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Effect from the king- and snow crab on Barents Sea benthos

Results and conclusions from the Norwegian-Russian Workshop in Tromsø 2010

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Effect from the king- and snow crab on Barents Sea benthos

Results and conclusions from the Norwegian-Russian Workshop in Tromsø 2010

Lis Lindal Jørgensen and Vassily Spiridonov (leaders)

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Source: Lis Lindal Jørgensen, IMR. Tank experiment, with king crab foraging on *Chlamys islandica*.

HAVFORSKNINGSINSTITUTTET
INSTITUTE OF MARINE RESEARCH

Background

November 15-17, 2010 a Russian – Norwegian workshop was arranged to evaluate the effect that the king crab and the snow crab have on bottom living invertebrates (benthos) in the Barents Sea. The workshop was named "the effects on benthos from the king- and snow crab in the Barents Sea" and was financed by "HAV 9 Introduserte arter" through the Directorate of Nature Conservation leaded by Ingrid Bysveen and the scientific work was leaded by IMR (Dr. Lis Lindal Jørgensen) and Dr. Vassily Spiridonov from the P.P. Shirshov Institute of Oceanology of the Russian Academy of Sciences, in Moscow. The goal was to gather the foremost experts of king- and snowcrab impact on benthos in Russia and Norway in a workshop to discuss the most updated knowledge on this issue. This report makes available updated science on the impact from the two relatively new crab species in the Barents Sea, from the coast and fjords, to the open Sea.

During the three day workshop in Tromsø, at the institute of IMR, 12 Russian, 12 Norwegian and 1 Italian scientist from 16 different institutions (see appendix 1) was discussing the effect from the king- and snow crab on Barents Sea benthos. This report gives a short introduction in some of the important details given by the speakers. This report is divided into three parts: 1) King crab and snow crab population dynamics, 2) King crab consumption of prey, and 3) Case studies of impacts.

Goal of the workshop is to find a common understanding of the effect on the benthos due to invading king crabs (and snow crabs if possible) in the Barents Sea.
This will be done by using data from:

- Several Norwegian and Russian geographical areas in the coastal and open waters of the Barents Sea where standing stock of benthos have been mapped.
- The foraging and consumption rate of the king crab investigated in previous studies on stomach content and laboratory experiments.
- Discussion on the increase and spreading of the king crab and snow crab population.

Content

Short summary

In the Russian part of the Barents Sea the king crab move east and deeper along the coast and might enter the outer White Sea area. The king crab movement is linked with shallow water mating (coastal) and foraging (deeper waters) migration. The king crab stays closer to the coast in Norwegian waters, but spread out to the sea in Russian waters. This pattern varies between the coast characterized by, steep walls and abrupt changes in depth (northern Norway and Western Murmansk Coast) and the open coastal areas of the eastern Barents Sea with gradually increasing depth. The adults might not move north and overlap with snow crab in Norwegian zone while already overlapping the off-shore populations of snow crab in the east.

The snow crab, today a self-producing population in the Barents Sea, is expected to increase to > 291 million specimens. Estimated carrying capacity of the Barents Sea is 436 million. The majority of snow-crabs have been recorded in waters below 2°C and small-sized crabs are exclusively found at the Goosebank, indicate a recruiting area. Warming can push the snow crab further north and the crab is likely to establish in Svalbard and Franz Josef Land.

King crab feeding studies shows that the sea star *Ctenodiscus cri*spatus and the bivalve *Bathyarca glacialis* are preferred by the king crab and should be used as indicator species in impact studies. Also abundant and widely distributed species within asteroids, ophiuroids and bivalves works well as indicator in both Russian and Norwegian areas. The king crab is a new species in the Barents Sea and the feeding behaviour and feeding mode is very flexible and will probably change over time. The snow crab, with its rapid movements, feed mostly on crustacea, polychaeta and fish.

Studies in the Porsanger fjord in 2008 and again in 2010 shows up to 6 times reduction of the benthic community biomass (sea stars, sea urchins, brittle stars and bivalves) together with an increase in numbers of the newly invaded king crab.

Studies in the Varanger area (Bøkfjorden) in 1994 and again in 2007 showed significant reduction in polychaetes, echinoderms and bivalves (but increase in *Myriochele* sp. and small bivalves) together with loss of structural and functional diversity and a sea bed with only a thin surface layer being oxygenated.

Motovsky Bay (first area invaded by king crab) was investigated in 1931, 1995 and 2003 and showed that Polychaeta increased while other groups of “preferred prey species” (echinoderms: *Ophiura sarsi*, *Ophiopholis aculeata* bivalves: *Astarte crenata*, *Elliptica elliptica*) of the king crab declined.

In the open outer part of Kola bay foraging rate of 5-40% of the annual benthic production in high crab-density areas was recorded. A decline in juvenile crabs was followed by increase in benthos biomass, and smaller benthic organisms dominate in high density crab areas. 50 juvenile crabs/1000m2 is suggested as a threshold level of benthic impact. Soft bottom communities are more vulnerable to crab impact than hard bottom communities.

Dolgaya Inlet was studied in 1990 and again in 2006 and showed that calacareous algae *Lithotamnium* sp., clams *Ciliatocardium ciliatum* and *Astarte crenata* and scallop *Chlamys islandica* were no longer dominant while the importance of barnacles *Balanus balanus* and *B. crenatus* had increased. The bivalve species richness had decreased from 24 to 16 species, and only 12 species were refund.

The Open Barents Sea with high predation pressures from the crab showed changes in the benthic communities. Most probably do to depletion of benthic prey, the king crab have gradually moved from shallow to deeper areas from 2001 to 2009.

In the open Barents Sea the preferred prey species of the king crab was *Astarte spp, Ctenodiscus crispatus* and two species of ophiuroids. These might be used as "Indicators". The annual benthic production of these prey species is calculated 84.9 g/m2. The crab forage 15g/m2 which is about 1/5 (=17%) of the annual production.

In rocky bottom Varanger fjord, 0-50m, a study showed that juvenile crabs are present in the coastal waters all year round, often with high density. In spring densities may reach 25 individuals per $100m^2$. For this area rich communities on hard substrate are common which show high spatial and temporal variation that can't be easily attributed to the impact of particular factors.

Conclusion: The king crab move further out in the sea in Russian waters compared to the Norwegian waters. This might have important implications on the distribution of feeding pressure and impact of crabs on benthic communities making them different in different areas. Though the king crab population is still spreading along the coast, the snow-crab population, spreading on the seafloor of the open sea, is expected to increase beyond the standing stock of king crab. The king crab has a measurable effect from foraging on large visible sea stars, brittle stars and bivalves and preferable prey will decrease while species, not preferred, will become dominant together with "hide or flight" bottom animals. Some areas show sign of almost extinction of large prey, and borrowing fauna inside the sediment might have decreased due to the foraging from the crab, and consequently left the sediment environment low in oxygen. Areas with refuge still have high biodiversity.

Examples of knowledge gaps and future directions

- The available living space (distribution area and carrying capacity) is different for the king- and the snowcrab, and the rate of increase in density in these species in new areas differs.
- The red king crab and the snow crab have similar feeding features (a diet and food composition) and the predator press on the benthos will depend on the ratio of density of forage benthos and their consumers in the given areas.

- The final distribution of the two crabs is unknown due to knowledge gap on physiology of the crab at different life history stages and sex, particularly with respect to temperature tolerance (high temp).
- The King crab is a generalist and opportunistic predator, feeding on what is available but, opporsit to the snowcrab, crustaceans seem to play a minor role in the king crab diet.
- There is a need to ccollect all existing estimates of the daily consumption derived from experimental and field studies.
- There is a need to conduct experiments on food consumption of different size groups of King crab under various temperature
- There is a need to rrefine growth and mortality parameters for King crabs and their prey for use in production models.
- There is a need to ccompare estimates of natural mortality used in the crab stock assessment models to the natural mortality values obtained from juvenile crab studies.
- There is a need to use production models to evaluate relative importance of different crab size and crab age groups for the total impact on benthic prey species and their communities.
- There is a need to make a review, comparing king and snow crab diet.
- There is a need to develop standardised methods of studying crab diet and combine field and lab studies.
- There is a need to develop a model that captures the dynamics between crab distribution (migration), prey availability and consumption by the king crab.
- To get an idea of possible changes in benthos, there is a need to find all pre-invasion data to compare to the current data on hard and soft bottom community diversity.
- Ongoing analyses of crab stomach contents from Varanger fjord should be compiled and a joint Russian/Norwegian assessment of ecosystem consequences should be started.
- Follow-up monitoring both temporal and spatial.
- Threshold fjords should be preferred as monitoring sites because they make up a “mini-cosmos” that can be assessed.
- Get stable isotope data in order to determine what the crab feed on.

Chapter 1. King crab and snow crab population dynamics

1.1 King crabs

Adults

The red king crab has been spreading in both Russian and Norwegian Southern Barents Sea (Fig. 1 and 2). The area of the present (i.e. 2010) Kamchatka crab distribution in the Barents Sea indicates that the species has spread along the Norwegian coast and passed the south-west of Hammerfest while its offshore limit does not extend far beyond 300 m isobath.

The king crab population in Norwegian part of the Barents Sea has been reduced from 5 million individuals in 2008, to about 3 million in 2010. In 2010 the quota regulated area are the largest ever as a consequence of the still spreading populations (source: Sundet).

In Russian part of the Barents Sea (REEZ) by 2008, the king crab was one of the most important commercially harvested species. The area of distribution of king crab today in REEZ is 30 000 square nautical miles (source: Bakanev). Since 2005 (opening of commercial crab fishery) the impact of fishery (including IUU catch) on the King crab stock became detectable, but there was no indication of significant overfishing. Critical condition of the stock was recorded in the late 2000s (Bakanev, 2009).

The Lithodidae crabs have, in general, not been reported to occur at subzero temperatures (Hall & Thatje, 2009) and the boreal red king crab makes no major difference to this.
In the early 2000s, in the east Barents Sea, the King crab distribution basically followed the boundary between the Barents Sea coastal area, dominated by the Murmansk current and its derivatives on one side and the Voronka of the White Sea, and the Kanin – Kolguev Shallow on the other side (Boitsov, 2003).

The minimum requirement for larval development ranges between 0 and 2 °C (Shirley & Shirley, 1989). But the temperature tolerance of king crab seems to differ between different populations. Some populations in the Okhotsk Sea, i.e. Ayan – Shantar Islands stock, lives in low temperature and seasonal ice; the juveniles of this population are exposed to subzero temperature for nearly half of the year while the adults overwinter in deeper areas where the temperature may be around 0°C or even lower. They exhibit the slowest growth and the lowest definitive size compared to the other King crab populations, but in high population abundance (Rodin & Myasoedov, 1982; Chernienko, 2011).

The Russian Barents Sea fishery data indicate that high concentrations of King crab (i.e. abundances with commercial interests) have moved further east and deeper along the coast of the Kola Peninsula during 2001 and 2009 (Fig. 2). This suggests that in the Barents Sea King crab might distribute further eastward than previously assumed and also into the outer White Sea area (so called Voronka) with its subzero winter temperatures. The juveniles crabs have currently been recorded here (Zolotarev, 2009).

King crab movement is believed to be linked with depth distribution and the crab from several big stocks in native areas move far from the coastal areas to migrate down to deep winter foraging areas, while to shallow water coastal areas when mating and molting.

This pattern seems to vary between the fjord coastal zone (northern Norway, Varanger fjord and, the fjords of the Western Murmansk Coast) and the more open coastal areas of the Eastern Murmansk coast (Fig. 1). While Russian areas east of the Kola Bay are more similar to the native king crab areas with gradually increasing depth when moving away from the coast (Slizkin & Safonov, 2001; Klitin, 2003), the Norwegian (and partly the western Russian) distribution area is characterized by steep walls and abrupt changes in depth close to the coastal zone and inside the fjords. This might give the crab the possibility to stay close to the coast year round. Patterns of local movement and migration of King crab in the fjord areas vs. more open coast of the southern Barents Sea may have important implications on the distribution of feeding pressure and impact of crabs on benthic communities making them different in different areas.

A consequence of this might be that the adults might not move north and overlap with snow crab in Norwegian zone due to the close contact with the coast (15nm from Norwegian coast). In Russia they spend more time off-shore and are already now found to overlap with snow crab.

Conclusion:
The Russian Barents Sea king crab move east and deeper along the coast of the Kola Peninsula and might distribute further eastward and into the outer White Sea area. King crab movement is linked with mating (coastal) and foraging (deeper waters) migration.

This pattern varies between the fjord coast characterized by steep walls and abrupt changes in depth (northern Norway and Western Murmansk Coast) and the open coastal areas of the Eastern Murmansk coast with gradually increasing depth.

The adults might not move north and overlap with snow crab in Norwegian zone while already overlapping the off-shore populations of snow crab in the east.

Important: knowledge gap on distribution due to the crabs being new species in the region.

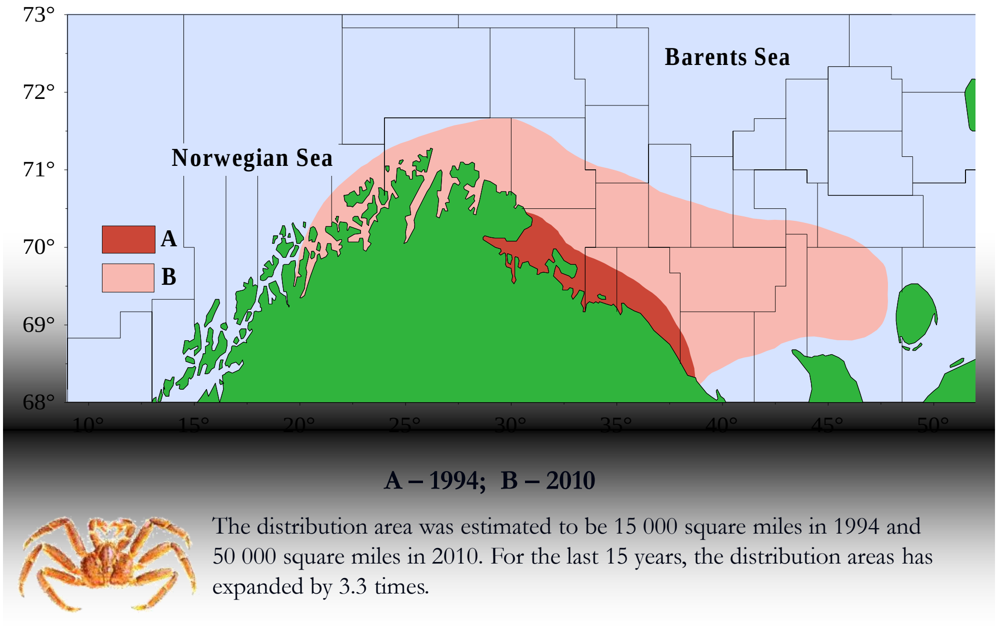


Figure 1. Distribution area of red king crab (source: Dr Sergei Bakanev, PINRO, Murmansk, Russia).

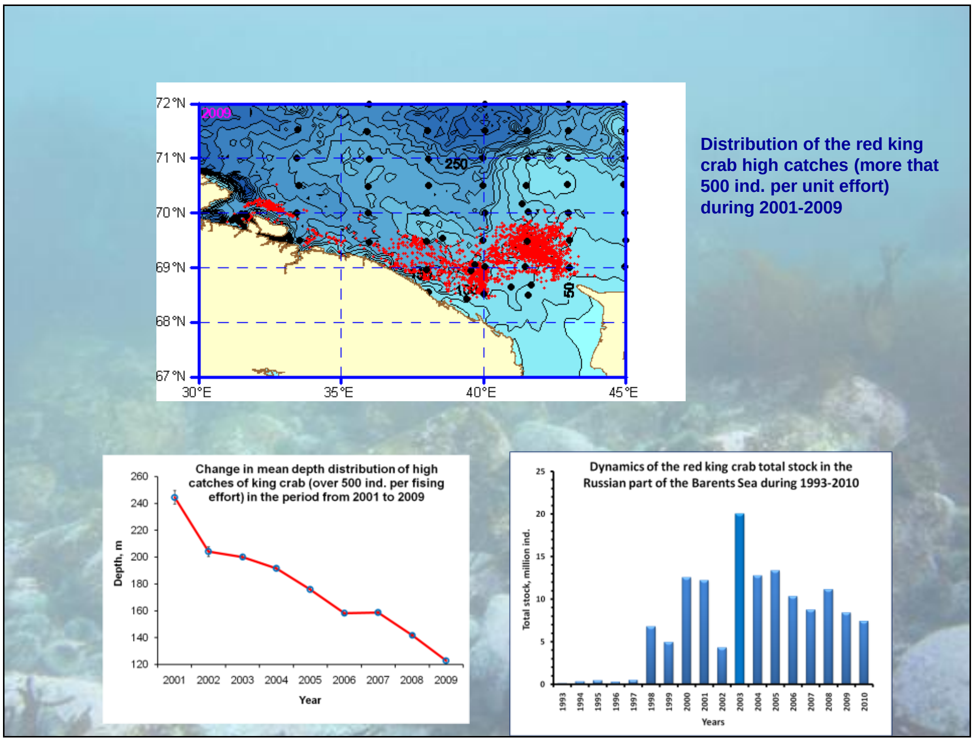


Figure 2. The eastward spread of the red king crab (upper map) and gradually deeper distribution (lower left figure) and fluctuating stock abundance (lower right figure). Source: Dr Igor Manuchin, PINRO, Murmansk, Russia.

Larvae

Larvae are expected to be the bottleneck of establishing new populations due to the temperature sensitivity and the need for substrate for settlement and habitat of juveniles.

The larvae are more tolerant to high temperatures then previously assumed. Klitin (2003) approximated the dependence of larval development duration from the field and laboratory data obtained from field and laboratory sources. Acceleration of the larval development with increasing ambient temperature may lead to nearly 1.8 times faster larval development at 8˚C compared to 4.5˚C. Along with the current trend of increasing summer temperature of coastal waters this may have serious consequences for the spreading of the king crabs and the establishing of new populations. However, in order to derive any predictions other factors, i.e. matching of crab spawning timing to the pelagic productivity peaks in the coastal waters, have to be examined.

Juveniles

Coastal bottom communities of Kola Peninsula Inlets are densely populated by juveniles and females of King crab all year round. Crab's density increase in spring during the reproductive migrations of males and may reach up to 25 specimens/100 m2 (source: Pereladov). In the coastal zone of Varanger fjord juvenile crabs (45-80mm) were identified in kelp, 5-15 meter depth (shallow), and on gravel beds. In Varanger fjord (Russian part) the migration activity of the King crab juveniles was low, and in the last 10 years the stock have had similar size composition between the year (Fig. 3), but different between season.

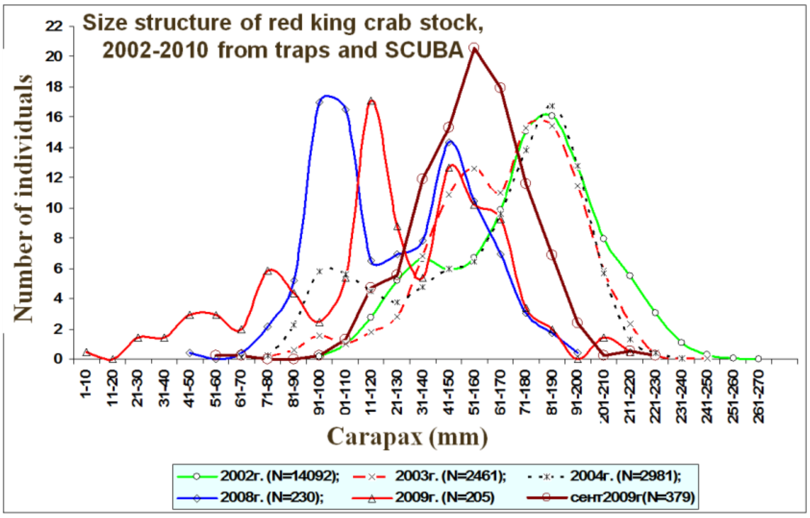


Figure 3. Size structure of red king crab stock in Russian Varanger fjord coastal waters (36 m depth) 2002-2010 from traps and SCUBA. (Source: Dr. Mikhail V. Pereladov, Russian Federal Research Institute of Fisheries and Oceanography (VNIRO), Laboratory of Coastal Research).

In shallow areas in May (spring) all groups of males and females were found. But as only few females remain in shallow water in September (autumn) no adult (>70 mm) crabs were found. A total of 10 094 000 crabs (1 575 000 commercial males) were recorded in a 181 km2 large area in Varanger fjord in one part of the year, while 4505 000 individuals (59500 commercial males) in another part of the year, probably due to migration of crabs offshore to colder waters (Pereladov, pers. comm.).

Commercial stock abundances seem to follow juvenile stock, which again correlates with temperature.

According to the data from the Varanger fjord, the local king crab stock is stable and well recovered. The recovery of the stock was recorded over 2 years after the high abundances of king crab juveniles.

In the Kola bay in the 2000s the abundance of juvenile crabs showed apparent increase from the southernmost area of distribution, near the cape Abram Mys (opposite to Murmansk) where it was generally low (< 1 1000 m-2), to the northern part of the bay where it was one or two orders of magnitude higher. Crabs older than 4-5 years occur on different types of seabed but show some preference to soft bottom. In the middle part of Kola bay main density was about 60 ind/1000 m2, (Pavlova, 2009).

Other areas are not well studied with regard to juvenile king crabs distribution and abundance because their surveys require detailed SCUBA based methods of counting and collecting. This is an important gap of knowledge because in case of numerous juvenile generations their role in the community and impact on its structure and functioning may be comparable to the one of adults.

Growth rate of juveniles in the Barents Sea assessed in the Dalnezelentskaya Inlet (East Murmansk coast of the Kola Peninsula) seems to be higher than in the Bristol Bay but lower than in the southernmost populations in the native range in the North-east Pacific (Dvoretsky, 2011). Climatic warming might also have an impact on the growth rate of the king crab.

1.2 Snow crabs

Snow crab was first recorded in the Barents Sea in 1996 (Box 1), but while king crab abundance reduced after 2005, the snow crab population is still increasing.

Box 1. The first registration of the snow crab in the Barents Sea (Source: Dr. Ann-Lisbeth Agnalt and Knut E. Jørstad. IMR).

History of the snowcrab:
1996 - Five individuals captured in Russian area
1999 - 15 individuals taken as by-catch in Russian area - occasionally also by-catch in Norway
2009 – Russians estimated to population to be 19 million crabs

Kuzmin 2001. VNIRO Publication
Alvsvåg et al. 2009. Biological Invasion
Bakanev & Pavlov 2009. Moscow meeting
Agnalt et al in press. Marine Invasive Crustacean.

The distribution area are estimated to be 50 000 square miles in 2000 and 800 000 square miles in 2010 (16 time increased in distribution (Fig. 4). The snow crab population increase was recorded between 2004-2008, and the currently numbers are 26,4 million specimens in 2010. This is expected to increase to over 291 million specimens. Estimated carrying capacity of the Barents Sea is 436 million legal males based on projections from stock assessment model.

The majority of crabs have been recorded in waters below 2°C (Source: Dr. Ann-Lisbeth Agnalt and Knut E. Jørstad. IMR), and as the snow crab prefers low temperatures it is not found near coastal areas (source: Dr. Sergei Bakanev).

The snow crab is today a self-producing population that increase in number in the Barents Sea, and small-sized crabs are exclusively found at the Goosebank (Fig. 5) and indicate a recruiting area (Source: Dr. Ann-Lisbeth Agnalt and Knut E. Jørstad. IMR).

Atlantic water input (Fig. 6) could push distribution of the snow crab to the north. Competition (space, overlapping diet etc) between snow and king crab may also influence distribution. Snow crab seems to have more limiting tolerance to temperature compared to the king crab, and the snow crab is more likely to establish in Svalbard and Franz Josef Land than king crab due to low temperature.

The snow crab expands more rapidly than the red king crab. However, the process of formation of high concentrations, including those significant for the fishery, can last longer. This can be due to different biological features of those species such as:

1) The optimum average annual habitation temperature.
2) The absence of the connection to coastal areas in the life cycle (for snow crab) or periodical migrations to coastal shallows which occur in the life cycle (for red king crab).
3) Unknown factors - knowledge gap

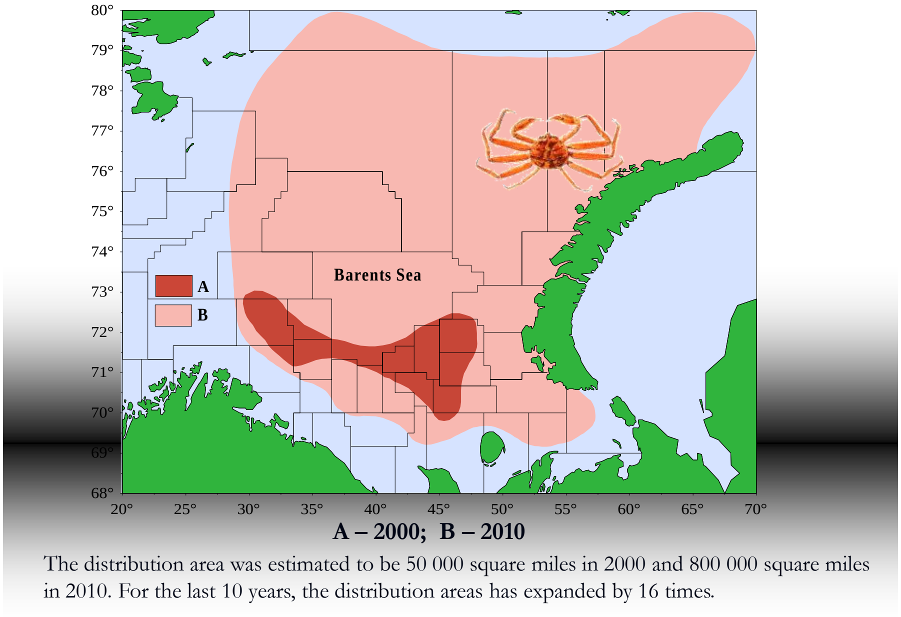


Figure 4. Distribution area of snow crab (source: Dr Sergei Bakanev, PINRO, Murmansk, Russia).

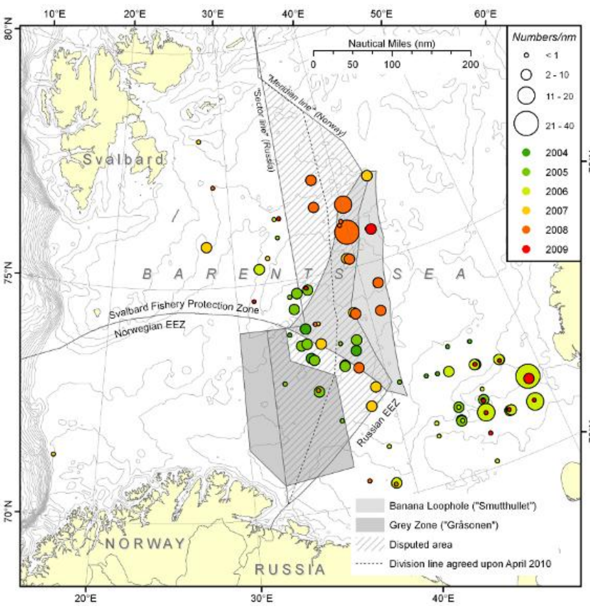


Figure 5. Registrations of the snow crab in the Barents Sea where green colours shows the first records (Goose bank in south east and Central Bank) and the red colours the most recently registrations.

Increasing its distribution range is most probably determined by low temperature (Fig. 6) (high boreal arctic species, but no indication it can tolerate sub-zero) and prey availability.

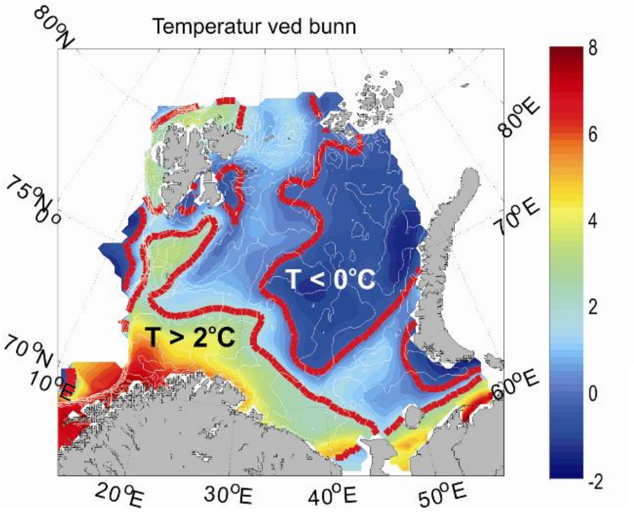


Figure 6. The bottom temperature in the Barents Sea, showing temperatures lower (blue) and higher (red) than 2°C (Source: MAREANO book – Dr. Randi Ingvaldsen).

It has been discussed from where the snow crab came into the Barents Sea. Preliminary analysis suggests that there are no genetically overlapping with Greenland and Canadian snow crab population. But the Bering Sea population showed high overlap. The western most record of *Chionocoetes opilio*, apparently belonging to the Pacific population, is from the north-eastern Laptev Sea (Sirenko, 2004) while in the Chukchi Sea this species is common (Vassilenko & Sirenko, 2009). This needs further investigation as literature on other species shows a natural spreading from the Bering Sea to the Barents Sea.

Conclusion:

The snow crab, today a self-producing population in the Barents Sea, is expected to increase to over 291 million specimens. Estimated carrying capacity of the Barents Sea is 436 million legal males.

The majority of crabs have been recorded in waters below 2°C and small-sized crabs are exclusively found at the Goosebank, indicate a recruiting area. Warming can push the snow crab further north and are likely to establish in Svalbard and Franz Josef Land.

1.3 Main points for king- and snowcrab

- The available living space (distribution area and carrying capacity) is different and the rate of increase in density in these species in new areas differs.
- The red king crab and the snow crab have similar feeding features (a diet and food composition), therefore the trophic press on benthos will be commensurate (corresponding) and depend on the ratio of density of forage benthos and their consumers in the given areas.
- Final distribution unknown due to knowledge gap on physiology of the crab at different life history stages and sex, particularly with respect to temperature tolerance (high temp).

Chapter 2. King- and snow crab foraging of prey

2.1 Consumption rate of the red king crab

Important questions of researching for the king crab foraging rate on benthos is:

- What are the preferred prey species and selection between these prey species and prey sizes.
- How many/much prey are foraged (killed or mortally wounded) by the crab.
- How fast is the prey foraged?
- When does the crab forage?

Results have shown that the fullness of the crab stomach depend on the tidal cycle (Fig. 7).

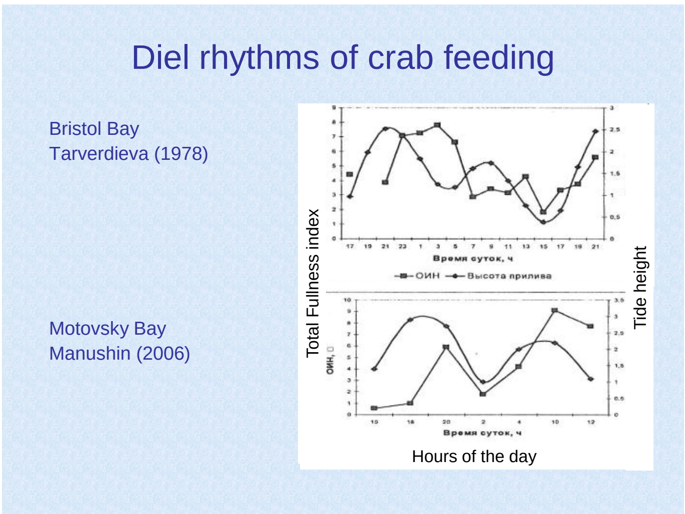


Figure 7. The dial rhythm of the red king crab (Source: Dr. Vassily Spiridonov P.P. Shirshov Institute of Oceanology of the Russian Academy of Sciences).

The stomach content of the king crab also varies between areas (Table 1) and the crab life stages (Fig. 8).

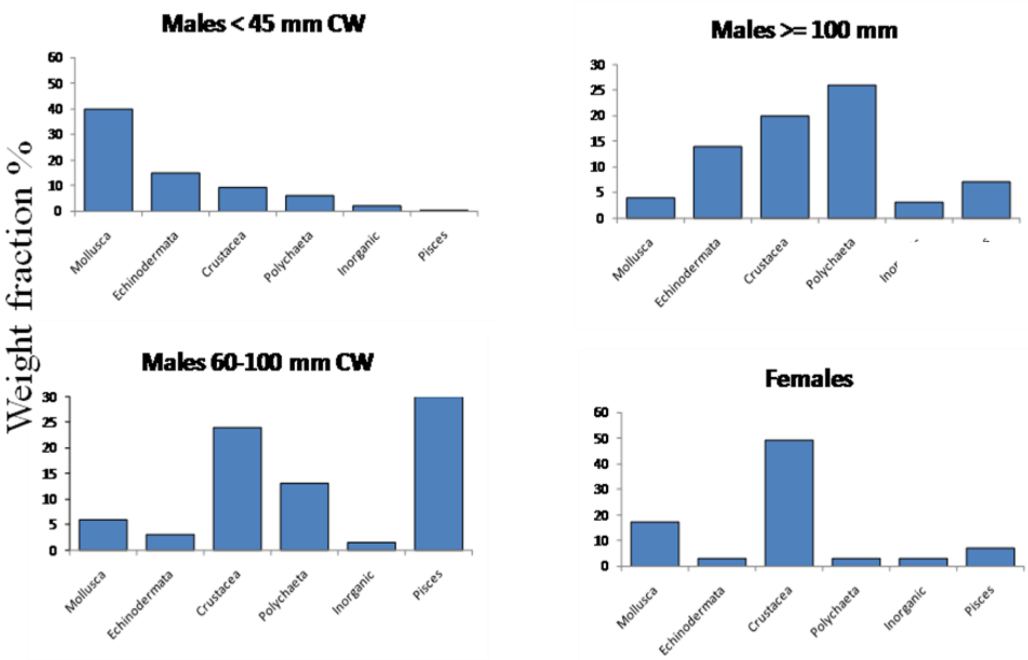


Figure 8. The weight fraction (%) of prey groups in stomachs of different sizes (CW= carapax width) of king crabs (Source: Dr. Ann-Lisbeth Agnalt and Knut E. Jørstad. IMR, from Dr. Pavlov 2007 and Agnalt et al in press. Marine Invasive Crust).

Table 1. Stomach content of king crabs (different age and size) of different areas and depth; mass composition data (Compiled by Dr. Vassily Spiridonov P.P. Shirshov Institute of Oceanology of the Russian Academy of Sciences).

Size or age group of crabs	**Area**	**Depth (m)**	**Year**	**Main stomach components (biomass) of the king crab.**		**Source**
				Summer	**Autumn - winter**	
0-2 years	Inlets of eastern Kola Peninsula	5-30	2004	Detritus, sponges, algae	Detritus, sea urchins, algae	Eletskaya, Shtrik 2006
2-4 years	Inlets of eastern Kola Peninsula	5-30	2004	Detritus, sea urchins, algae	Sea urchins, cirripeds, algae	Eletskaya, Shtrik, 2006
Juveniles, CL 12-53mm	Guba Teriberka	5-40	2002	Bivalves (especially bissusses of mussels)	No data	Tarverdieva 2003
CW mainly 101 – 239mm	Motovskiy Bay	180-225	2001	No data	Fish carrion, polychaets (mainly *Spiochaetopterus typicus*), echinoderms	Anisimova, Manushin 2003
109-148	Off eastern Kola Peninsula	60-270	2001	No data	Echinoderms, bivalves	Anisimova, Manushin 2003

Other studies show (Fig. 8) those juvenile crabs (CW <45 mm) mainly used molluscs as food, while adult males showed a dominance of polychaets, crustaceans, and echinoderms, or crustaceans and fish in their diet (source: Dr. Ann-Lisbeth Agnalt and Knut E. Jørstad).

In the Kola Bay, on shallow water with soft/mixed bottom, juvenile crabs (CL 15-100 mm) foraged/killed a prey biomass equal to 5-15% of the crabs own body-mass per 24 hours (Fig. 9), and the juveniles had a higher consumption per biomass (C/B) compared to the adults (Pavlova, L. pers.com, Pavlova, L. 2008).

Juveniles (0-4 years) in shallow water (5-40 m) were found to have detritus, sponge, algae and sea urchins in the stomach, independent of area and season (Table 1). Adults (100-240 CL) have mostly echinoderms, bivalves, polychaetes and fish carrion. However mass composition of the stomach content are limited (Table 1) and most studies on King crab feeding operate with frequencies of occurrence.

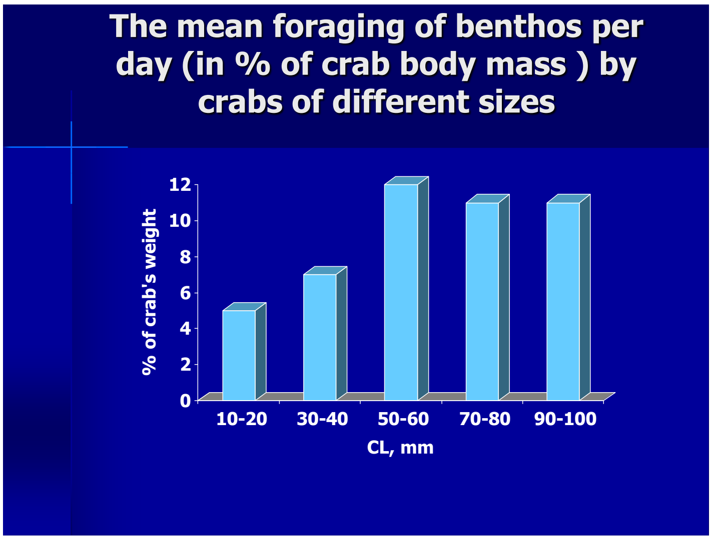


Figure 9. Foraging of benthos by juvenile crabs from shallow coastal Kola Fjord (source: Dr. Lyudmila Pavlova, Murmansk Marine Biological Institute of KSR RAS).

Juveniles change their food preference as they increase in body size, and when reaching approximately 50 mm Carapax lenght they have a close to similar diet as the adults. Food was dominated by echinoderms, mostly sea urchin (*Strongylocentrotus* sp. from 2-3mm to 60-70mm) and mollusks (*Mytilus edulis*, from a few mm up to 5cm).

In the Russian waters on the shelf of the Kola Peninsula, the main food groups of the King crab were Echinodermata, Bivalvia, Gastropoda and Polychaeta (Anisimova and Manushin, 2003). Foraging also included organisms killed, but not consumed. Foraging rate is at the highest when the crab is 50-60 mm carapace length, and reduces for larger sized crabs. Large males (3-4kg) consume about 100% body mass per year at 3°C, and the consumption increases with increasing temperatures (Manushin, 2003; Joint RN Report 2005). A king crab kills about twice the biomass consumed (6-8 kg annually).

The benthic biomass in the East Murman area is 31 g ww/m2 with an annual production of benthos of 157 g ww/m2. The crab eats 7.5 g ww/m2 of benthos and destroys 15 g ww/m2 in year. So annual foraging of crabs, in high crab density areas, is half of the benthic biomass and 1/10 of the total benthos annual production. Annual foraging of crabs range between 5 to 40% of the total benthos production. This calculation (foraging model) was based on a average crab size of 120mm CL that approximately eat 10 times its body weight annually (source: Manuchin, Anisimova, Lubin).

For the Dalne-Zelenetskaya inlet, Britayev et al. (2006) calculated [by extrapolating the findings by Pavlova and Rzhavsky (2006)] that crab juveniles (length of carapace less than 88 mm) may consume between 3850 and 7100 kg of wet benthic biomass per year, while the total biomass of macrobenthos on soft bottom of the inlet is estimated to be about 5000 kg. However, the biomass of the soft bottom benthos was probably underestimated because not all types of sediments were sampled equally effectively (Rzhavsky et al., 2006).

On the purely soft sediments, king crabs use a characteristic feeding method: following the scooping-up of sediment to the depth of 10-15 cm) by the lesser chela and then sieving organisms using the third maxillipeds (Rzhavsky and Pereladov, 2003; Jørgensen, 2006). The rate of bioturbation and removal of benthic organisms for such mode of feeding remain unknown.

In any case, King crab feeding on soft sediments appears to have low selectivity while underwater observations indicate that foraging on hard substrates is selective (Pereladov and Rzhavsky, 2003).

Laboratory results (source: Jørgensen 2006 and Jørgensen and Primicerio 2007) suggest that prey foraging rates (killed or mortally damage prey) on scallops (*Chlamys islandica*) increase with crab body weight from 85g (juveniles) to 400g (large adults) per 24 hours (Jørgensen and Primicerio 2007) (Fig 10) while small juveniles forage 1-26 g (Pavlova et al 2007).

When offered a varied diet of several prey species large (~3kg), medium (~1.7kg) and small (~0.5kg) crabs forage 400g/24 h (200-600g/24h), 300g/24 H (200-400g/24h) and 85g/24h (50-140g/24h) gram prey (*Chlamys islandica*/*Mytilus edulis*/*Strongylocentrotus* spp./*Asterias rubens*) respectively (source: Jørgensen 2006).

Big, long-lived species may be threatened. Scallops believed to be particularly vulnerable because they have no size refuge. Scallop beds might be even more threatened in low diversity areas (Fig. 11).

The foraging rate estimates show that the king crab invasion threatens native benthic species with slow motility and growth.

Among the vulnerable prey, scallops are particularly exposed due to accelerating predation rates as function of predator density and size, and of alternative prey availability.

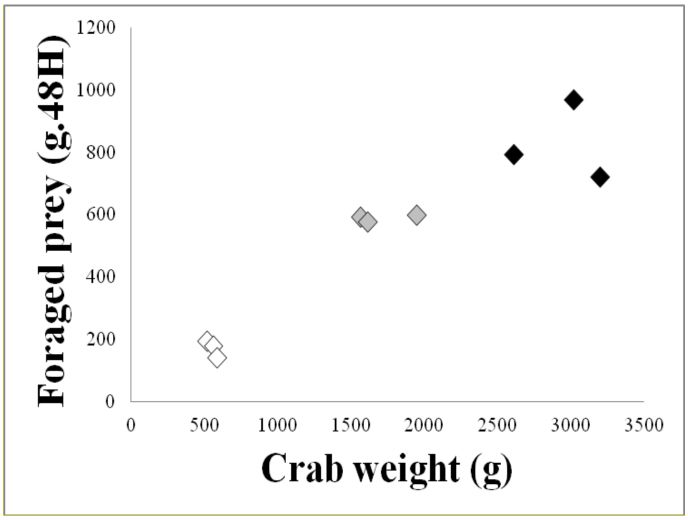


Figure 10. Amount of foraging *Chlamys islandica* (killed or mortally damage) in gram/48hours for small, medium and large crabs. (source: Jørgensen and Primicerio 2007).

Large crabs seem to prefer scallop over sea stars, sea urchins and blue mussels, while small crabs seem to prefer sea stars over scallops. Both crab sizes eats a variety of prey species when given several prey types which indicates that scallops in a high diversity scallop bed is less vulnerable compared to a scallop bed with a scallop monoculture.

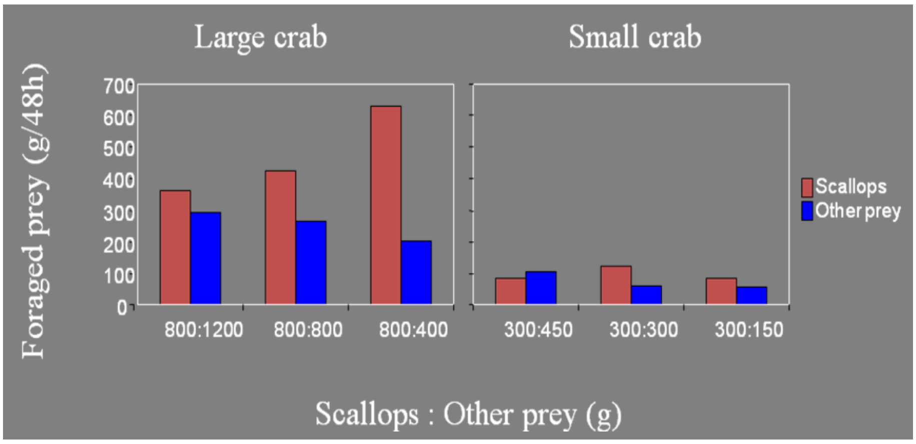


Figure 11. Large and small crabs foraging on scallops and ”other prey” when offered in different (800:1200, 800:400 and 300:450, 300:150 gram) or in similar (800:800 and 300:300 gram) amount of weight. (source: Jørgensen and Primicerio 2007).

In a density dependent foraging laboratory study (source: Jørgensen and Primicerio 2007), large crabs foraged the same amount of prey independent of number of crabs (1, 3 or 6) in the tank. Medium sized crabs forage more at high density (6 crabs in the tank) which might be explained by the crab stressing each other and therefore killing/mortally damaging more prey than eaten. Small crabs did not change forage rate with increasing density.

King crab leaving finger prints on scallops (Picture 1) can work as a indicator when relating scallop predation to king crab predation. If scallops had died a “natural death” or were foraged by a sea star, the scallop valve might be intact.

The workshop agrees on that the King crab is a generalist and opportunistic predator, feeding on what is available. Crustaceans seem to play a minor role in the king crab diet.

Some benthic species may be regarded as prey references of the king crab and might be used as indicator species. In particular the widely distributed sea star *Ctenodiscus crispatus* and some other asteroids and ophiuroids can be considered as such indicator species on soft bottom due to significant reduction of this species has been recorded on both Russian and Norwegian side (Porsanger fjord, Motovskiy bay). Other prey indicator species includes bivalves (preferred food and relatively stable populations due to slow growth) such as *Bathyarca glacialis* and *Chlamys islandica*.

The crab forage on dominant species in the community, and it is possible to focus the crab impact studies to these species (source: Anisimova).

Picture 1. King crab “finger prints” on scallops (source: LL Jørgensen).

2.2 Knowledge gaps

Information of crab feeding on hard bottom and near-shore areas is lacking for most areas of the present crab range. This is important information due to the ecological value of these areas. There is a need to study the feeding behaviour of the king crab, keeping in mind that it is a new species in the Barents Sea, its feeding mode is very flexible and will probably change over time.

2.3 Snow crab

The snow crab feed on benthos and fish. Feed mostly on crustacean (Tab. 2), polychaetes and fish (capelin mainly). These crabs show rapid movement, thus being able to capture (fast) moving prey.

Snow crab consumption: Diet data from Pavlov (in Russian, PINRO) can be used in combination with stock abundance to calculate consumption and Russian far-east/North-American studies.

2.4 Recommendations

- Collect all existing estimates of daily consumption derived from experimental and field studies.
- Conduct experiments on food consumption of different size groups of King crab under various temperatures
- Refine growth and mortality parameters for King crabs and their prey for use in production models.
- Compare estimates of natural mortality used in the crab stock assessment models to the natural mortality values obtained from juvenile crab studies.

- Use production models to evaluate relative importance of different crab size and crab age groups for the total impact on benthic prey species and their communities.
- Make a review, comparing king and snow crab diet.
- Develop standardised methods of studying crab diet and combine field and lab studies.
- Develop a model that captures the dynamics between crab distribution (migration), prey availability and consumption by the king crab.

Table 2. Stomach content of snow crabs (no 115) from the eastern Barents Sea (Source: Dr. Ann-Lisbeth Agnalt and Knut E. Jørstad. IMR, from Dr. Pavlov 2007 and Agnalt et al in press. Marine Invasive Crust)

Food items	**Weight fraction %**	**Dominance %**	**Occurrence freq %**
Crustacea	**32.2**	**15.6**	**41.6**
Copepoda (*Oithona similes*, *Calanus finmarchicus*)	+	0.7	9.7
Amphipoda	0.2	1.0	0.6
Cumacea (*Eudorella*, *Diastylis*)	4.2	0.7	5.6
Isopoda (*Saduria sabini*)	7.5	2.0	2.4
Euphausiacea	0.2	1.0	1.4
Decapoda	20.1	10.2	6.6
Pandalus borealis	6.9	8.9	2.3
Pagurus pubescens	12.4	0,3	0.7
Chionoecetes opilio, Hyas sp.	0.8	1.0	4.8
Polychaeta	**18.9**	**25.4**	**52.6**
Sipunculoidea (*Golfingia oculata*, *Phascolion strombus*)	**2.5**	**0.7**	**0.9**
Mollusca	**8.3**	**15.3**	**44.4**
Bivalvia	6.6	10.9	34.0
Gastropoda	1.3	2.7	17.1
Antalis entalis	0.4	1.7	3.3
Echinodermata	**8.1**	**8.8**	**20.2**
Ophiura sarsi	8.1	8.8	20.2
Foraminifera	**0.2**	**4.4**	**6.1**
Bryozoa	+	**0.3**	**0.3**
Pisces	**17.9**	**14.9**	**27.5**
Nematoda	+	**0.6**	**1.0**
Detritus	**9.4**	**9.5**	**20.6**
Inorganic components*	**2.5**	**4.5**	**18.8**

Chapter 3. Case studies of king crab impact

3.1 Porsanger fjord, Norway, 30-300m, coarse to soft bottom.

Presented by Dr Lis Jørgensen (IMR).
For publications see: Jørgensen et all (in prep), Fuhrmann et all (in prep).

Comparative studies in the Porsanger fjord, where same stations were studied in 2008 and again in 2010 shows up to 6 times reduction of the benthic community biomass. This is most likely a direct effect of the king crab foraging. This is concluded on the fact that prey species such as sea stars, sea urchins, brittle stars and bivalves all showed sign of reduction in abundance and biomass together with an increase in numbers of the newly invaded king crab. These data are currently being published (Source: Dr. Lis L. Jørgensen, IMR).

3.2 Varanger fjord, Norway, 10-90m, soft bottom.

Presented by Dr. Eivind Oug (NIVA) and Dr. Sabine Cochrane (APN). For publication see: Oug et al. (2010).

An investigation from 2007-2009 in areas of Varanger (Fig. 13) showed an epifauna of sponges and of detached kelp-fragments, fish, and otherwise a very species poor community with small echinoderms (<3cm). A similar investigation in 2006 from areas of the comparative Porsanger fjord (almost without any king crabs) *Ctenodiscus crispatus* dominate, together with crustaceans, some flatfish, sea anemones, and large sea urchins.

The Varanger infauna (Bøkfjorden) was sampled in 1994 (deep water) and again in 2007 (deep and shallow). This investigation showed a reduced Shannon wiener index (one unit drop) and evenness (one unit drop= high dominance of some species). Analyse of the species composition showed significant reduction in polychaetes. But some polychaet species show an increase (*Myriochele* sp) (Fig 14). Bivalves reduced, apart from small species which increased. Echinodermata showed a significant reduction.

Feeding groups (suspension, surface deposit, subsurface deposit feeders and carnivores/omnivores) seems to stay the same (relative composition), but the species composition had changed.

The sedimentary environment was investigated by photos of the sediment profile and surface. The markedly reduced fauna (epi and infauna) had most probably lead to loss of structural and functional diversity. Biological activity in the Bøkfjord shallow station showed poor habitat quality with only a thin surface layer being oxygenated. This station also had a low biodiversity. Deeper station had better habitat quality. Poor habitat quality could be caused by king crab reducing the bioturbating fauna. The top layer of the sediment may keep the sediment oxygenated in the top layer or else will this cause fundamental change in sediment integrity with strong layering and progress towards anoxia in deeper layers.

3.2.1 *Knowledge gaps*

There is a need for essential knowledge on soft bottom ecosystem functioning and production. Risk management- do species assemblages become more susceptible to other environmental stressors?

Where “crab tracks” was observed the polychaetes *Galathowenia* and *Myriochele* dominated. They live in tubes and can seek shelter inside these. The polychaeta Nephtyiidae moves fast moving and were found only (almost) in areas with crabs. There is a dominance of “hide or flight” strategy bottom animals in king crab areas. Areas with refuge still have high biodiversity

3.2.2 *Future directions*

- Analyse of crab stomach contents from Varanger fjord should be compare with results of Manushin, Pavlova etc. and a joint Russian/Norwegian assessment of ecosystem consequences (local vs systems effects, food webs, sediment function) should be started.
- Follow-up monitoring both temporal and spatial.
- Kobbholmfjord has a shallow sill, but is quite open mouth. Threshold fjords should be preferred as monitoring sites because they make up a “mini-cosmos” that can be assessed.
- Get stable isotope data in order to determine what the crab feed on.

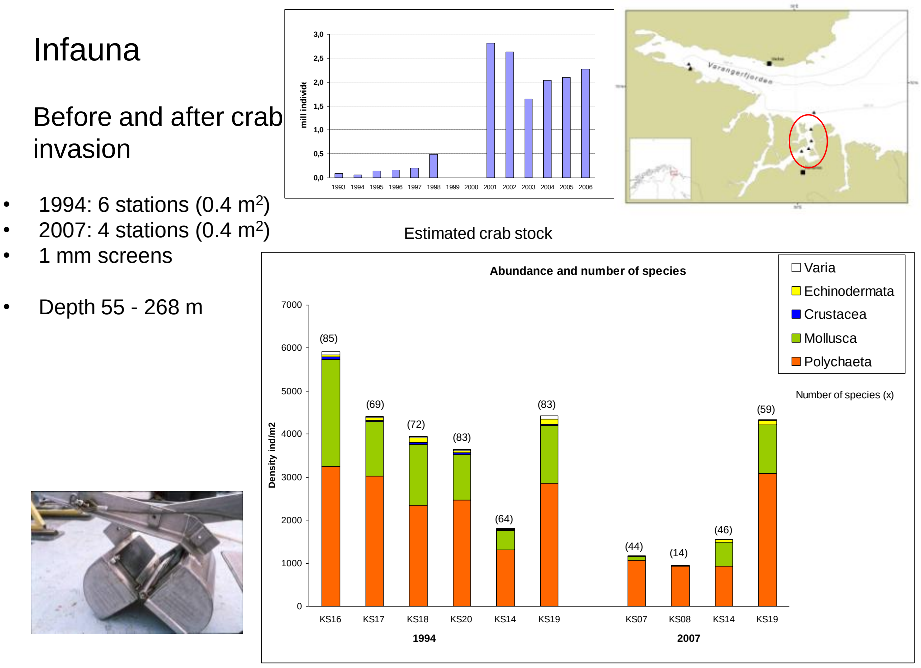


Figure 13. Benthos standing stock and benthos production of selected areas of Varanger fjord (NO) Source: Eivind Oug (NIVA), Sabine Cochrane (APN)

Bøkfjord infauna

Changes for dominant macrofauna (> 50 ind m^{-2}) at revisited stations (198-264 m)

	Mean density ind. m^{-2} 1994	2007	Change (%) 1994-2007
Polychaeta			
Lumbrineris mixochaeta	390	73	-81
Scoloplos /Leitoscoloplos	138	4	-97
Prionospio cirrifera	51	-	-100
Spiophanes kroeyeri	73	4	-95
Chaetozone setosa	232	-	-100
Euclymenidae (incl. *Praxillella*)	332	25	-92
Maldane sarsi	198	416	110
Galathowenia oculata	223	935	319
Myriochele olgae	28	418	1396
Laphania boecki	431	1	-100
Proclea malmgreni	82	1	-98
Bivalvia			
Yoldiella frigida /fraternal	263	168	-36
Yoldiella lenticula	277	19	-93
Dacrydium vitreum	73	33	-56
Thyasira equalis	155	325	109
Thyasira pygmaea	434	224	-48
Sipunculida			
Golfingia cf *minuta*	75	21	-72
Echinodermata			
Ctenodiscus crispatus	13	-	-100

Figure 14. Benthos standing stock and benthos production of selected areas: Varanger fjord (NO) Source: Eivind Oug (NIVA), Sabine Cochrane (APN)

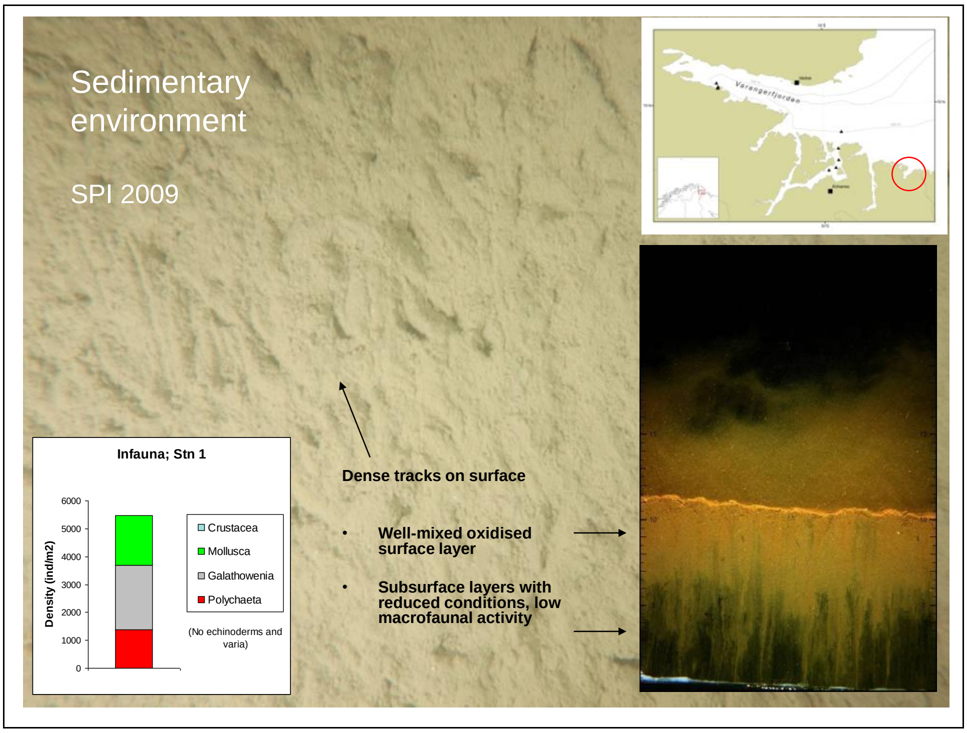


Figure 15. Sediment surface (left) and profile (right) and infauna composition (box-diagram) of Koppholmfjorden, in Varanger fjord (NO). Source: Eivind Oug (NIVA), Sabine Cochrane (APN). The surface sediments show crab tracks. The crab digs its claws up to 5 cm into the sediments when foraging. Sediment profiles in crab track and no crab track sediments looks similar. But benthic fauna composition on the "no crab track" sediment had more molluscs.

3.3 Varanger fjord, Russia, 0-50m, hard bottom.

Presented by Dr. Mikhail V. Pereladov (VNIRO). For publications see Pereladov, 2003; Perealdov et al., 2009.

Since the year 2001 the Laboratory of Coastal Research of VNIRO conducts regular survey of the coastal waters of the Russian part of Varanger fjord focused at the dynamics of King crab population and particular components of benthic communities, i.e. kelps (Fig. 16) and populations of sea urchins (*Strongylocentrotus* spp., *Echinus esculentus*), Iceland scallop (*Chlamys islandica*), horse mussel (*Modiolus modiolus*).

This study shows that juvenile crabs are present in the coastal waters all year round, often with high density. During spring, with the adult migration to the shore, densities may reach 25 ind 100m-2. For this area rich communities on hard substrate are common (Figs 16, 17) which show high spatial and temporal variation that can't be easily attributed to the impact of particular factors.

Currently the data on sea urchin population density were analyzed. This characteristics does not correlate with king crabs abundance, and the current data do not indicate a definite King crab impact on sea urchins population within the first decade of the XXI century.

3.3.1 Knowledge gaps:

There is a need to find any pre-invasion data to compare to the current data on hard and soft bottom community diversity to get an idea of possible changes. The program started in the Russian part of Varanger fjord in 2001 has to be continued to perform long term monitoring. Lagoons of Ambarnaya Inlet should be studied because they represent a partly isolated system with little other anthropogenic disturbance than the effect from the crab.

3.3.2 Future directions for coordinated Norwegian-Russian studies in Varanger fjord:

Analyses of crab stomach contents from Varanger fjord should be compared with results of Manushin, Pavlova etc. and a joint Russian/Norwegian assessment of ecosystem consequences (local vs systems effects, food webs, sediment function) should be started.
Follow-up monitoring both temporal and spatial.

Kobbholmfjord has a shallow sill, but a quite open mouth. The lagoons of Ambarnaya Inlet (Guba Ambarnaya) have a very narrow and shallow entrance and a significant depth inside. Such threshold fjords should be preferred as monitoring sites because they make up a "mini-cosmos" that can be assessed.

Get stable isotope data in order to determine what the crab feed on.

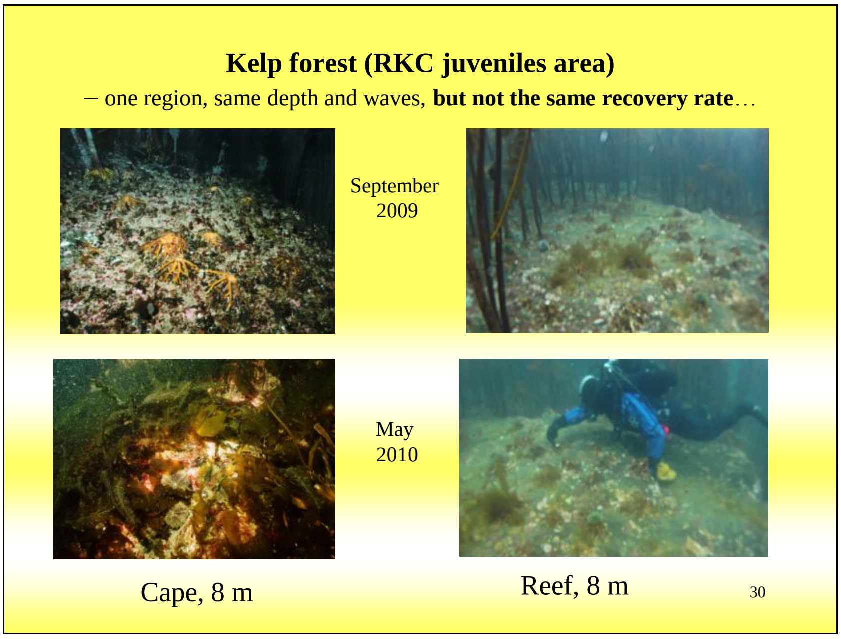


Figure 16. Kelp communities in the Russian part of Varanger fjord. Source: Mikhail V. Pereladov (VNIRO). Dynamics of Red King Crab (RKC) juveniles in the Russian part of the Varanger fjord coastal waters in 2001-2010 - with some reflections about their influence on sublittoral macrobenthos (ps: editororial changings to text).

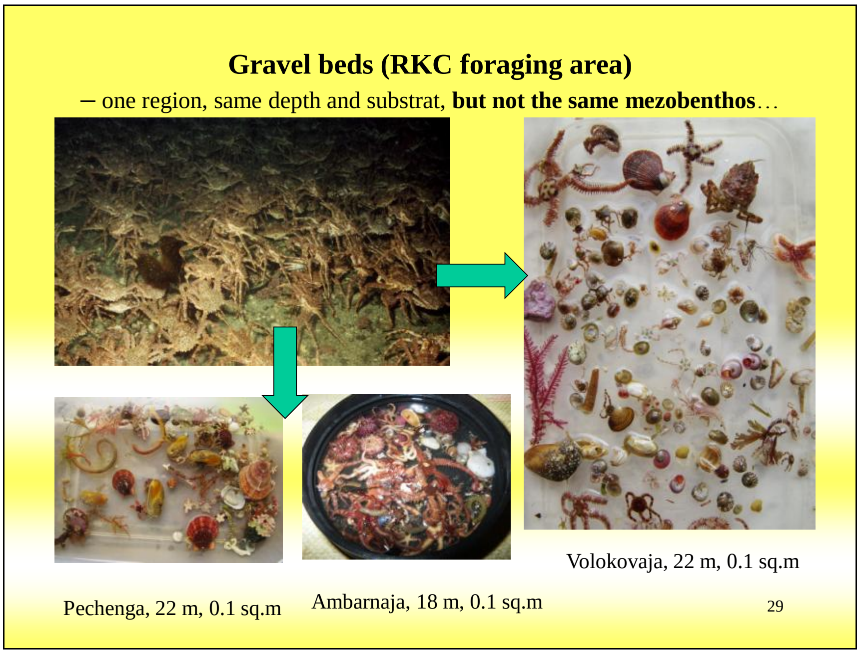


Figure 17. Juvenile king crabs and characteristic benthic organisms on hard substrates of the Russian part of Varanger fjord. Source: Mikhail V. Pereladov (VNIRO). Dynamics of Red King Crab (RKC) juveniles in the Russian part of the Varanger fjord coastal waters in 2001-2010 - with some reflections about their influence on sublittoral macrobenthos (ps: editororial changings to text)

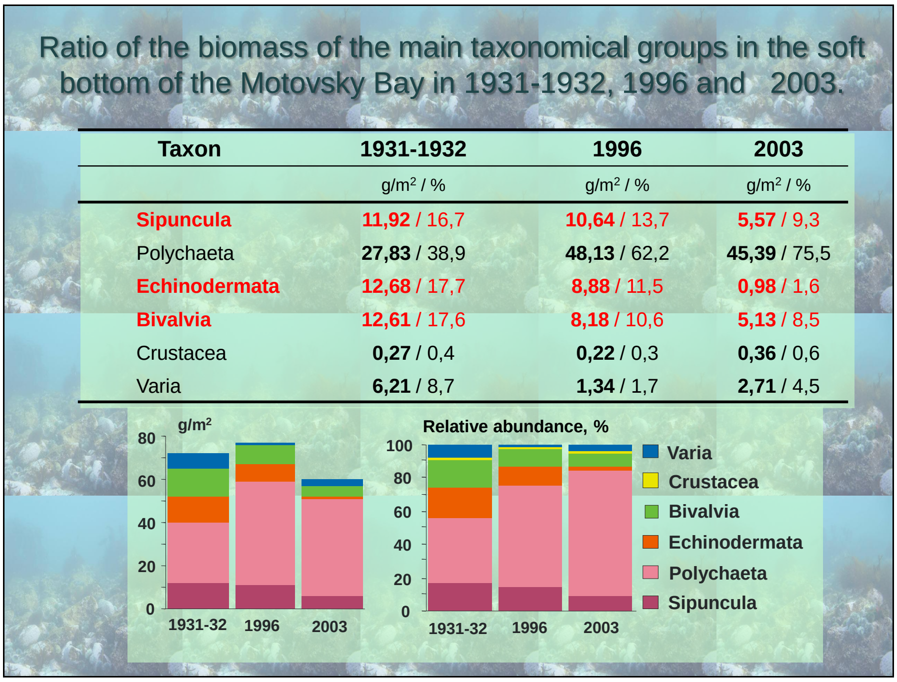
3.4 Motovsky Bay, Russia, 50-200m, soft bottom

Presented by Dr. Natalya Anisimova, Igor Manushin and Pavel Lyubin (PINRO). For publication see: Frolova et al., 2003.

Motovsky Bay was the first area to be invaded by the crab. This area has also been subjected to benthic surveys before the crab entered and is therefore qualified as a "before (1931), "in the beginning" (1995) and "during" (2003) study (Fig. 18). The biomass of benthos was slightly higher in 1996 compared to 1931, and slightly lower in 2003. Fish-trawling was intense in outer part of the fjord 1989-1994 where the biomass of benthos increased. But in the years 1996-2003 trawling decreased and total biomass of benthos declined (more than halved) from 1996 to 2003. Fish remains could have increased the biomass of carnivorous benthos in the earlier years. There were changes in biomass composition of the community over the time period when the Polychaeta increased their biomass contribution, while other groups declined.

This indicates that the king crab activity might have changed the soft bottom communities over the past 70 years. In 1995 the polychaet-biomass increased from 39 to 62% while the echinoderms decreased from 17 to 11% of the total fauna. At depth below 100 m, which are frequently occupied by the Kamchatka crab, some previously common echinoderms (*Ophiura sarsi, Ophiopholis aculeata*) and bivalves (*Astarte crenata, Elliptica elliptica*) were virtually absent (Frolova et al. 2003).

By 2003 the standing stock of "preferred prey species" (Fig 20, Tab 3) of king crab has declined, and they were no longer dominant in the community while many "non-prey species" of the king crab have become more dominant.



Taxon	1931-1932	1996	2003
	g/m² / %	g/m² / %	g/m² / %
Sipuncula	**11,92** / 16,7	**10,64** / 13,7	**5,57** / 9,3
Polychaeta	**27,83** / 38,9	**48,13** / 62,2	**45,39** / 75,5
Echinodermata	**12,68** / 17,7	**8,88** / 11,5	**0,98** / 1,6
Bivalvia	**12,61** / 17,6	**8,18** / 10,6	**5,13** / 8,5
Crustacea	**0,27** / 0,4	**0,22** / 0,3	**0,36** / 0,6
Varia	**6,21** / 8,7	**1,34** / 1,7	**2,71** / 4,5

Figure 20. Benthos in the southern part of the Barents Sea and fjords. (Source: Natalya Anisimova, Igor' Manushin, Pavel Lubin (PINRO)).

Table 3. Dominant species in the soft sediment of the Motovsky Bay in the periods 1931-1932, 1996 and 2003. Species in red have shown reduction in the given period. (Source: Natalya Anisimova, Igor' Manushin, Pavel Lubin (PINRO)).

Species	1931-32	1996	2003
Maldane sarsi	* 38,15	* 41,1	* 47,1
Golfingia m. margaritacea	* 25,75	* 13,5	* 16,3
Ctenodiscus crispatus	* 20,1	* 8,0	4,02
Nothria hyperborea	* 17,21	3,9	1,39
Bathyarca glacialis	* 16,95	* 10,4	3,56
Astarte crenata	* 14,55	1,86	1,84
Edwardsiidae g. spp.	* 14,35	* 5,45	* 11,37
Phascolion s. strombus	* 12,17	5,02	2,01
Ophiura sarsi	* 11,80	3,64	3,55
Spiochaetopterus typicus	* 9,35	* 7,5	1,5
Nephtys ciliata	* 8,84	* 21,9	* 12,48
Galathowenia oculata	* 7,84	* 12,9	3,22
Nicomache lumbricalis	* 6,55	2,64	4,49
Terebellides stroemi	* 5,23	* 5,9	3,63
Lumbrineris fragilis	* 4,80	3,87	2,77
Yoldiella lenticula	* 3,93	* 13,4	* 11,51
Ophelina acuminata	* 3,78	3,65	0,09
Clavularia arctica	* 2,80	-	-
Lepeta coeca	* 2,49	0,44	1,08
Icasterias panopla	* 2,23	-	-

3.4.1. Knowledge gaps and future directions.

Data for the coastal zone (0-50 m), where juvenile and young king crabs are concentrated, are lacking for the Motovsky Bay.

Comparing the 1931 data with new data was done by using the survey description in the literature (Leibson, 1936). There is a need to search for the actual station by station data in the archives and do comparison using multivariate statistics.

Stations done in 1931, 1996, 2003 have to be revisited and re-sampled using comparable methods in order to identify trends or reversibility of changes.

3.4.2 Kola bay, Russia, 5 to 30m, rocky and soft bottom.

Presented by Dr. Lyudmila Pavlova, Murmansk Marine Biological Institute of KSR RAS. For publication see: Pavlova, 2009; Britayev et al., 2010.

In the Kola Bay little quantitative historical benthic data are available. In 2006, the biomass of benthic invertebrates was negatively correlated with number of red king crab on soft-bottom. In the coastal area of Kola Peninsula the productivity of benthic communities is higher on hard, than on the soft substrates. Moreover, hard substrates are usually covered by macrophythes which has the possibility to hide small invertebrates from predators. So, in general, soft bottom communities seem more vulnerable to crab impact than hard bottom communities (Source: T.A. Britayev, Y.V. Deart, A.V. Rzhavsky, A.N. Severtsov Institute of Ecology and Evolution, Russian Academy of Sciences, Moscow, Russia).

The inner-most part of Kola bay showed the highest abundances of benthic animals (Fig. 19). This was declining out the bay, but finally increased in the open part of the bay. In the open outer part of the bay with high density of the king crab, the biomass of the soft bottom benthos particularly of some large “crab prey” species was low. The productivity of soft bottom and some of the hard bottom fauna communities was low. This is most likely due to the fact that the main bulk of the benthos production is consumed by predators.

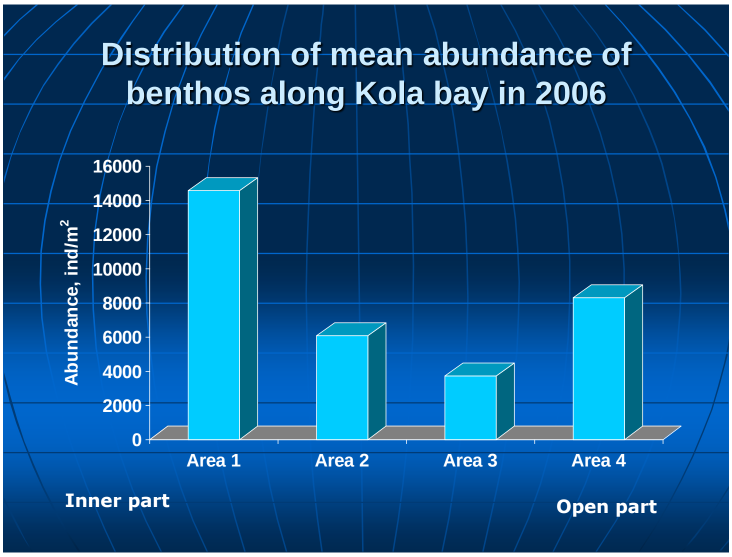


Figure 18. Abundance of benthos along the Kola bay from inner to outer part (Source: Dr. Lyudmila Pavlova)

Main food groups for the juvenile king crab are bivalves, gastropods and polychaets with an annual foraging of 5-40% of the benthic production in high crab-density areas. Foraging also included organisms killed, but not consumed.

Past years decline in juvenile crabs have been followed by increase in benthos biomass (bivalves and polychaeta indicators of predation). 50 juvenile crabs/1000m2 is suggested by Dr. Pavlova as a threshold level of benthic impact.

Changes in the size structure of the benthos were recorded, and smaller benthic organisms dominate in high density crab areas. But as Kola Bay is a polluted area, the bay might not be a good reference point due to the high anthropogenic impact.

3.5.1. Knowledge gaps and future directions

There is a need to use Derjugin's (1915) data and other historical material to identify changes in benthic species composition and occurrence (quantitative comparison is hardly possible) in the Kola Bay.

Study seasonal changes in King crab distribution and abundance and estimate their foraging rate changes round year.

Conduct monitoring by regular re-sampling of the benthic stations in the Kola Bay performed in the first half of the 2000s.

3.6 Bays and inlets of the East Murmansk Coast

Presented by: T.A. Britayev, Y.V. Deart, A.V. Rzhavsky, A.N. Severtsov, Institute of Ecology and Evolution, Russian Academy of Sciences, Moscow, Russia.
For publication see: Britayev et al., 2006a,b, 2007, 2009, 2010; Rzhavsky et al., 2006.

Studies have been performed in Dolgaya Inlet, Yarnyshnaya inlet, Dalnezelenetskaya inlet with a recorded mass appearance of crabs in the mid 1990's (Fig. 19).

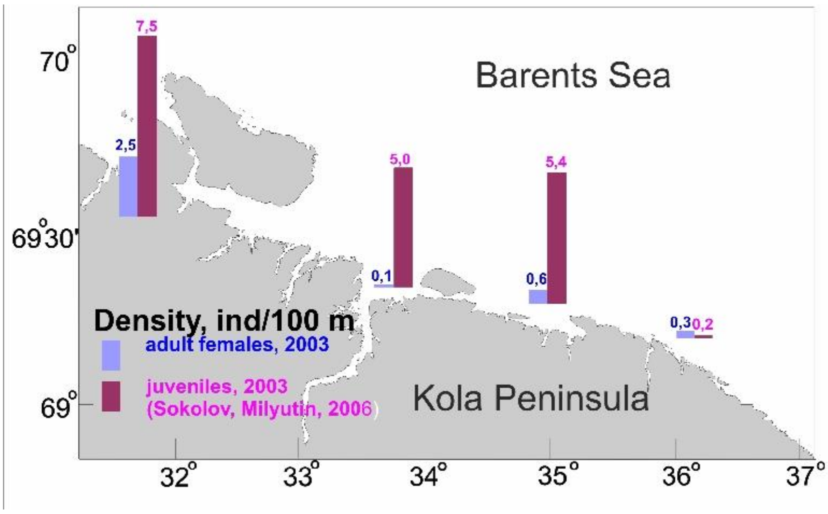


Figure 19. Crab density in Motovsky Bay (to the left), Kola Bay, Zelenaja/Dolgaja Inlet and Yarnishnaja/Dalnezelenetskaja Inlet (to the right). (Source: T.A. Britayev, Y.V. Deart, A.V. Rzhavsky, A.N. Severtsov Institute of Ecology and Evolution, Russian Academy of Sciences, Moscow, Russia).

A grab survey in the Dolgaya Inlet in the 1990 (low amount of king crab) and again in 2006 indicated considerable changes which have been taking place during the 15 years. Only 3 types of communities vs. 6 in 1990 were found in 2006. Most notable change was within the dominance pattern: calacareous algae *Lithotamnium* sp., clams *Ciliatocardium ciliatum* and *Astarte crenata* and scallop *Chlamys islandica* were no longer dominant while the importance of barnacles *Balanus balanus* and *B. crenatus* had increased. During the 15 years the bivalve species richness decreased from 24 to 16 species, and only 12 species were refund (Britayev et al., 2007; 2009, 2010). One can attribute this to the predation impact of king crabs which are known to feed frequently on particular species of clams and scallops. The points weakening this explanation are the absence of "finger-print" of king crab given crushed bivalve shells and the illegal dredging for scallop that likely has been going on in this area.

In 2002 – 2004 a survey of epifauna on hard bottom of Dalnezelenetskaya Inlet was replicating Propp's (1971) study from 1960s. The result indicated that species richness did not change, the principal "type specific communities" identified by Propp (1971) were present (Britayev et al., 2007) while the changes in the dominance pattern were moderate. Compared to the situation in the 1960s the mean density of sea urchins, *Strongylocentrotus* spp. on the exposed areas decreased by one order of magnitude while the decrease of the biomass was less pronounced.

In sheltered habitats, i.e. in the kelp and calcareous algae biotopes the average biomass of sea urchins increased (Britayev et al., 2006a,b, 2007). This was interpreted as a possible effect of crab predation on juvenile sea urchins leading to decreasing their population density and associated acceleration of individual growth (Britayev et al., 2006b; 2007).

Soft bottoms communities at depth of 3-20 m in the Dalnezeleneteskaya Inlet were dominated by the bivalve *Macoma calcarea*, the polychaete *Cistenides granulata*, or *Nephtys pente* and may be considered as variations of the *M. calcarea* community. Data for the long term comparison are absent (Rzhavsky et al., 2006; Britayev et al., 2007; 2010).

3.6.1. Knowledge gaps and future research

Dolgaya Inlet should be investigated again in order to follow possible changes in diversity and structure of communities.

3.7 Open waters in the southern Barents Sea, Russia, 100-250m, soft bottom.

Presented by Dr. Natalya Anisimova, Igor Manushin and Pavel Lyubin (PINRO).
An observed eastward shift of King crab commercial concentrations, from deeper to shallow areas, might be due to food depletion.

At stations in the open Barents Sea (Fig. 21) with high crab density, the diversity of benthos was relative high (~ 65 sp/0.1m2).

The preferred prey species of the king crab was investigated by comparing stomach samples and available benthos (Fig. 21) and showed that *Astarte* spp, *Ctenodiscus crispatus* and two species of ophiuroids were among the top priority and might be used as "Indicators".

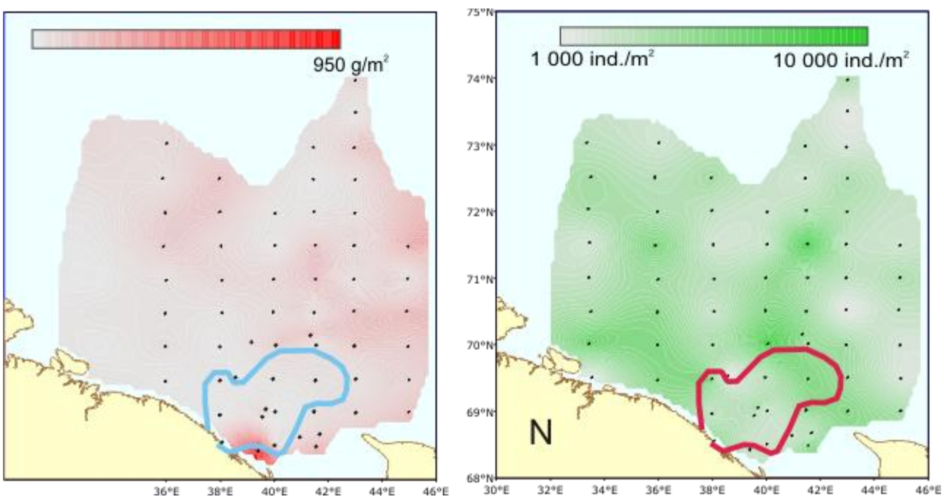


Figure 21. The area of the open Barents Sea covered for the study of king crab effect on the benthos (biomass red, and abundance green). (Source: Natalya Anisimova, Igor' Manushin, Pavel Lubin (PINRO).

Preferred prey taxa and its production, g/m^{2}year^{-1}
(according to content of crab stomachs)

Astarte spp.	- 2.67	*Crenella decussata*	- 2.26
Ctenodiscus crispatus	- 6.36	*Macoma calcarea*	- 0.76
Ophiocten sericeum	- 0.10	*Ophiura sarsi*	- 0.72
Ophiura robusta	- 4.72	*Phascolion strombus*	- 0.31
Scaphopoda g. spp.	- 2.47	*Spiochaetopterus typicus*	- 19.05
Yoldiella spp.	-9.32		

Figure 22. The prey species (from stomach studies) of the king crab and the production of the prey. (Source: Natalya Anisimova, Igor' Manushin, Pavel Lubin (PINRO).

The annual benthic production in the open waters in the southern Barents Sea is calculated to 204g/m2 (benthic biomass: 78.8 g/m2, abundance: 5535 ind./m2, and 4°C). If this calculation is done only on the king crab prey species (biomass: 31.2g/m2) the annual benthic production is 84.9 g/m2.

The total amount of benthos consumed by crabs is 7.5 g/m2 annually. When including prey remains not eaten but killed, the real "consumption" of benthos is 15g/m2. The calculation shows that in 2003 the crabs had consumed about half of the prey benthic biomass which is about 1/5 (=17%) of the annual production (Fig. 23).

The main conclusion from the Open Barents Sea case study is that the predation pressures from the crab on benthos is high and have caused changes in the benthic communities. This might also be indicated by the still decreasing mean depth distribution with high catches of king crab. From 2001 to 2009 the crab has moved gradually to shallow areas; most probably do to depletion of benthic prey.

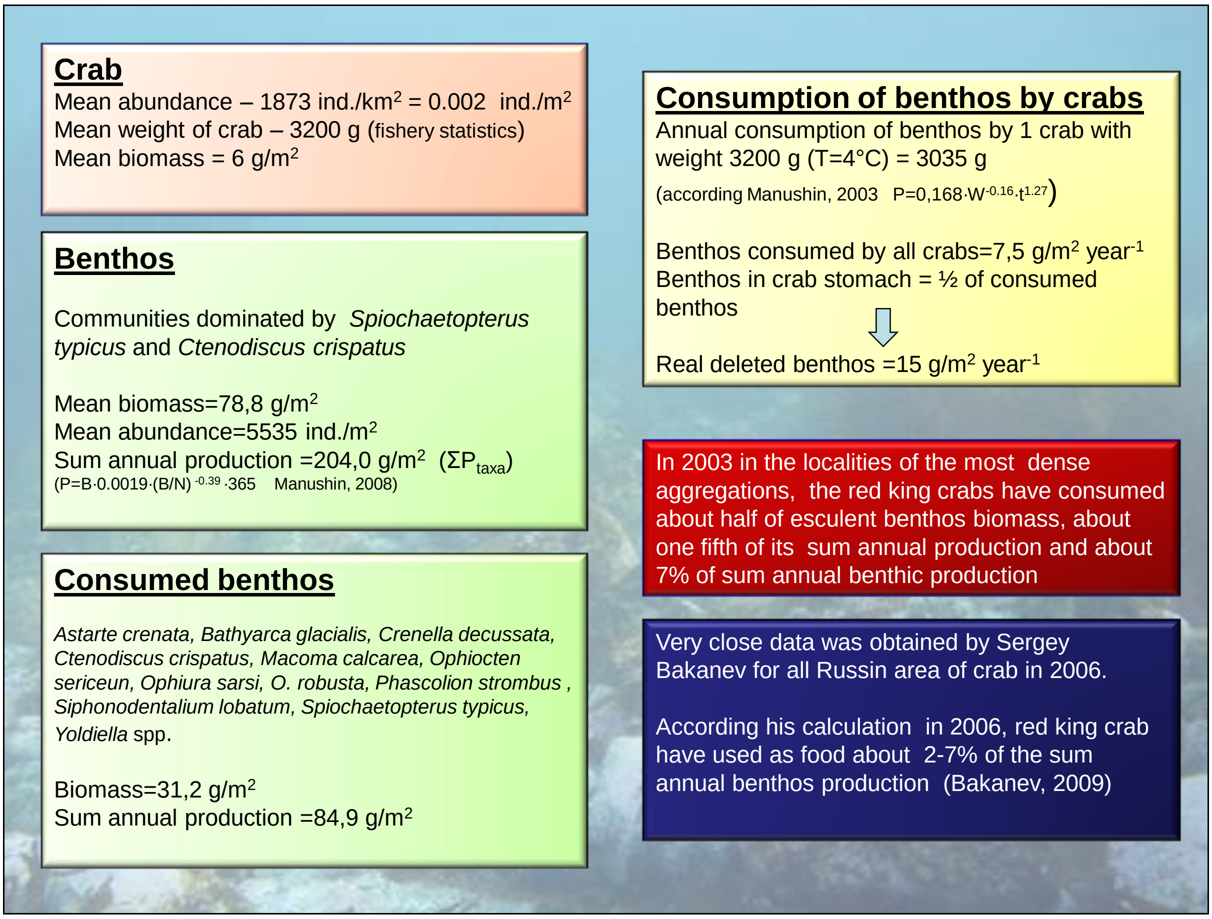


Figure 23. Calculation of consumption of benthos by the king crab in the southern part of the Barents Sea and fjords. Source: Natalya Anisimova, Igor' Manushin, Pavel Lubin (PINRO).

3.8 Calculation of production

Presented by Dr. Stanislav Denisenko (ZIN)

Statistical tests show that biomass information of benthos is quite reliable due to random distribution between stations and samples. The information of biomass is therefore useful for calculating standing stock and average biomass of benthos.

Abundance information is much less reliable due to the paternally temporal and spatial distribution of benthos. But "abundance" might be used in indirect evaluations of zoobenthos production, which are not using individual growth rates or population biomass changes. (ex. Brey 1999, 2000).

Different temperature regime in different areas of the Barents Sea might cause high error in benthic production calculations, and there is a need for an equation which are resistant to temperature changes.

Calculation of the P/B ratio of benthos in the Barents Sea shows a renewing of biomass every second year in warm years. A high correlation between the distribution and production of benthos was shown.

Biomass-abundance equations can be used in production calculations instead of Brey's equations, but there is a need to include a respiration coefficient.

3.9 Main points

- More severe impact was recorded on benthic animals in king crab areas in Norway compared to Russian. This is likely due to different migration/dispersal of the king crab in different life stages, differences between years and the continuing spreading into new areas of the crab.
- It is difficult to detect predation effects in shallow areas with hard bottom. These hard-bottom communities may be more resistant to king crab impact due to the higher biomass and productivity as well as low annual crab density of adult crabs. Predation pressure from adult king crabs differ throughout the year (adult on shallow areas 3-4 months per year), while juveniles predates year-round.
- The rocky bottom benthic communities are a 3 dimensional habitat with high productivity and many hiding areas. Compared to soft deeper bottoms in stable waters, are shallow rocky communities more adapted to seasonal and multi-year changes related to natural variability/disturbance (currents, wave action etc), and thus be more robust to king crab impact.
- In soft bottom areas king crab predatory effects are more evident. In deep water areas (>100m) on soft bottom, species composition has changed according to the foraging of the king crab (generalist predator feeding on the most abundant prey). The impacts may be larger in fjords and bays (semi-enclosed) because migration is believed to be more limited in these areas.
- In fjords the predation pressure might be constant due to non-distinct migration pattern. In more open areas might the colonisation history determine the migration pattern because the crab goes deeper at the later stage of the invasion stage as seen in the Russian areas.
- In the open area in Russia the crab perform seasonal migrations. The immature crab stock is expected to remain in the shallow areas year round. But the picture is blurred because the migratory pattern is not as set as the literature from the Pacific suggests.

3.10 Knowledge gaps and challenges:

- There is a need to do a Norwegian-Russian review on the seasonal migration of king and snow crab and the abundance of the crabs in different shallow and deep areas.
- There is a need to investigate if the king crab is distributed everywhere during all seasons. And if not – how should the sea bed be divided (foraging areas, reproductive and molting areas, juveniles areas etc) in order to calculate the impact rate from the king crab to the separate parts of the Barents Sea benthos?

- There is a need to know where, and for how long, the crabs represent a predation pressure.
- There is a need of a review on benthic standing stock and productivity data for the Barents Sea with focus on methodology and measures of the king crab impact.
- The predation pressure and diet of the red king crab should be calculated and measured from standardising methods, including units used.
- There is a need to identify ecological units of assessments (closed vs open areas) of impact. Identify expected high impact areas.
- Snow crab vs king crab distribution – to what extent the life cycle and predation are temperature dependent?
- How to combine the different methods employed to find the carrying capacity of the benthic system to king crab (ABC method, Comparison of juvenile/adult crab density with biomass of macrozoobenthos, production function approach, long-term observation, field observations (annual and daily variation), preference).
- Model of impact of king crab vs other factors (temperature/climate change, fishery). Establishing the carrying capacity of benthos to king/(snow) crab predation.
- Varanger fjord: there exist both Norwegian and Russian studies in this fjord. Should be a joint NO-RU comparison.
- Missing link: shallow areas should be explored to establish ecological significance and king crab impact.
- What are the consequences of the king crab predation on benthic organisms recycling detritus. Will this population diminishing or disappear from the system leading to a sea bottom that becomes a sink for detritus (biological production)?
- There is a need for essential knowledge on soft bottom ecosystem functioning and production. Risk management- do species assemblages become more susceptible to other environmental stressors?

Acknowledgement:
Thanks to DN for financing this workshop and report and to Mona Fuhrman and Jannike Falk Petersen for taken notes during the workshop and stimulating to the discussions. Thank to Jan Sundet and Jannike Falk Pettersen for given the introduction talks.

Appendix 1. Participants.

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Sergej Olenin	Uni	Bergen	Russia
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Alexander Rzhavsky	Ins Eco and Evo	Moscow	Russia
Alexey Golikov	Kazan State Univer.	Moscow	Russia
Anna Zalota	Shirs. ins of ocean	Moscow	Russia
Mikhail Pereladov	Coastal Res Lab	Moscow	Russia
Natasja Anisimova	PINRO	Murmansk	Russia
Igor Manushyn	PINRO	Murmansk	Russia
Sergei Bakanev	PINRO	Murmansk	Russia
Ludmila Pavlova	MMBI	Murmansk	Russia
Stanislav Denisenko	ZIN	St Petersburg	Russia
Lis L.Jørgensen	IMR	Tromsø	Norway
Jan Sundet	IMR	Tromsø	Norway
Knut E. Jørstad	IMR	Bergen	Norway
Eivind Oug	NINA	Grimstrad	Norway
Sabine Cochrane	APN	Tromsø	Norway
Jannike Falk Petersen	UiTø/APN	Tromsø	Norway
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Torstein Pettersen	UiTø	Tromsø	Norway
Mona Fuhrmann	UiTø	Tromsø	Norway
Nina Mikkelsen	UiTø	Tromsø	Norway
Helena Mikkerlsen	UiTø	Tromsø	Norway
Immacolata Faccia	Assoc. Nomofazù	Italia	Norway
Ingrid Bysveen	DN	Trondheim	Norway
Hermod Larsen	Fiskeridirektoratet	Finnmark	Norway

Appendix 2. Presentations given at the workshop.

Session 1: King crab and snow crab population dynamics

- Biology and abundance dynamics of the king crab (*Paralithodes camtschaticus*) in the Barents Sea and fjords of Norway. SenSc. Jan Sundet.
- Stock abundance of the king crab (*Paralithodes camtschaticus*) in the REZ of the Barents Sea in 1994-2010 Dr S Bakanev.
- Biology and abundance dynamics of the snow crab (*Chionoecetes opilio*) in the Barents Sea. Dr S Bakanev.

Session 2: King crab consumption of prey

- Foraging rate of the red king crab: preferred food and production of the crab's prey. Dr L Pavlova.
- Feeding of the red king crab in the open water of the Barents Sea and in Russian fjords (Varanger fjord, Motovsky Bay). Dr Igor' Manushin.
- What is the preferred prey species of the king crab, laboratory and field observations. Dr L Jørgensen.
- Consumption of fish eggs, spatial and quantitative measures PhD N Mikkelsen, 30 min.
- How to evaluate food consumption of the king crab, *top down* and *bottom up* approaches Dr V Spiridonov
- Potential ecosystem effects of snow crab in the Barents Sea" Dr Jørstad

Session 3-4: Benthos standing stock and production of selected areas.

- Standing stock and productivity of benthic communities. Dr T. Pettersen.
- Porsangerfjord. Dr L Jørgensen, PhD. M Fuhrmann.
- Varanger NO fjord. Drs E Oug and S Cochrane
- Dynamic of Red King Crab juveniles in the Russian part of Varanger fiord coastal waters in 2001-2010 and some reflections about their influence on sublittoral macrobenthos. Dr Pereladov
- Varanger RU - open water, Motovsky Bay, Open Barents Sea in king area. Dr. N Anisimova.
- An overview of studied inlets of Kola peninsula with special attention to soft bottom communities. Dr. T Britayev.
- Shallow-water benthic communities of Kola Bay: standing stock and productivity. Dr. Pavlova
- Open Barents Sea in snowcrab and king crab area. Dr S Denisenko.

Session 5: Snow crab

What do we know, and is it possible to use the knowledge that we have gain from the king crab research. Dr S Bakanev

Session 6: What are our questions, results and conclusions of this workshop (round table discussion)

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