program" assumes the following steps in order to achieve these goals:

- Organisation of conditions which provide higher effectiveness of harvesting;
- Support of the aquaculture development;
- Provision of the effective governmental control.

Several sub-programs have been created within the "Program":

1. The organisation of Fisheries;
2. The Aquaculture Development;
3. Modernisation and encouragement of innovation in the Fisheries complex.

The realisation of the "Program" is oriented to the specified period of 2014-2020. As a result, the external competitiveness of the region's enterprises is expected (Committee on the Fisheries Industry in the Murmansk region, 2013).

It is obligatory to form the long-term control system over marine bio resources and a long-term development of aquaculture and mariculture. One of the urgent requirements is a development of processing industry and provision of quality and safety of marine bio resources.

Apart from the executive state government bodies, several organisations will take part in realisation of the "Program" (Committee on the Fisheries Industry in the Murmansk region, 2013). These organisations are:

- The PINRO;
- The Murmansk State Technical University (MSTU);
- The Union of the Northern fishery managers;
- The Northwestern Fishing Industry Syndicate;
- The Association of Coastal fishery managers and farming enterprise of Murmansk;
- Fishing, fish-processing and aquaculture enterprises.

Conclusion

In the thesis, I have investigated the problem of a sustainable snow crab fishery in the Russian Barents Sea. The investigations of the snow crab biology show that this species has specific living requirements. Although this crab is an alien in the Barents Sea, it has found appropriate conditions similar to those in its natural area of habitation. The fact that biological behaviour is analogous with the one in a native ground suggests that the snow crab may adapt to the Barents Sea and form its own niche. Patterns of moulting, migration seasons, and the size of matured crab indicate that the stock is likely to develop in the future. This explains why snow crab has widely dispersed all over the Barents Sea basin already. The comparison of several management regimes in this industry was done. A number of recommendations were set as a possible way out of the current problems in the Russian snow crab fishery.

It is probably too early to talk about the large-scale snow crab industry in the Barents Sea. However, performed investigation allows to claim that there are good perspectives on its development and sustainability. Addressing to this question seems to be reasonable, as snow crab industry is a new field in the Murmansk region. Scientific surveys provide data, and in terms of the new industry, this research and development should be investigated further.

The governmental interest to the crab industry revives gradually. There is a need in a competition on the world market. Foreign experience proves that this industry is an advantageous and profitable business under appropriate regulation.

Snow crab fishery in the Barents Sea opens in 2014, as the scientific surveys have showed positive results. It is reported that the snow crab abundance increases, and this fact supposes that the future fishery has good perspectives to become profitable. Joint researches of Russian and Norwegian scientists discovered a significant growth of the snow crab abundance with the CW of more than 100 mm. It is possible, that a snow crab fishery in the Russian Barents Sea is sustainable if the above-mentioned restrictions and recommendations are applied. This would require that a special Program aimed at a long-term fisheries development is created and approved. Although, basic and main management measures are already in place, some of them are insufficient yet. The regulating system needs a high control over the fisheries industry in the Murmansk region from the governmental side, as well as a financial support.

Thus and so, main recommendations for the development of the fisheries management in the Murmansk region are as follows:

- Facilitation of bureaucratic actions;
- Gradual decline in customs duties on imports and exports;
- Control over the fishing gears and volumes of production;
- Control over the fishing season;
- Control over the number of vessels.

The future snow crab fishery in the Russian Barents Sea requires the following improvements in order to become sustainable:

- Tighter control on the legislation enforcement;

- Attraction of investments;
- Social protection;
- Provision of obvious benefits;
- Staffing;
- Staff incentive schemes;
- Further development of the regulatory framework;
- Cooperation with science and provision of regular surveys.

Reference list

Agnalt A.-L., Pavlov V., Jørstad K.-E., Farestveit E., Sundet J. 2011. The snow crab. *Chionoecetes opilio* (Decapoda, Majoidea, Oregoniidae) in the Barents Sea. In: *In the Wrong Place - Alien Marine Crustaceans: Distribution, Biology and Impacts.* Springer Science+Business Media B.V. 283-300 10.1007/978-94-007-0591-3_9

Alien species in Norway – with the Norwegian Black List 2012. 2012. Gederaas L., Loennechen Moen T., Skjelseth S., Larsen L.-K.: editors. Norwegian Biodiversity Information Centre. Trondheim. 216 pp.

Alunno-Bruscia, M. and Sainte-Marie, B. 1998. *Abdomen allometry, ovary development, and growth of female snow crab, Chionoecetes opilio (Brachyura, Majidae), in the northwestern Gulf of St. Lawrence*. NRC.

Anonymous. Alaska Federal Fisheries Management – Sustainable Fisheries Division. NOAA Fisheries, National Marine Fisheries Service, Alaska Regional Office. Accessed January 28, 2013. http://alaskafisheries.noaa.gov/sustainablefisheries/

Anonymous. Alaska Fisheries Science Center. National Marine Fisheries Service. Snow crab *Chionoecetes opilio*. Accessed: 10 October 2013. http://www.afsc.noaa.gov/Education/oceanlife/crabs/snow_crab.htm

Anonymous. Alaska Fisheries Science Center. Shellfish Assessment Annual Eastern Bering Sea Crab Survey. NOAA Fisheries. Accessed: 31 January 2013. http://www.afsc.noaa.gov/kodiak/shellfish/crabEBS/crabsurvey.htm

Anonymous. Alaska Snow Crab NOAA Fish Watch. 2012. Accessed January 28, 2013. http://www.fishwatch.gov/seafood_profiles/species/crab/species_pages/alaska_snow_crab.htm

Anonymous. Atlantic Canada Exports. Sustainability. 2011. Accessed January 30, 2013. http://atlanticcanadaexports.ca/sustainability/

Anonymous. 11 January 2009. "What to do with snow crab in the Barents Sea?" *The Fishermen Newspaper*. Accessed February 11, 2013. http://fishonline.ru/chto_delat_s_krabom-strigunom_v_barentsevom_more_news962.html [in Russian]

Anonymous. 12 July 2012. Bering Sea Crabbers: "Ghost fishing" not a problem in the Bering Sea. *IntraFish*. Accessed April 20, 2013. http://www.intrafish.com/global/news/article1345286.ece

Anonymous, 15 October 2012. Alaska announces 2012/13 crab quotas. *SeaFoodSource.com*. Accessed January 28, 2013. http://www.seafoodsource.com/newsarticledetail.aspx?id=18108

Anonymous. 14 January 2013. More than 36000 tonnes of crab are caught in the Far East. Accessed 13 November 2013. http://www.fishnews.ru/news/20293 [in Russian]

Anonymous. 30 June 2013. Spreading snow crab population in Barents Sea cause of concern. Science Poles. Accessed: 12 November 2013. http://www.sciencepoles.org/news/news_detail/spreading_snow_crab_population_in_barents_sea_cause_of_concern

Anonymous. 28 October 2013. Agreed allocation of snow crab aimed at harvesting in 2014. Committee on the Fisheries Industry in the Murmansk region. Accessed: 8 November 2013. http://rybolovstvo.gov-murman.ru/news/912b2a9b-3f9c-11e3-bed4-000c290d5291/ [in Russian]

Assessment of snow crab in the southern gulf of St. Lawrence (areas 12, 19, 12e and 12f) and advice for the 2013 fishery. 2013. Science Advisory Report 2013/002. Canadian Science Advisory Secretariat. Gulf Region. 24 pp.

Badmakhalgaev, L.Z. and Orlova, S.K. 2012. Problems and prospects of functioning of the fishery complex of Russia. *AGTU Newspaper*. 91-101. [in Russian]

Baharev, S.A. and Krasnikov, I.V. 2003. Ecological-economical estimation of the crab harvesting. *Journal of the Kamchatka State Technical University*. 91-95. [in Russian]

Bakanev, S. 2009. *Population dynamics of the king crab (Paralithodes camtschaticus) in the Barents Sea (simulation experiment).* PINRO. Murmansk

Bakanev, S.V. and Pavlov, V.A. 2010. Modelling the abundance dynamics of snow crab (*Chionoecetes opilio*) in the Barents Sea. *Problems of Fisheries*. 11(43):485-496.

Bakay Yu., Karasev A. 2008. The effects of the red king crab acclimatization in the Barents Sea – parasitological aspects. In: Sundet, J.H. and Berenboim, B., editors. *Research on the red king crab (Paralithodes camtschaticus) from the Barents Sea in 2005-2007.* IMR, PINRO. Tromsø, Murmansk.

Barnard, D.R. and Burt, R. 2007. *Alaska Department of Fish and Game. Summary of the 2005/2006 Mandatory Shellfish Observer Program Database for the Rationalised Crab Fisheries.* Alaska Department of Fish and Game, Division of Commercial Fisheries. Kodiak

Bering Sea and Aleutian Islands Crab Rationalization Program Report Fishing Year 2011/12 July 1, 2011–June 30, 2012. 2012. NOAA's National Marine Fisheries Service (NMFS), Alaska Region Restricted Access Management (RAM). 97 pp.

Chabot D., Sainte-Marie B., Briand K., Hanson J.M. 2008. Atlantic cod and snow crab predator-prey size relationship in the Gulf of Saint Lawrence, Canada. *Marine Ecology Progress Series.* 363:227-240. doi:10.3354/meps07384

Comeau M., Conan G.Y., Mayno F., Robichaud G., Therriault J.-C., Storr M. 1998. Growth, spatial distribution and abundance of benthic stages of the snow crab (*Chionoecetes opilio*) in

Bonne Bay, Newfoundland, Canada. *Canadian Journal of Fisheries and Aquatic Sciences*. 55(1):262-279. doi 10.1139/f97-255

Commercial Fisheries. Alaska Department of Fish and Game. 2013. Accessed January 28, 2013. http://www.adfg.alaska.gov/index.cfm?adfg=fishingCommercial.main

Committee on the Fisheries Industry in the Murmansk region. Government Program of the Murmansk region "*Development of the Fisheries Industry in the Murmansk region for the period 2014-2020"*. 2013. Murmansk. [in Russian]

Community Development Quota (CDQ) Program. NOAA Fisheries. Accessed April 16, 2013. http://alaskafisheries.noaa.gov/cdq/default.htm

Convention on Biological Diversity of 1992. Accessed: 14 November 2013. http://www.cbd.int/convention/text/default.shtml

Dalrymple M., Knoska J., Peters K. 1999. Patent №US6687583. USA.

Dahle G., Agnalt A.-L., Farestveit E., Jørstad K., Sevigny J.-M., Parent E., Hardy S.M. 2012. *Genetic analysis of snow crab (Chionocetes opilio) in the Barents sea – where are we?* Institute of Marine Research. Bergen.

DFO. Snow crab. Fisheries and Oceans Canada. 2011. Accessed January 30, 2013. http://www.dfo-mpo.gc.ca/fm-gp/sustainable-durable/fisheries-peches/snow-crab-eng.htm

Dobrovolskii, A.D. and Zalogin, B.S. 1982. *Seas of the USSR*. MSU. Moscow. [in Russian]

Donaldson W.E., Cooney R.T., Hilsinger J.R. 1981. Growth, age and size at maturity of Tanner Crab, *Chionoecetes bairdi* MJ Rathbun, in the Northern Gulf of Alaska (Decapoda, Brachyura). *Crustaceana*. 40(3):286-302.

Duplyakov, A. 2013. Newspaper Interview for the News Agency FishNet. Published: 14 January 2013. Accessed: 13 November 2013. [in Russian]. http://www.fishnet.ru/news/promysel_i_pererabotka/31469.html

Eldholm, O. and Ewing, J. 1971. Marine geophysical survey in the southwestern Barents Sea. *Journal of Geophysical Research.* 76(17):3832-3841 DOI: 10.1029/JB076i017p03832

Eldholm, O. and Talwani, M. 1977. Sediment distribution and structural framework of the Barents Sea. *Geological Society of America Bulletin* 88(7):1015-1029 doi: 10.1130/0016-7606(1977)88<1015:SDASFO>2.0.CO;2

Elner, R.W. and Beninger, P.G. 1995. Multiple reproductive strategies in snow crab, *Chionoecetes opilio*: physiological pathways and behavioural plasticity. *Journal of Experimental Biology and Ecology*. 193:93-112.

Elven R., Ødegaard F., Oug E., Sandvik M. 2012. Alien species: introduction, establishment and spread. In: Gederaas L., Moen T.L., Skjelseth S., Larsen L.-K., editors. *Alien species in Norway – with the Norwegian Black List*. Norwegian biodiversity information centre. 17-56.

Elverhøi, A. and Solheim, A. 1983. The Barents Sea ice sheet – a sedimentological discussion. *Polar research*. 1(1):23-42 DOI: 10.1111/j.1751-8369.1983.tb00729.x

Ernst B., Orensanz J.M., Armstrong D.A. 2005. Spatial dynamics of female snow crab (*Chionoecetes opilio*) in the eastern Bering Sea. *Canadian Journal of Fisheries and Aquatic Sciences*. 62(2):250-268. doi 10.1139/f04-201

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 Sciences.* 68(3):479-488. doi: 10.1093/icesjms/fsq192

Falk-Petersen, J. and Armstrong, C.W. 2013. To have one's cake and eat it too: managing the alien invasive red king crab. *Marine resource economics*. 28(1):65-81.

FAO © *Chionoecetes opilio (O.Fabricius, 1788)*. In: Fisheries and Aquaculture Department. Accessed September 28, 2013. http://www.fao.org/fishery/species/2644/en

Fina, M. 2005. Rationalisation of the Bering Sea and Aleutian Islands crab fisheries. *Marine Policy*. 29 (4):311-322. doi http://dx.doi.org/10.1016/j.marpol.2004.05.005

Fitch, H. 2013. *Bering sea snow crab. Season opens october 15. Total allowable catch announced*. News release. Alaska Department of Fish and Game Division of Commercial Fisheries. Dutch Harbor. 3pp.

Fisheries and Oceans Canada. Snow crab. Date modified: 28 June 2013. Accessed: 9 November 2013. www.dfo-mpo.gc.ca/fm-gp/sustainable-durable/fisheries-peches/snow-crab-eng.htm

First update of the Integrated Management Plan for the Marine Environment of the Barents Sea–Lofoten Area. Meld. St. 10 (2010–2011). Report to the Storting (white paper). Recommendation of 11 March 2011 from the Ministry of the Environment, approved in the Council of State the same day. (white paper from the Stoltenberg II Government). Accessed: 13 November 2013. http://www.regjeringen.no/en/dep/md/documents-and-publications/government-propositions-and-reports-/reports-to-the-storting-white-papers-2/2010-2011/meld-st-10-20102011.html?id=682050

Fisheries and Oceans Canada. *Snow Crab (Chionoecetes opilio) Newfoundland and Labrador Region 2009 – 2011*. Accessed 13 November 2013. http://www.dfo-mpo.gc.ca/fm-gp/sustainable-durable/fisheries-peches/snow-crab-eng.htm

Fisheries Management Plan for Bering Sea /Aleutian Islands. King and Tanner Crabs. 2011. North Pacific Fishery Management Council. Anchorage.

Foyle T.P., O'Dor R.K., Elner R.W. 1989. Energetically defining the thermal limits of the snow crab. *The Journal of Experimental Biology*. 145:371-393.

Frolov I., Danilov A., Dmitriev V., Gerasimova T. 2008. *Barents Sea*. Federal State Budgetary Institution "Arctic and Antarctic Research Institute". St. Petersburg.

Goryanina S.V., Bakanev S.V., Pavlov V.A. 2013. The PINRO materials explaining of the snow crab TAC in the Barents Sea for corrections of the harvest in 2014. Accessed 14 November 2013. www.pinro.ru/n22/index.php/ru/obslush/1171-2013-07-31-14-13-42 [in Russian]

Government of Canada. Agriculture and Agri-Food Canada. Snow crab. Accessed: 13 November 2013. http://www.ats-sea.agr.gc.ca/sea-mer/4809-eng.htm

Gravel K.A, Watson L.J., Pengilly D. 2006. *The 2005 Eastern Bering Sea snow crab Chionoecetes opilio Tagging study*. Alaska Department of Fish and Game, Division of Sport Fish and Commercial Fisheries. Anchorage

Greenberg J.A., Herrmann M., MacCracken J. 1995. An international supply and demand model for Alaska snow crab. *Marine Resource Economics*. 10:231-246

Grigoryeva, N. 2010. Seasonal Dynamics of the Crab Larvae in Minonosok Inlet (Posyet Bay, Peter the Great Bay, the Sea of Japan) in 2000-2004. *China-Russia Bilaterial Symposium. Proceedings of China - Russia Bilateral Symposium on "Comparison on Marine Biodiversity in the Northwest Pacific Ocean"*. Qingdao: A.V. Zhirmunsky. Institute of Marine Biology of the Far Eastern Branch of the Russian Academy of Sciences. 155 – 164.

Gudimova, E.N. 2002. *Benthic invertebrates in the Barents Sea: resources, perspectives of usage, ecology*. MMBI. Apatity.

Gudlaugsson, S.T. 1993. Large impact crater in the Barents Sea. *Geology*. 21(4):291-294 doi: 10.1130/0091-7613(1993)021<0291:LICITB>2.3.CO;2

Hamre, J. 1994. Biodiversity and exploitation of the main fish stocks in the Norwegian-Barents Sea ecosystem. *Biodiversity and Conservation*. 3(6):473-492 doi 10.1007/BF00115154

Hebert M., Miron G., Moriyasu M., Vienneau R., DeGrace P. 2000. Efficiency and ghost fishing of the snow crab (*Chionoecetes opilio*) traps in the Gulf of St. Lawrence. *Fisheries Research, 2001*. 52(3):143-153. http://dx.doi.org/10.1016/S0165-7836(00)00259-9

Hemmingsen W., MacKenzie K., Jansen P.A. 2008. Report on trypanosome infections of cod in the southern Barents Sea. In: Sundet, J.H. and Berenboim, B., editors. *Research on the red king crab (Paralithodes camtschaticus) from the Barents Sea in 2005-2007*. Editors: IMR, PINRO. Tromsø, Murmansk.

Hibler, W.D. 1979. A Dynamic Thermodynamic Sea Ice Model. *Journal of Physical Oceanography* 9:815-846.

Hjelset, A.M. 2012. *Female life-history parameters in the introduced red king crab (Paralithodes camtschaticus, Tilesius 1815) in the Barents Sea: a study of temporal and spatial variation in three Norwegian fjords*. Faculty of Biosciences, Fisheries and Economics. Department of Arctic and Marine Biology. Institute of Marine Research. Tromsø.

Hjelset A.M., Sundet J.H., Nilssen E.M. 2009. Size at sexual maturity in the female red king crab (*Paralithodes camtschaticus*) in a new settled population in the Barents Sea, Norway. *J.Northw.Atl.Fish.Sci*., 41:173-182. doi: 10.2960/J.v41.m633

Ingvaldsen R., Loeng H., Asplin L. 2002. Variability in the Atlantic inflow to the Barents Sea based on a one-year time series from moored current meters. *Continental Shelf Research*. 22(3):505-519

Jensen, K.R. (no date). Chionoecetes opilio. NOBANIS – Marine Invasive Species in Nordic Waters – Fact sheet. Copenhagen. 7 pp.

Jørgensen L.L., Manushin I., Sundet J.H. 2005. *The intentional introduction of the marine red king crab Paralithodes camtschaticus into the Southern Barents Sea.* International Council for the Exploration of the Sea. Copenhagen.

Jørgensen, L.L. and Nilssen, E.M. 2011. The invasive history, impact and management of the red king crab *Paralithodes camtschaticus* off the coast of Norway. In: Galil B.S., Clark P.F., Carlton J.T., editors. *In the wrong place - alien marine crustaceans: distribution, biology, impacts*. Springer. Netherlands.

Jørstad K.E., Agnalt A.-L., Dahle G., Hufthammen M. [no date]. *Genetical and ecological effects of the intentionally introduced red king crab (Paralithodes camtschaticus) and the accidentally introduced snow crab (Chionoecetes opilio) in the Barents Sea.* Institute of Marine Research. Bergen

Kruse G.H., Bez N., Booth A., Dorn M.W., Hills S., Lipcius R.N., Pelletier D., Roy C., Smith S.J., Witherell D. 1999. *Spatial processes and management of marine populations.* University of Alaska Sea Grant Collage Program. Anchorage.

Landvik J.Y., Bondevik S., Elverhøi A., Fjeldskaar W., Mangerud J., Salvigsen O., Siegert M.J., Svendsen J.-I., Vorren T.O. 1998. The last glacial maximum of Svalbard and the Barents Sea area: ice sheet extent and configuration. *Quaternary Science Reviews*. 17:43-75

Larichev, Y. 2009. Crime rate and problems of crime prevention in trade of marine biological resources. *Society and Law*. 156-166. [in Russian]

Lovrich, G.A. and Sainte-Marie, B. 1997. Cannibalism in the snow crab, *Chionoecetes opilio* (O. Fabricius) (Brachyura: Majidae), and its potential importance to recruitment. *Journal of Experimental Biology and Ecology*. 211:225-245.

Matishov, G.G. 2008. *Biology and physiology of the red king crab from the coastal zone of the Barents Sea.* Kola Science Center, Russian Academy of Sciences. Apatity.

Mikkelsen, N. and Pedersen, T. 2012. Invasive red king crab affects lumpsucker recruitment by egg consumption. *Marine ecology progress series.* 469:87-99. doi: 10.3354/meps09917 https://www.ub.uit.no/munin/handle/10037/5031

Miller, R.J. 1976. North American Crab Fisheries: Regulations and their Rationales. *Fishery Bulletin*. 74(3):623-633

Mills C.M., Townsend S.E. Jennings S., Eastwood P.D., Haughton C.A. 2007. Estimating high resolution trawl fishing effect from satellite-based vessel monitoring system data. *ICES J. Mar. Sci*. 64(2):248-255. doi 10.1093/icesjms/fsl026

Moriyasu, M. and Lanteigne, C. 1998. *Embryo development and reproductive cycle in the snow crab, Chionoecetes opilio (Crustacea: Majidae), in the Southern Gulf of St. Lawrence, Canada.* NRC.

NOAA FishWatch. US Seafood Source. Alaska snow crab. Accessed: 9 November 2013. www.fishwatch.gov/seafood-profiles/species/crab/species_pages/alaska_snow_crab.htm

Order of the Federal Agency of the Fisheries of 6 July 2011 N671. Registration number 21499. Published 8 August 2011. Moscow. [in Russian]

Orensanz J., Ernst B., Armstrong D.A., Stabeno P., Livingston P. 2004. *Contraction of the geographic range of distribution of snow crab (Chionoecetes opilio) in the eastern Bering Sea: an environmental ratchet?* CalCOFI Rep. 65-79.

Orensanz J.M., Armstrong J., Armstrong D., Hilborn R. 1998. Crustacean resources and vulnerable to serial depletion – the multifaceted decline of crab and shrimp fisheries in the Greater Gulf of Alaska. *Reviews in Fish Biology and Fisheries*. 8:117-176. doi 10.1023/A:1008891412756

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

Ottersen, G. and Stenseth, N.C. 2001. Atlantic current governs oceanographic and ecological variability in the Barents Sea. *Limnology and oceanography*. 46(7):1774-1780. doi: INIST-CNRS, Cote INIST : 2892, 35400009932378.0180

Oug, E. and Sundet, J.H. 2008. Alteration in soft bottom fauna in Varangerfjord after the red king crab. In: Sundet, J.H. and Berenboim, B., editors. *Research on the red king crab (Paralithodes camtschaticus) from the Barents Sea in 2005-2007.* IMR, PINRO. Tromsø, Murmansk.

Paulin, J. Bering Sea snow crabbers prevail over stubborn ice enroute to quota. *Alaska Dispatch.* 14 June 2012. Accessed January 28, 2013. http://www.alaskadispatch.com/article/bering-sea-snow-crabbers-prevail-over-stubborn-ice-enroute-quota.

Pavlov, V. and Sokolov, A. 2003. On the biology of snow crab *Chionoecetes opilio* (Fabricius, 1788) in the Barents Sea. In: *Bottom Ecosystems of the Barents Sea*. VNIRO. Moscow. [in Russian]

Pavlov, V.A. 2005. Snow crab opilio – a new component of the Barents Sea fauna. *Alien species in Holarctic*. Rybinsk. Rybinsk Publishing House. [in Russian]

Pavlov, V.A. 2006. *The new data on the snow crab Chionoecetes opilio (Fabricius, 1788) in the Barents Sea*. PINRO. Murmansk.

Pavlova L.V., Kuzmin S.A., Dvoretsky A.G. 2005. *King crab invasion into the Barents Sea: history, results, perspectives.* MMBI. Apatity. [in Russian]

Perveeva, E.R. 2007. *Distribution and biological characteristics of snow crab Chionoecetes opilio (Brachyura, Majidae) on the western shelf of Sakhalin Island in April-May 2005.* VNIRO.

Perveeva, E.R. 2009. *Modern stock status of the snow crab Chionoecetes opilio in the Sakhalin Island waters.* Development of the Far East and Kamchatka: Regional problems. Publishing house “Kamchatpress”. Petropavlovsk-Kamchatsky. 101-104.

Pinfold, G. 2006. *Overview of the Atlantic snow crab industry*. Department of Fisheries and Oceans, Atlantic Council of Fisheries and Aquaculture Ministers. Quebec.

Quotas set downward for new Alaska king, snow crab fisheries. *IntraFish*. 16 Oct 2012. Accessed April 20, 2013. http://www.intrafish.com/global/news/article1357360.ece

Report of the Standing Committee on Fisheries and Oceans. 2011. *Report on the snow crab industry in the Atlantic Provinces and Quebec.* House of Commons. Ottawa.

Rodina, E. 2004. *Contraband of marine products. Economic, social, legislative and ecological problems of the Sea of Okhotsk and ways of resolution*. Kamchatka State Technical University. Petropavlovsk-Kamchatsky. 197-206. [in Russian]

Rugolo L.J., Haaga J.A., MacIntosh R.A. 2001. *Report to Industry on the 2001 Eastern Bering Sea Crab Survey.* Alaska Fisheries Science Center. Kodiak.

Sainte-Marie B., Sevigny J.-M., Smith B.D., Lovrich G.A. 1996. Recruitment variability in snow crab (*Chionoecetes opilio*): Pattern, possible causes and implications for fishery management. *Symposium on high latitude crabs. Institute Maurice-Lamontagne*. Quebec.

Sakshaug E., Bjørge A., Gulliksen B., Loeng H., Mehlum F. 1994. Structure, biomass distribution, and energetics of the pelagic ecosystem in the Barents Sea: a synopsis. *Polar Biology*. 14:405-411 doi 10.1007/BF00240261

Sakshaug, E. 1997. Biomass and productivity distributions and their variability in the Barents Sea. *ICES Journal of Marine Science*. 54(3):341-350 doi: 10.1006/jmsc.1996.0170

Schauer, U. and Fahrback, E. 1999. A dense bottom water plume in the western Barents Sea: downstream modification and interannual variability. *Deep Sea Research Part I: Oceanographic Research Papers.* 46 (12): 2095‑2108. doi http://dx.doi.org/10.1016/S0967-0637(99)00046-1

Selin, N.I. 2002. Regeneration of limbs in males of the Tanner crab *Chionoecetes bairdi* and *Chionoecetes opilio*. *Russian Journal of Marine Biology*. 171-174

Shellfish Assessment Annual Eastern Bering Sea Crab Survey. NOAA Fisheries Alaska Science Center. Accessed January 31, 2013. http://www.afsc.noaa.gov/kodiak/shellfish/crabEBS/crabsurvey.htm

Siddeek M.S.M., Wade E., Moriyasu M. 2009. Proposed harvest control rule for managing the snow crab stock in the southwestern Gulf of St. Lawrence, Canada. *Fisheries Research*. 95:268-279. http://dx.doi.org/10.1016/j.fishres.2008.09.032

Slagstad D., Støle-Hansen K., Loeng H. 1990. Density driven currents in the Barents Sea calculated by a numerical model. *Modelling, Identification and Control*. 11(4):181-190 doi: 10.4173/mic.1990.4.1

Sorteberg, A. and Kvingedal, B. 2006. Atmospheric forcing on the Barents Sea winter ice extent. *Journal of Climate.* 19(19):4772-4784. Print ISSN: 0894-8755

Swift J.H., Takahashi T., Livingston H.D. 1983. The contribution of the Greenland and Barents Seas to the deep water of the Arctic Ocean. *Journal of Geophysical Research: Oceans (1978-2012).* 88(C10):5981-5986 doi 10.1029/JC088iC10p05981

Tremblay, M.J. 1997. Snow crab (*Chionoecetes opilio*) distribution limits and abundance trends on the Scotian Shelf. *J. Northw. Atl. Fish. Sci*. 21:7-22.

Vessel Monitoring Systems (VMS). NOAA Fisheries. National Marine Fisheries Service, Alaska Regional Science Center.

Vorren T.O., Lebesbye E., Andreassen K., Larsen K.-B. 1989. Glaciogenic sediments on a passive continental margin as exemplified by the Barents Sea. *Marine Geology*. 85:251-272.

Zheng, J. and Kruse, G.H. 2000. Recruitment patterns of Alaskan crabs in relation to decadal shifts in climate and physical oceanography. *ICES Journal of Marine Science*. 57(2):438-451. doi: 10.1006/jmsc.1999.0521