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RESEARCH ON THE RED KING CRAB (*Paralithodes camtschaticus*) FROM THE BARENTS SEA IN 2005-2007

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Oktober 2008

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Preface

This report summarizes research activities on the red king crab in the Barents Sea the recent three years. It is a collection of extended abstracts/small articles on the different research activities carried out in the frames of a 3-year joint research program on the king crab, initiated by the Russian-Norwegian Fishery Commission in the period 2005 – 2007. The report was presented at the 37th Session of the Fishery Commission in Bergen, October 13th – 17th 2008.

Editors have been Jan H. Sundet, Institute of Marine Research, Norway and Boris Berenboim, PINRO, Russia, and we want to thank Ellen Dølvik Eliassen for great help with corrections of the manuscript.

1. State of the stock and assessment methods

1.1.1 Dynamics of the stock and distribution of the red king crab in REZ in autumn 2005-2007

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The stock dynamics and distribution of commercial red king crab males in REZ of the Barents Sea in August-October 2005-2007 were analyzed. In total, 447 research tows were carried out.

A comparison of the red king crab commercial male distribution throughout the studied period shows a gradual migration eastward of the major part of the stock (Figure 1.1). The migration took place during an increase in water temperature in the southern Barents Sea in this period.

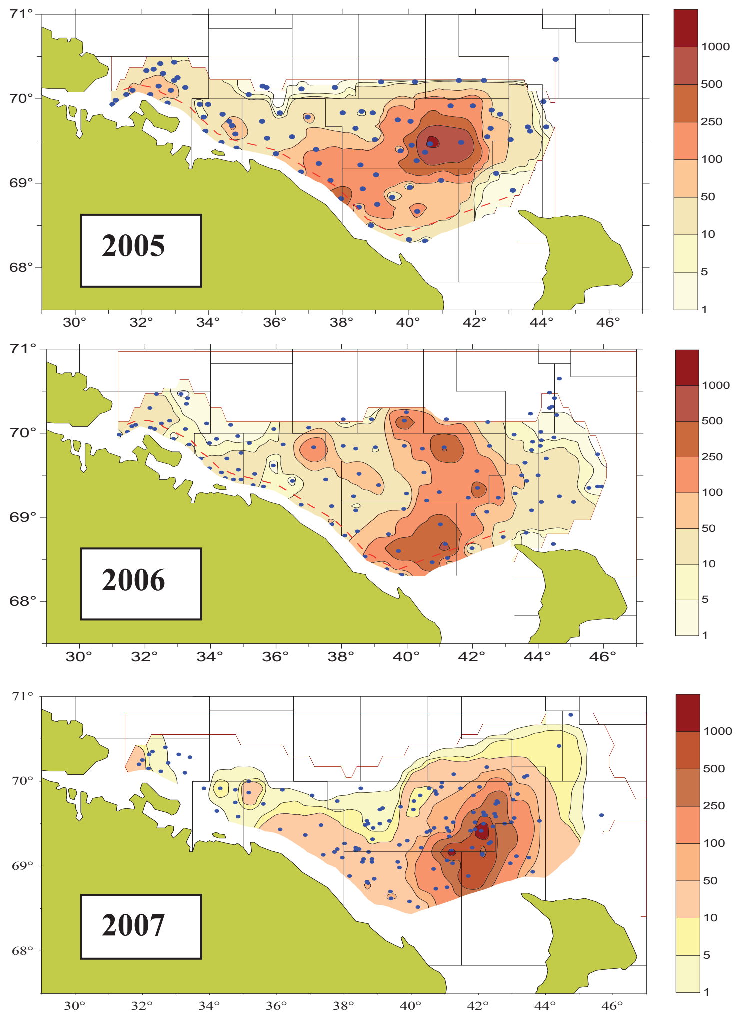

Figure 1.1. Distribution of the red king crab in REZ of the Barents Sea, August-October 2005-2007.

The main characteristics of the hydrographic regime in the southern Barents Sea in the period studied were a high advection of heat with warm currents of Atlantic origin. In 2006 and 2007 the positive anomalies of water temperature in the bottom layer were the highest (2-3ºC) of the latest 7 years, in the Russian part of the red king crab area.

At the same time, concentrations and density of the commercial sized crab gradually decreased in the Russian zone. A progressive reduction in the commercial stock index from 8.84 x 10^6ind. in 2005 to 6.64 x 10^6ind. in 2006 and 5.85 x 10^6ind. in 2007. Reduced recruitment, especially in 2005 and 2006, intensive harvesting and high natural mortality in older age groups, are possible reasons for this decrease.

On the other hand, in 2006-2007 a gradual rise in the abundance of prerecruits was found, and a significant recruitment to the commercial stock in 2008-2009 is expected (Figure 1.2).

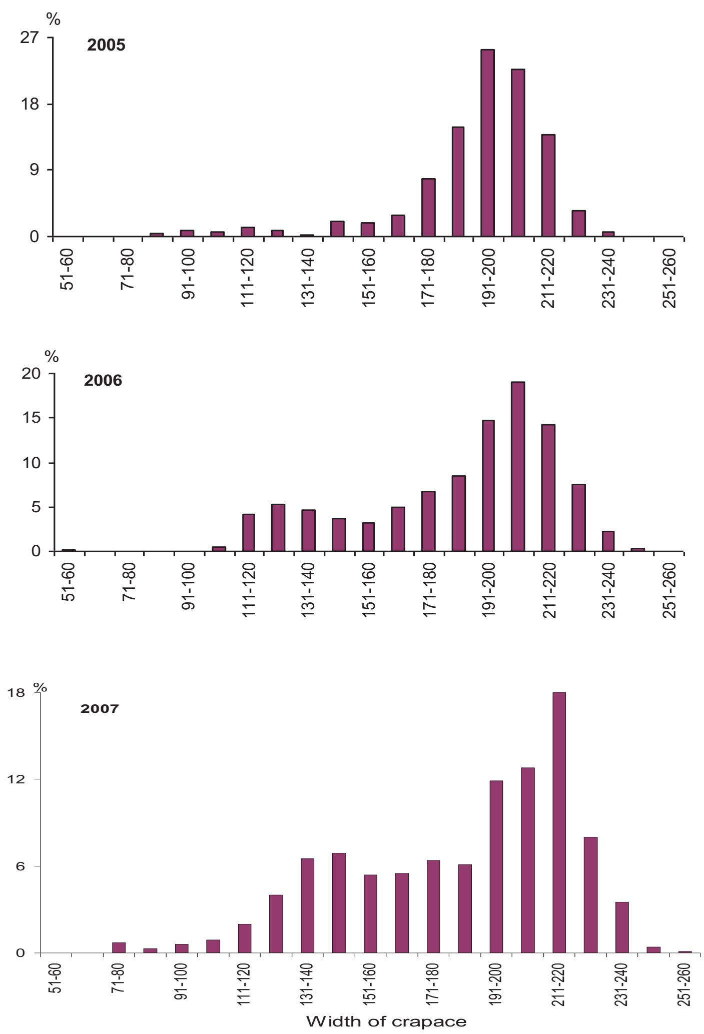

Figure 1.2. Size distribution of male red king crab from the Russian zone of the Barents Sea, based on data from trawl surveys, August-October 2005-2007.

Variations in the red king crab size distribution indicates progressive ageing of the commercial stock where the carapace width in the modal group of males from a strong year-class is approaching a maximum. The increase in the prerecruit abundance allows a considerable recruitment to the commercial stock during 2008.

During 2005-2007, most catches are males with carapace width larger than 170-180 mm. The abundance of this large sized crab will probably decrease. Therefore, in 2008-2009, recruits will make up the bulk of the commercial stock.

1.1.2 Trawl and trap survey assessment of the red king crab in Norwegian waters

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1.2.1 Assessment history

A joint Russian –Norwegian research fishery for the red king crab (RKC) was initiated in both countries economical zones in 1994 and continued until 2002. The annual total catch quota was based on an estimate of the number of males larger than minimum legal carapace length (Olsen 1996). From the beginning, the crab stock in the Norwegian waters was assessed only by trap surveys. In 2000 we started an annual trawl survey for assessing the king crab stock. As the king crab stock increased, this fishery became increasingly more important along with a need for better and more reliable stock estimates. Therefore, a new special designed beam-trawl was built to assess the crab stock based on an area swept method.

In the period 1993 - 1999 traps were used as sampling device in the annual assessment surveys for the red king crab in Norwegian waters (Kuzmin & Løkkeborg 1998). The conical traps used in fisheries and surveys the first years were shown to be less useful for assessment purposes and new square collapsible traps were introduced in 1999 (Stiansen et al. 2007). Open sea areas between Vardø and Nord Cape were selected for the use of traps in assessing the crab stock. Here, large stones dominate the bottom surface making it unsuitable for trawling in major parts of the area.

1.2.2 Gear and description of method

Trawl

The trawl is in fact an enlarged copy of a standard Agassiz trawl with certain modifications of sizes and material used (Figure 1.3). In front there is an 6 meter wide and 1 m height iron frame with a net attached behind. Each side end of the frame is equipped with 20 cm wide steel runners to prevent the heavy iron frame to sink into soft mud. In addition, several floats are attached to the top of the frame to lighten its weight on the bottom. The bottom net and the cod end, is made of polyethylene net with a mesh size of 135 mm, and the top panel of 40 mm mesh size net.

The whole net is about 15 m long from opening to the cod end, and is attached to the side ends of the iron frame in upper and lower position. The net opening is reinforced with a 5 mm steel chain which also secures a closest possible contact with bottom surface. Along each side of the net, three 12 inches floats are mounted to prevent tearing on the net from bottom. The trawl is towed by two wires attached to each end of the frame.

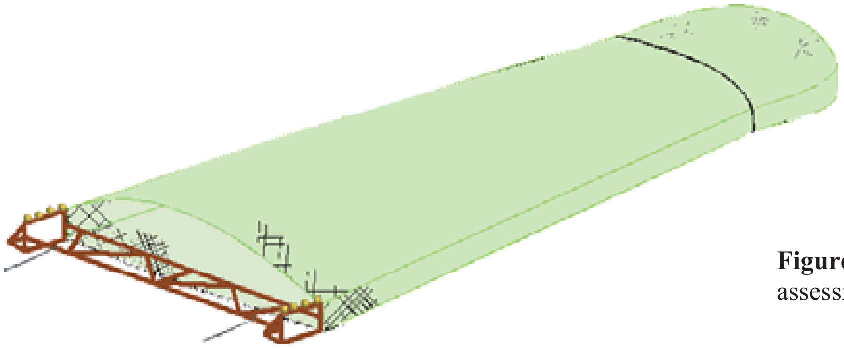

Figure 1.3. Trawl used in king crab stock assessment

Each haul last for 30 minutes with the trawl at bottom with a speed of 1.5 knots. A Scanmar ™ depth sensor is mounted on the top of the frame for recording when the trawl reach bottom. During surveys there are always a trade-off between available ship time and the number of sampling stations, but all depths are sampled as representative as possible. When used in the crab stock assessment, this trawl is assumed to catch 100 % of all crabs within its opening, since the lower part of the net continuously is sweeping the upper sediment. This assumption may though be jeopardized when sampling at rough and stony bottom substrate.

The routine trawl sampling stations carried out during the annual king crab surveys in Norwegian waters are shown in Figure 1.4. As seen in the figure we use trawl only in the fjords. The number of trawl stations on the annual surveys in Varangerfjord, Tanafjord, Laksefjord and Porsangerfjord are about 60, 23, 20 and 27 respectively. These numbers may vary slightly from year to year in the different fjords. Such geographically divided sampling also entail that the king crab stock is estimated for each area separately.

Figure 1.4. Sampling stations using trawl during the annual king crab survey in Norwegian waters.

Juvenile crabs stay at shallow waters (< 30 m) throughout the year and move down to deeper areas at sizes larger than about 50 – 60 mm carapace length (Wallace et al. 1949). Since the shallow part of the fjords in Finnmark usually has rough bottom, these sizes of king crabs are not easily caught in the trawl we use. Based on catch size distribution from many samples we have experienced that the lowest size threshold for representative samples of king crabs in this trawl seem to be about 70 mm carapace length. Therefore, we agreed with our Russian colleagues that the term “total stock” includes only crabs of both sexes larger than 70 mm carapace length. We do also believe that due to behavioral aspects of female crabs, the representativeness of adult females in the catches might sometimes be skewed. The estimates of the adult female stock may therefore be biased. We believe, however, that we are able to achieve adequate samples of the target part of the crab stock, males larger than the minimum legal size of 137 mm carapace length.

Traps

In the first years of the Norwegian king crab investigation we used the Japanese conical traps with entrance on the top (Figure 1.5). This type were exchanged with a new type of collapsible square traps (Figure 1.6) specially developed for the handling from small coastal vessels (Stiansen 2007). After 2000, all commercial and scientific sampling were carried out using this square type. The barriers for using traps for stock assessment purposes are that all traps have a particular effective fishing area (EFA). Research is now being carried out to reveal the EFA for these square traps, but until we have these results we have been using an estimate based on EFA from other trap types (conical and large Alaska type) of approximately 30 000m^2.

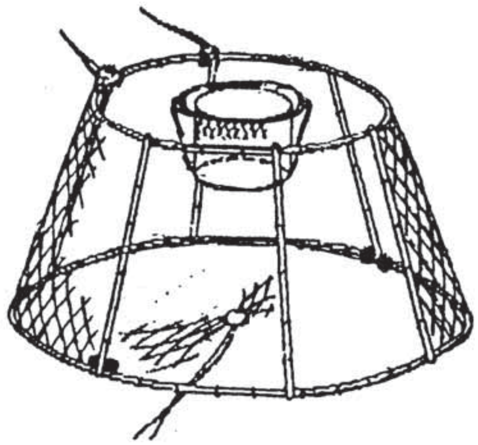

Figure 1.5. Japanese conical king crab traps with entrance on the top.

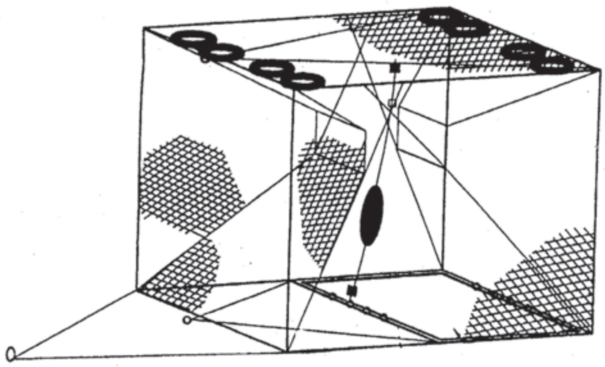

Figure 1.6. Collapsible square king crab traps.

1.2.3 Estimates

Trawl

Stock estimates of legal size red king crabs in different fjords and open offshore areas, in the period 2000 – 2006 are shown in Figure 1.7. This is the period when the estimates are based on swept area using the king crab trawl in the fjords and traps in the outer areas.

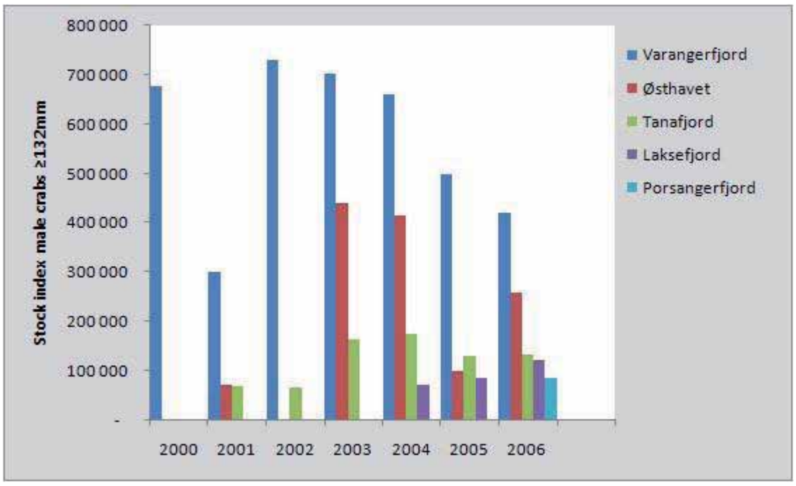

Figure 1.7. Stock estimates of legal size red king crabs in different fjords and open offshore areas, in the period 2000 – 2006

Traps

A complete trap survey in the outer areas within the 12 nm border will for the first time be carried out in 2008. In 2007 we did a survey out to 60 nm in the eastern part of the outer areas (Figure 1.8).

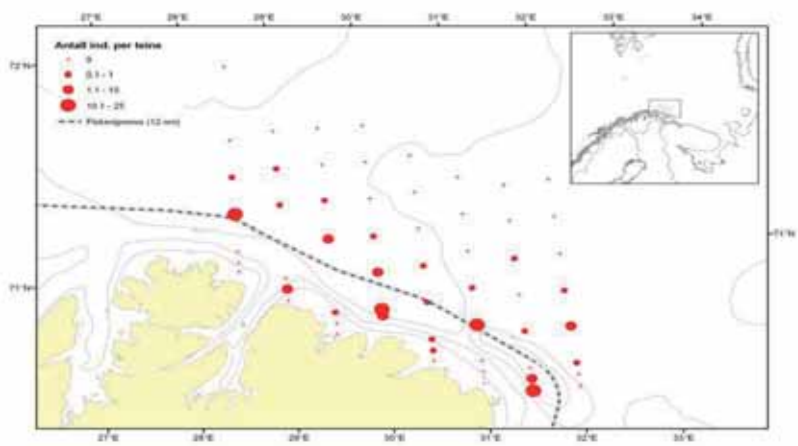

Figure 1.8. Catches of king crab pr. trap in outer areas along the coast of Finnmark during a trap survey in 2007.

In total 332 king crabs were caught during this survey of which 277 were males and 55 females. The size range of all crabs was from 82 to 182 mm carapace length (Figure 1.9). The legal male stock was estimated to be about 374 000 crabs within the 12 nm border in the area surveyed by traps in 2007. This is an increase of about 100 000 compared to 2006.

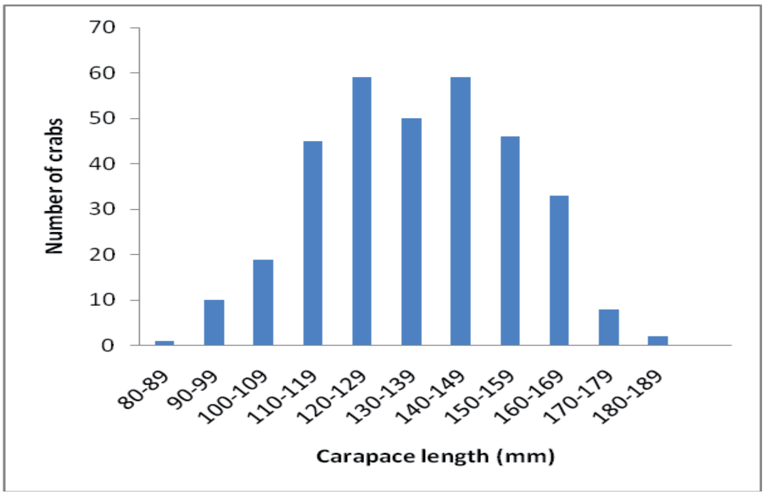

Figure 1.9. Carapace length distribution of male (277) and female (55) king crabs caught during a trap survey in offshore areas in 2007.

1.2.4 Method limitations

Trawl

The king crab trawl used in these investigations operates more like a dredge, and we assume that it catches all crabs present within the width of its opening. This is not tested, but intuitively this will probably be true on soft bottom sediments. However, in some areas investigated where the bottom sediment is of a more roughly type the catch efficiency will be less, dependent on how uneven the surface is. Although, by assuming a 100 % catch efficiency of the trawl, the outcome will always be an underestimate of the crab stock investigated.

As many other decapod species the red king crab has a patchy distribution. Our experiences even suggest that male and female crabs have a different pattern of patchiness. Since our estimates of crab abundance is based on average density, the sampling area of each trawl haul as well as the number of hauls are crucial for the accuracy of each estimates.

Traps

Using a fixed EFA on traps entails large uncertainties in this assessment method. EFA is dependent on several parameters that can't be assessed, such as bottom topography, water currents, bait quality etc. This method is therefore judged to be much more insufficient than the swept area method.

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1.3 Dynamics of the red king crab (*Paralithodes camtschaticus*) abundance in the Barents Sea and the use of the LBA cohort model for its estimation

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A stochastic length-based population model (LBA) was constructed for Barents Sea red king crab, incorporating growth function and gradual recruitment over length. Process and observation errors were incorporated simultaneously using a state-space modeling framework. Bayesian approach was used to estimate abundance, recruitment and natural mortality and derived variables relevant for management advice.

Estimated abundance of length-age groups showed a good fit to the data from trawl surveys. Over the whole observation period all groups greatly increased their abundance (Figure 1.10). In 1994-1996 abundance of all groups remained at a stable low level. In the above period, the length composition consists of two strong year-classes of relatively high abundance. One year-class dominated the fishable stock in 1994-1995. The other is less prominent, but can be traced by relatively high abundance of length classes CL90-CL100 in 1994, CL110-CL120 in 1995, CL130-CL140 in 1996 and CL150-CL160 in 1997.

The strong year-class represented by high abundance of CL90 in 1999-2000 is easily seen in Figure 1.10. This year-class was first noted as CL90 in 1997 and during a few years it recruited to the fishable stock. The highest abundance of the fishable stock was recorded in 2003, when the strong year-class was represented by the group CL130-CL170; which peaked during the study period 1994-2003. It was this year-class that dominated the fishery in 2005-2006, and entailed a many-fold increase of fishery pressure. It is worth noting that since 1999 this yearclass has been represented in the population by 3-5 length groups. This indicates that when reaching legal sizes, males of the same age may differ greatly in size. Estimated growth increment in legal crabs, which on average is 17 mm, may vary widely, and there is a certain probability that crabs may grow from one length group to the three next groups.

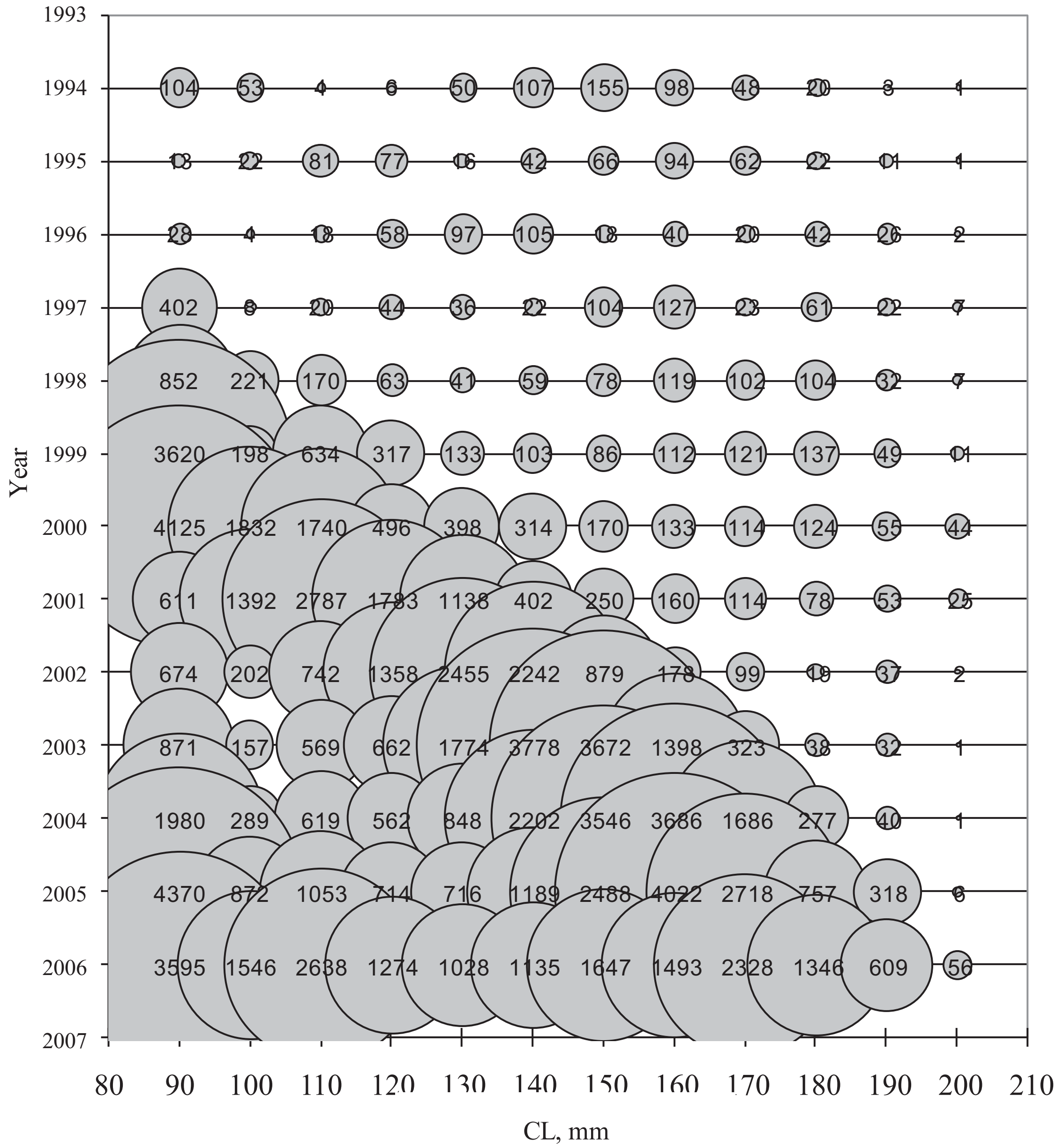

Figure 1.10. Abundance (1000 individuals) of male red king crab of different length classes in 1994-2006 based on LBA.

Variations in abundance, substantial outliers in the estimates and trends in residues indicate a good reliability of the estimates achieved using the LBA model. However, the algorithm of calculations and the number of parameters make the model too complicated and cannot be justified by a high quality of the input data, assumptions and theories, which support such assumptions.

The probability of getting more reliable estimates by using this model is quite high. At present, the distribution pattern of pre-recruits-2 does not permit us to get a reliable estimate of their abundance which also introduces noise to the estimate of the fishable part of the population. Reliability of the estimate of smaller length groups may be improved at least due to two reasons. The first and highly unlikely reason is a change in the distribution pattern so that the majority of pre-recruits-2 may become susceptible to capture during trawl survey. The second is conducting a survey in coastal areas. On the other hand, the trawl catchability towards pre-recruits-2 is much lower than towards older age groups, and at low abundances and low catchability the precision of the estimate is getting poorer. A higher precision in this case may be achieved through a change in sampling gear. Instead of, or in addition to trawl survey, surveys in the coastal waters may be conducted using dredge, diving or traps. Incorporation of such data into simulations may increase the probability, and our abundance estimates will be close to the absolute abundance. Results from the present research showed good prospects for the use of the stochastic version of the LBA model as a tool for estimation of the stock dynamics, TAC and a management strategy of the red king crab stock in the Barents Sea.

2. Ecology of the red king crab in the Barents Sea

2.1. Crab feeding

2.1.1. Monitoring the red king crab stomach content

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Trophic research on the red king crab from the Barents Sea indicates its significant feeding plasticity and quite low selectivity. A local food composition of this crab species involves, as a rule, the most abundant and accessible benthos organisms and other food items. The number of prey species found in the stomachs of the red king crabs includes 177 taxons of bottom invertebrates, algae and other objects. Polychaetes, bivalves, echinoderms and fish residues are the most frequent categories found in the stomachs.

A long-term study (1994-2005) permit us to reveal the red king crab feeding dynamics in the south eastern part of the Barents Sea from the Russian-Norwegian border to 35ºE. The period of crab occurrence in this area is a little more than 40 years. We studied the dynamics of feeding as the total and individual indices of stomach fullness, the portion of empty stomachs and ratios of the main food items in the diet.

Until the mid-1990s, the crab primarily fed on benthos organisms such as molluscs and echinoderms, in the western Murman. This is similar to the findings in the native area (Figure 1.1). In the mid 1990s, the first radical change in feeding pattern was registered. The number of crabs with empty stomachs abruptly rose and the total index of stomach fullness (TISF) dropped (Figure 2.2). The changes may be indicative of a deterioration of the feeding conditions.

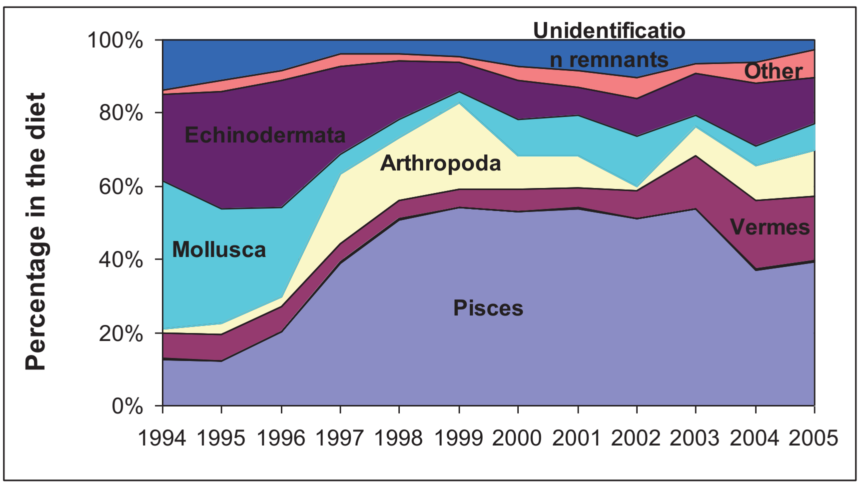

Figure 2.1. Ratio of the main components in the red king crab diet in the western Murman in 1994-2005

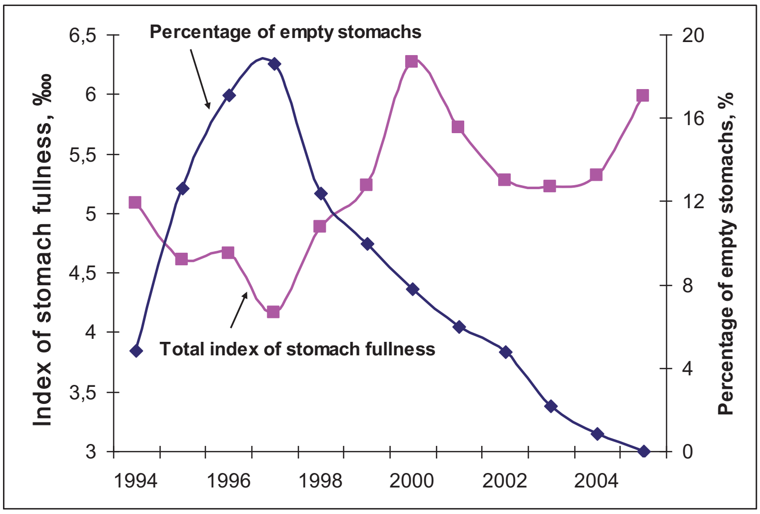

Figure 2.2. Indices of the red king crab feeding intensity in the western Murman in 1994 -2005.

In the late 1990s, there was a constant increase in the portion of fish residues in the diet, which reached 50% and continued to be at that high level until 2003 (Figure 2.1). Thus, in that period, crab feeding could be characterized as a kind of facultative necrophagy. The increase in the portion of fish remnants in the crab diet was accompanied by the rise in stomach TISF and reduction in the relative number of crabs with empty stomachs. This was probably caused by the depletion of the availability of bottom invertebrate species. A transition to fish waste as alternative food source therefore developed.

Since 2003, when the consumption of fish remnants decreased followed by an increase in benthos prey species, although the relative amount of fish were still remarkably high.

The changes mentioned above correspond to the growth of the red king crab stock abundance in the western Murman in 1997-2003 as well as to a reduction in the following years.

The analysis of feeding dynamics allows us to assume that the abundance of crabs in the western Murman is supported and determined by the trophic environment capacity including two main components: benthos available for the crab and the remnants from fishery. The benthos is the main and base food item, while fish is a forced additive food supply since the decrease in crab abundance, the intensity of feeding on fishing remnants also drops.

In 2001, the monitoring of the red king crab feeding in the south-eastern part of the up-to-date Barents Sea area (the eastern coastal area and the Murman Shoal) was initiated. Unlike the western Murman, the red king crabs appeared there much later and they have only been there for 15 years. The pattern of the crab diet development in this area is the same as found in the western Murman. First, there is dominance of benthos organisms followed by an increase in the consumption of fish remnants as the crab stock grows (Figure 2.3).

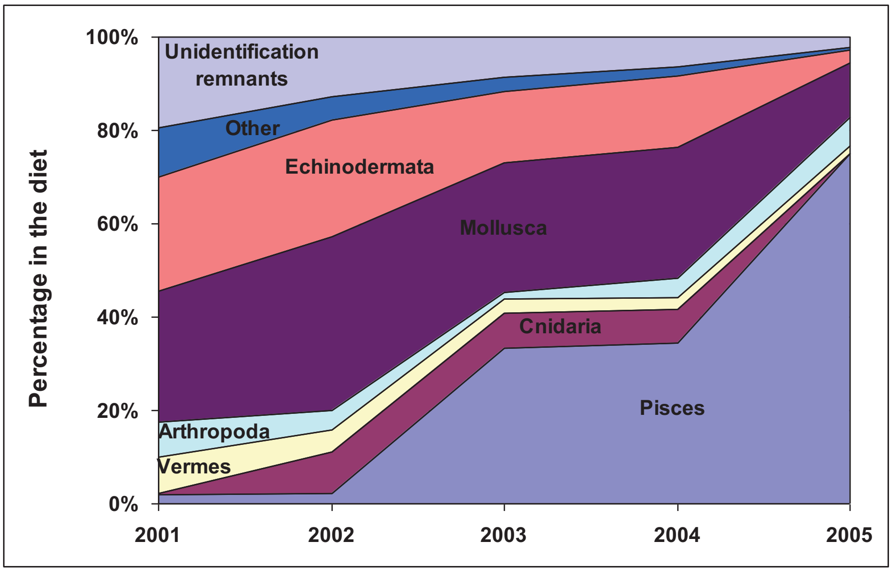

Figure 2.3. Ratio of the main components in the red king crab stomachs the eastern Murman in 2001- 2005.

The difference from western Murman is an increase in the portion of empty stomachs and a simultaneous rise of both TISF values and the percentage of fish wastes (Figures 2.3 and 2.4).

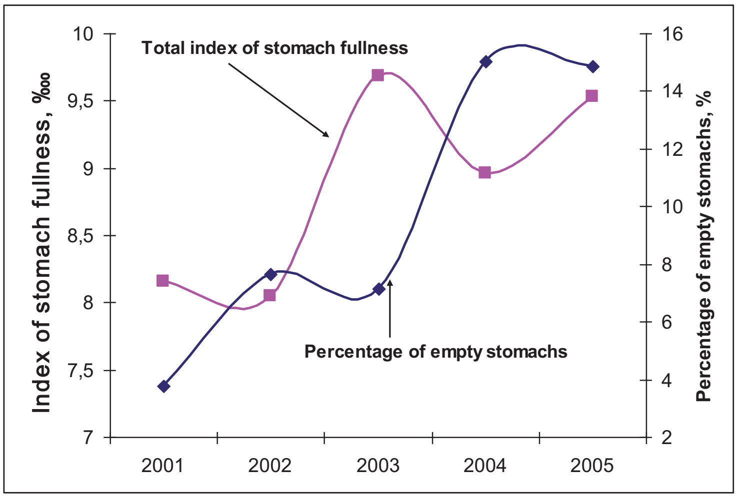

Figure 2 4. Intensity of the red king crab feeding in the eastern Murman in 1994 -2005.

This may be caused by the feeding behavior of individuals growing in the conditions of the sufficient food supply (benthos) and those ones having already adapted to feeding on unusual food (fish remnants). Probably, in the area of the initial settlement (in the western Murman), only a long starvation made some individuals change the type of feeding behavior (the transition to consuming unusual food), while, in the eastern areas, the crab stock was primarily formed due to adult commercial males having migrated there from the western areas and mostly being already adapted to feeding on fish wastes.

In 2003-2005, the index of the red king crab total stock in the Russian waters of the Barents Sea varied within 13-20 x 10^6 ind.. Thus, the analysis of feeding and calculation data allows us to conclude that the trophic capacity of this area is close to its limit. The data obtained to a certain extent corroborate the forecast by O.Gerasimova and M.Kochanov (1997). According to their calculations, "the upper limit of the red king crab abundance in the current habitat in the Barents Sea may amount to about 15 x 10^6 ind.".

Thus, the investigations showed that the food composition of the crab was determined by the number of the most abundant and accessible food items among which the live benthos organisms were the most preferable. The adaptation of the introduced crab population to the trophic capacity of the new habitat is the same in both areas, but differs in the time of introduction. Live benthos predominates as food during the first stages of introduction. When the crab abundance grows, the portion of benthos organisms in the stomachs decreases, while the presence of fish wastes increases. In the case of reduction in abundance, the portion of the diet reverses again.

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2.1.2. Rhythm of the red king crab feeding activity

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One of the main parameters of animal feeding behaviour is periodicity. Many marine organisms synchronize the food consumption with certain environment cycles including the light and tidal rhythm. This work was done in order to determine the periods of feeding pattern of the red king crab.

The material for study was:

- Data from a station made by PINRO in the Motovsky Bay of the Barents Sea on September 5-6 1998
- Data from an observations made by VNIRO in the Bristol Bay in the Bering Sea on September 11-12 1972 (Tarverdieva, 1978)
- Official red king crab catch statistics for the eastern coastal area of the Barents Sea in 2002-2006.

The tidal amplitude are calculated using the Tides (ver.3.7) and Tidecalc (ver.1.1) software for the coastal sites which are the nearest to the surveyed areas.

According to M.Tarverdieva, the food consumption by the red king crab was maximal during night and afternoon (Figure 2.5). In the Motovsky Bay of the Barents Sea, maximum was during morning and evening (Figure 2.6). This indicates no relationship between daytime and crab feeding activities. In the Motovsky Bay, the samples were taken at depths of 120 m which makes a relationship between feeding and light regime doubtful. However, comparing variations in TISF with the tidal cycle, some coincidence were found. An existing relationship between tidal cycle and feeding periodicity is shown by a dispersion analysis made in the Excel software.

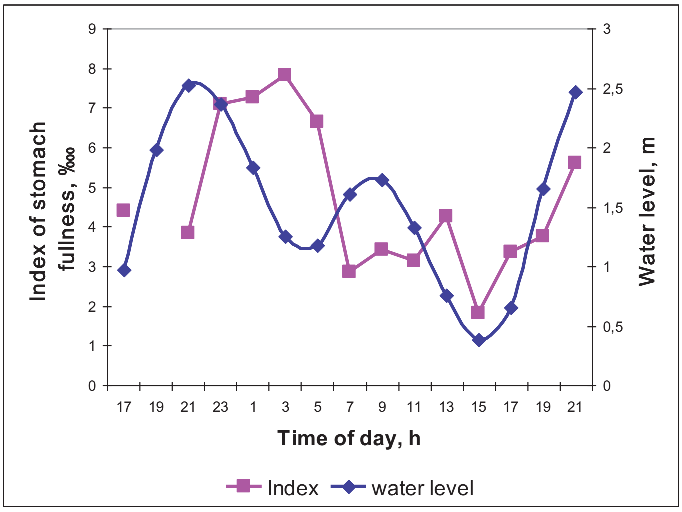

Figure 2.5. Dynamics of the red king crab stomach TISF and a tidal cycle on September 11-12 1972 in the Bristol Gulf of the Bering Sea.

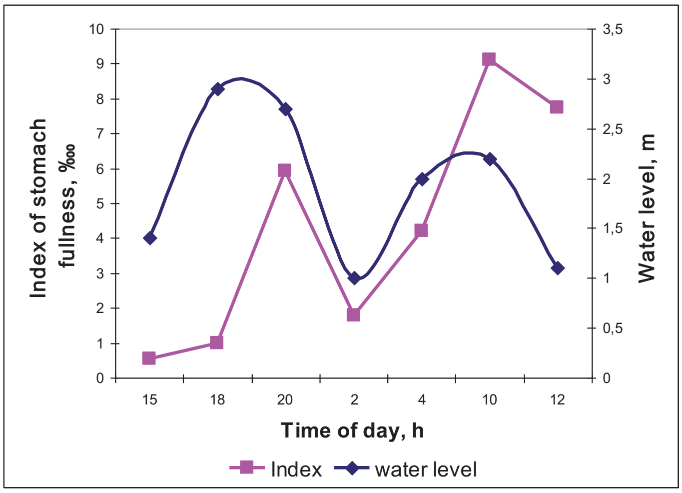

Figure 2.6. Dynamics of the red king crab stomach TISF and a tidal cycle on September 5-6 1998 in the Motovsky Bay of the Barents Sea.

The presented plots show that the increase in crab stomach TISF begins after the high tide. This may be explained by more intensive search of food by the crab with the start of the flow tide. One can therefore conclude that there is a relationship between the tidal cycle and the red king crab feeding. It should be noticed that crabs feed, primarily, during ebb and digest food during flow.

Since the current speed regularly rises during both ebb and flow and the TISF only increases during the ebb, it should be recognized that the tidal current speed is not the only factor determining the intensity of the crab feeding.

It is well known, that the tidal dynamics has the periodicity, which is not only daily, but also monthly. To clear up any dependence between monthly tidal cycle and the feeding pattern of crab, data on fishing statistics were used. In harvesting the crab, traps with bait is used. The catch should therefore show a pattern dependent on the monthly tidal cycle. To reveal any monthly periodicity data on the catch of crab males of commercial size per trap was calculated. Since the soak time of the trap were scattered, a soak time of three days was adopted (the day of hauling the trap and two days before). After that, the mean catch per trap was compared to the high tide for that date. It is known that the lunar months consist of 29-30 days, and it includes approximately the same tidal cycles with spring and neap tides. Thus, each tidal cycle lasts for 14-15 days. Further analysis was made by the data averaged by days (for such tidal cycle).

The dispersion factor analysis shows the variations in catches in relation to tidal cycle. The official data on fishery season 2003 when each vessel had a scientific observer aboard showed the best correspondence to the half month tidal cycle (Figure 2.7).

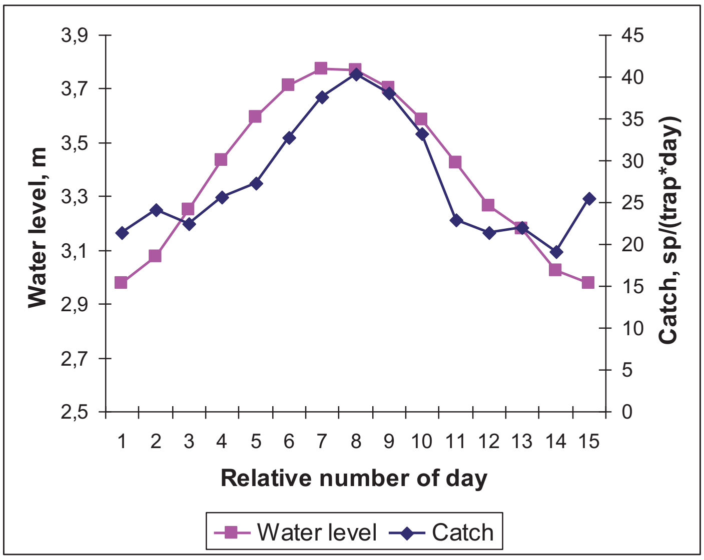

Figure 2.7. Mean day catch per trap and the full water height during the tidal cycle in eastern coastal area in 2003.

The onset of a commercial fishery and a reduction in the state monitoring of crab catch, revealed a less convincing correlation between data from the fishery statistics and the tidal cycle (Figure 2.8). At the same time, the data from VNIRO (kindly given by V.Sokolov) indicate that the synchrony of catches and tidal cycle is remaining (Figure 2.9).

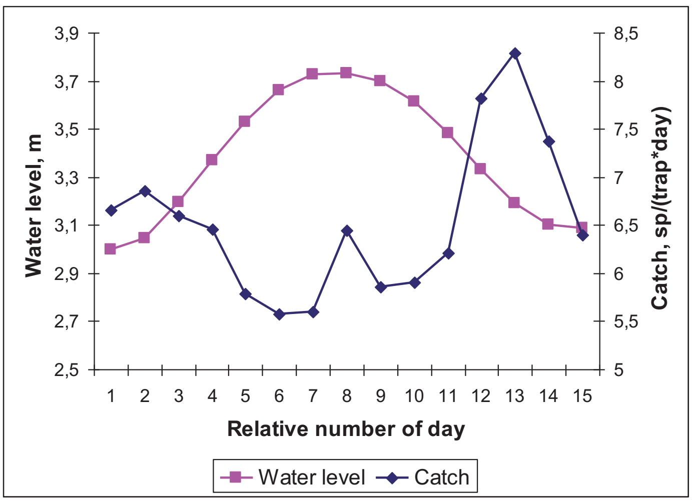

Figure 2.8. Mean daily catch per trap and the diurnal tidal rhythm in the eastern coastal area in 2005.

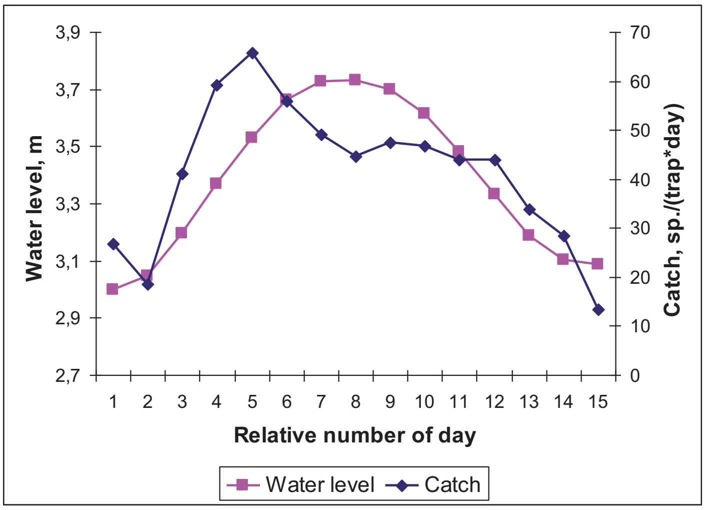

Figure 2.9. Mean daily catch per trap and the diurnal tidal rhythm in the eastern coastal area in 2005, data from a scientific observer (VNIRO).

It should be noted that the dependence of trap catches on the moon phases is pointed out also in the papers by S.Hasegava (1974) and B.Ivanova (1994).

Thus, the results indicate that feeding behavior of the red king crab is characterized by daily and monthly periodicity. The increase in TISF of the crab stomachs starts after the onset of the ebb, and its maximal and minimal values correspond to the times of high and low tides. In the periods of spring the catches of the red king crab increase which probably is connected with the increase in the effective catch areas of the traps. Therefore, during one month, there were two periods where the crab was more active, resulting in an increased number of crabs attracted to the traps.

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2.1.3. Selectivity in the red king crab feeding in the Barents Sea

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Today most of the biological data on feeding habits of red king crab is based on stomach content. Since 1994, the content of more than 1200 stomachs has been analyzed, and this gives information of great value in understanding crab feeding in the Barents Sea (Anisimova, Manushin, 2003). Despite its importance, selectivity as an indicator of feeding habits has not yet been studied. Also in evaluating the effect on the environment, selectivity of feeding is one of the most important parameters.

To estimate the characteristics of the red king crab feeding in the eastern part of the area, stomachs of 66 crabs (48 males and 18 females) were taken at 6 stations in autumn 2001(Table 2.1). In 2003, to study the selectivity of crab feeding, dredge samples of benthos were obtained (Figure 2.10). The stations were made within 60-270m depth range. Table 1 gives the characteristic of the stations where parallel benthos and crab stomach samples were taken.

Table 2.1. Sampling stations for estimating selectivity in the red king crab feeding.

No.	Depth, m feeding	Depth, m benthos	Ground type	Benthos biomass g/m^2
45	60	63	sand, stones	193.491
66	70	64-65	hempseed husk, stones	112.182
68	75	70-72	sand, hempseed husk	227.877
65	120	111-114	sand	45.474
63	187	186-188	muddy sand, pebble	45.519
62	270	229-173	muddy sand	105.493

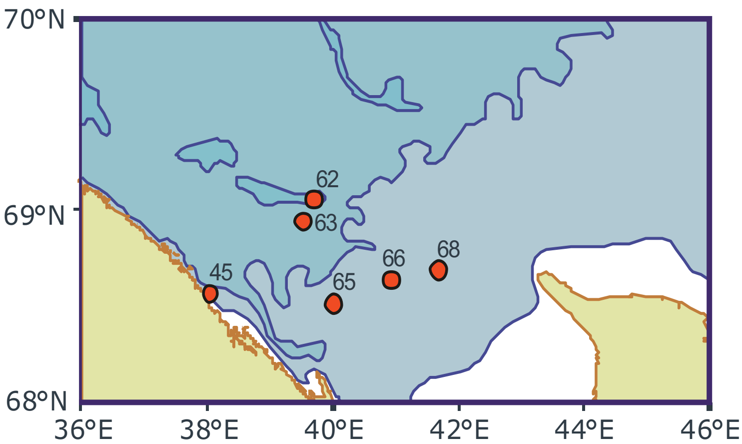

Figure 2.10. The sites of sampling stomachs and benthos to study the red king crab feeding selectivity.

The crab selectivity of species and groups of invertebrates as prey was estimated using the selectivity index (Ivlev, 1955) by formula:

$$E = \frac{r_i - p_i}{r_i + p_i},$$

where E – selectivity index, r_i – percentage of the prey i , p_i – percentage of the food item i in the environment. In the biocenosis, the portion of species or a group of invertebrates, crab food items, was calculated as the ratio of biomass or taxons of the species and the summarized biomass of all the organisms in the community.

The analysis of the stomach content of 1236 crabs collected from 1994 to 2003 allowed us to specify the list of bottom organisms which were the main food items of the red king crab in the Barents Sea. In all, there were 177 taxons of algae and animals where 130 are the representatives of macrozoobenthos. The most frequent in the crab stomachs were mollusks – 66.5% in the studied stomachs, polychaetes – 55.8%, ascidians – 43.6% and echinoderms – 41.6% (Table 2.2). The polychaeta was found in 15% of the studied stomachs, representatives of genus *Astarte* (mollusks) in 5% of the stomachs, sea urchins from genus *Strongylocentrotus* and the sea star *Ctenodiscus crispstus* from echinoderms (4% and 3%, respectively), are registered in the crab stomachs often. All of them are quite large forms of zoobenthos and are immobile or slow moving. They all moves on the sediment or digs in the upper layers. Within the red king crab area these species form high densities and biomass, and communities with their predominance occupy considerable areas of bottom.

The analysis of the portion of the main systematic groups of invertebrates in the stomachs of the red king crab and benthos biomass allowed the selectivity of the crab feeding on those animals to be calculated (Table 2.3). More detailed analysis permitted us to specify this index in relation to smaller taxonomic groups of invertebrates (Table 2.4).

As Table 2.4 shows, sipunculids, crustaceans, gastropods, sea stars and ophiurans are the groups most vulnerable for red king crab predation. These are the groups by which, evidently the crab food supply should be calculated and the influence on the local fauna should be estimated.

Table 2.2. Food items of the red king crab in the Barents Sea and their frequency of occurrence in the crab stomachs (by data of 1994-2003).

Taxon	Taxon frequency of occurrence, %	The most abundant food item	Item frequency of occurrence, %
ALGAE	26,29	*Desmarestia aculeate*	2,43
Type SARCOMASTIGOPHORA	7,69	Foramenifera g. spp.	6,88
Type CILIOPHORA	0,16	Tintinnidae g. sp.	0,16
Type PORIFERA	0,81		
Type CNIDARIA	10,52		
Class Hydrozoa	8,50	*Symplectoscyphus tricuspidatus*	1,38
Class Anthozoa	2,10	Alcyonacea g. spp.	0,89
Type NEMERTINI	0,32		
Type CEPHALORHYNCHA	0,65		
Type ANNELIDA	55,83		
Class Polychaeta	55,83	*Spiochaetopterus tipicus*	15,45
Type SIPUNCULA	17,56	*Phascolion strombus strombus*	7,69
Type Echiura	0,16		
Type ARTICULATA	22,98		
Class Pycnogonida	0,97		
Class Maxillopoda	1,38	*Calanus finmarchicus*	1,38
Class Cirripedia	5,10	*Balanus* sp.	3,80
Class Malacostraca	12,54		
Order Euphausiacea	0,40		
Order Mysidacea	0,16		
Order Cumacea	0,32	*Diastylis* sp.	0,16
Order Isopoda	0,65	*Calathura brachiata*	0,24
Order Amphipoda	2,51	Gammaridea g. spp.	0,49
Order Decapoda	8,98	*Paralithodes camtschaticus*	2,91
Type MOLLUSCA	66,50		
Class Aplacophora	0,08		
Class Gastropoda	28,88	Naticidae g. spp.	3,80
Class Scaphopoda	12,46	*Antalis entails*	3,72
Class Bivalvia	49,92	*Astarte* sp.	5,42
Class CEPHALOPODA	0,08	Octopoda g. spp.	0,08
Type BRACHIOPODA	1,62	*Hemithyris psittacea*	0,81
Type BRYOZOA	3,72		
Type ECHINODERMATA	41,67		
Class Asteroidea	15,94	*Ctenodiscus crispatus*	3,16
Class Ophiuroidea	14,00	*Ophiura sarsi*	1,21
Class Echinoidea	11,57	*Strongylocentrotus* sp.	4,61
Class Holothuroidea	0,57	*Molpadia borealis*	0,16
Type Chordata	43,61		
Class Ascidiacea	12,14	*Pelonaia corrugata*	4,53
Superclass Pisces	35,92		

Table 2.3. Percentage of the main systematic groups of invertebrates in red king crab stomach content, total biomass of benthos and the selectivity index.

Taxon	Weight portion in diet, %	Weight portion in benthos, %	Selectivity index
Coelenterates	0.5	3.5	-0,74
Worms	9.6	17.0	-0,28
Crustaceans	14.9	10.3	0,18
Mollusks	26.5	46.2	-0,27
Echinoderms	46.3	8.3	0,70

Table 2.4. Percentage of different taxonomic groups in the stomach contents of the red king crab, in total biomass of benthos and index of their selectivity.

Taxon	Percentage in feeding, %	Percentage in benthos, %	Selectivity index
Polychaeta	8.6	16.4	-0,31
Sipuncula	0.9	0.6	0,24
Crustacea	14.9	10.3	0,18
Gastropoda	7.0	2.6	0,46
Bivalvia	17.0	43.2	-0,43
Brachiopoda	1.3	1.8	-0,16
Asteroidea	12.1	1.0	0,85
Echinoidea	1.4	3.6	-0,46
Ophiuroidea	18.1	2.9	0,73

The selectivity of crab feeding on the different groups of animals depending on their biomass and depth was considered. These values themselves, evidently, don't play a great part in crab food preference, however, the synchronous variations of biomass indices and individual stomach fullness indices (IFI) were noted for the groups with positive selectivity index (Figure 2.11), and that dependence was absent for the group with a negative selectivity index (for instance, polychaetes).

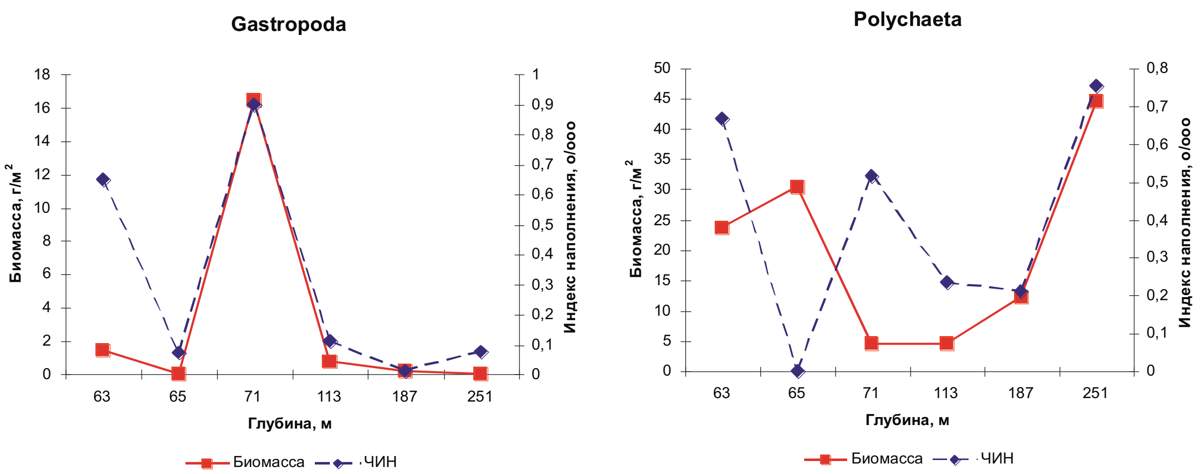

Figure 2.11. Variations of biomass in the community and individual index of crab stomach fullness by gastropods and polychaetes depending on depth.

The comparison of the total biomass of benthos and stomach fullness index by bottom organisms showed that crab fed most intensively in the sites with the average benthos biomass (Figure 2.12). At larger depths of occurrence, with similar biomass, the index of stomach fullness is higher. Possibly it was connected with the increase in the portion of infauna including the prey groups most often occurring in the crab stomachs, such as *Ctenodiscus crispatus*, S*piochaetopterus typicus* and *Astartidae* spp. It should be noticed that the densest concentrations of the red king crab during the feeding are distributed at large depths.

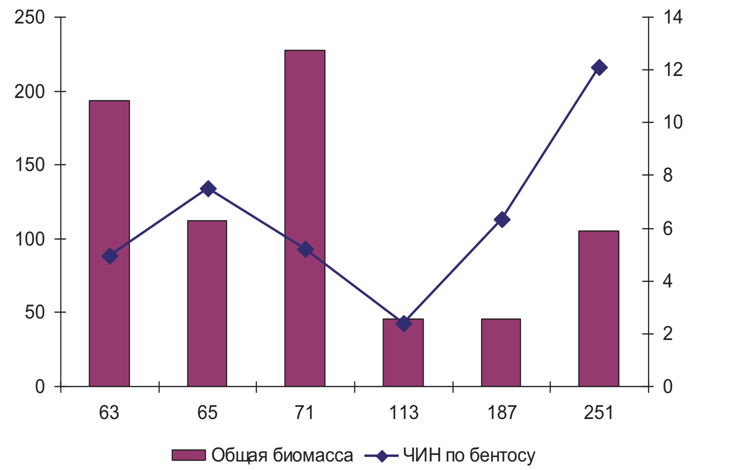

Figure 2.12. Variations of total benthos biomass and of the individual index of crab stomach fullness by benthos depending on depth.

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2.2. The Red king crab and benthos communities

2.2.1. Distribution of the red king crab compared to benthic communities

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The research surveys for crabs and the geographical distribution of fishery indicate that the crabs are distributed unevenly, both in the western and eastern areas in the open sea. In the autumn-winter feeding period it may form local concentrations. The analysis of factors determining localization of fishery concentrations is interesting from both theoretical and practical point of view and it is considered in the presented chapter.

To characterize the current state of benthic communities in the area of the red king crab, data collected at 95 stations of the southern Barents Sea in a cruise with RV "Romuald Muklevich", from 5 August to 1 September 2003 (Figure 2.13).

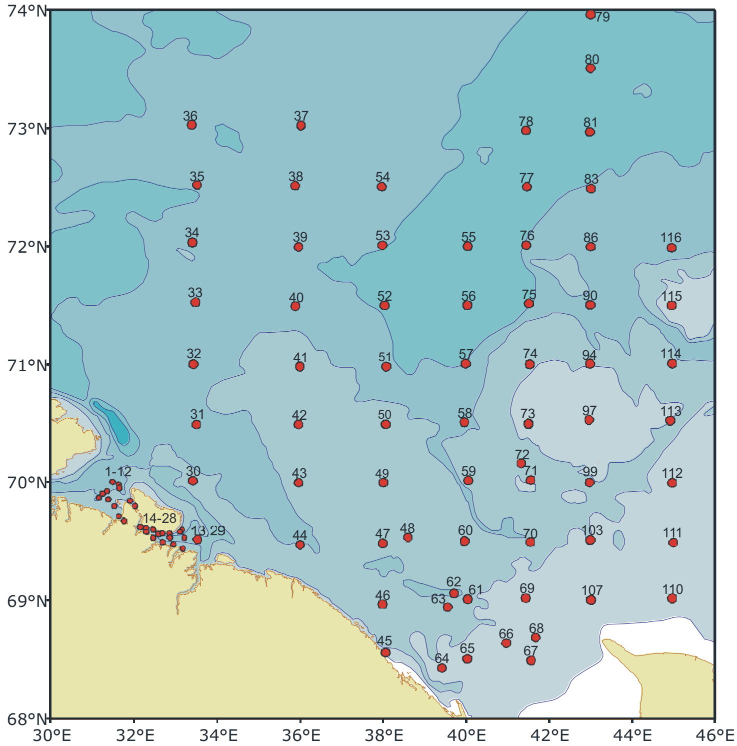

Figure 2.13. Stations of benthos sampling in the southern Barents Sea during the cruise of RV "Romuals Muklevich" in 2003.

The pattern of the red king crab distribution in the open sea areas was evaluated based on the results from research crab surveys in 2003-2005, the distribution of crab by-catches in the fishery for bottom fish and the pattern of the red king crab fishery in 2003-2005.

The pattern of by-catches showed an unclear distribution of the red king crab, but it allowed us to determine the borders of its distribution within REZ quite distinctly (Figure 2.14). The presented map shows well that the vectors of settling coincide with the direction of the main currents in the Atlantic (the Central branch of the North Cape Current and the main branch in the Murman Current). It can also be observed well as the cold waters of the Central Deep bound the distribution of crabs in the northern area.

More distinct localization of crab concentrations was shown by autumn crab trawl surveys and the areas of concentrated fishing efforts. Despite, in some years, localization of concentrations may somewhat differ, the results from the research in 2002-2005 show four areas where, in autumn-winter, stable crab concentrations were observed (Figure 2.15):

– the northwestern area of the Rybachja Bank (Area1 in Figure 2.15),
– local bottom through in the southern area of the Murmansk Shallows (Area 2 in Figure 2.15),
– the end part and the deep slopes between the Murmansk Bank and the North Kanin Bank (Area 3 in Figure 2.15).
– Svyatoy Nos Shallows (Area 4 in Figure 2.15).

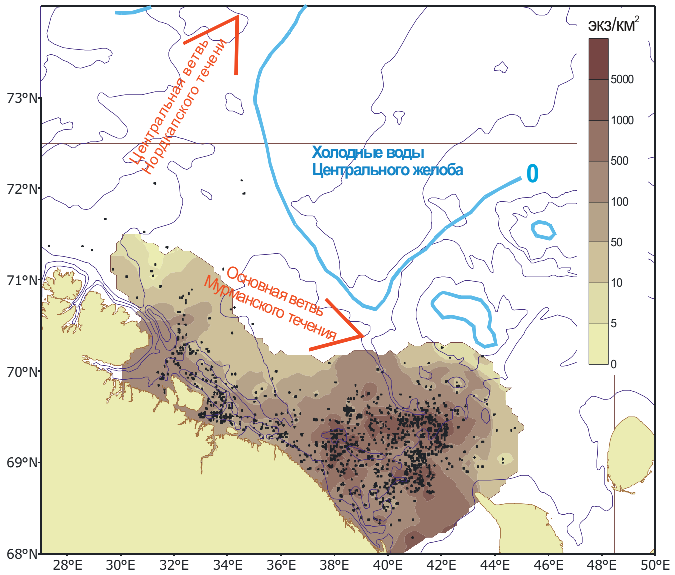

Figure 2.14. By-catch of the red king crabs in the bottom fish fishery in 2002-2005, ind./km^2. Red arrows show the main flows of warm currents, blue line – mean long-term position of zero isotherm.

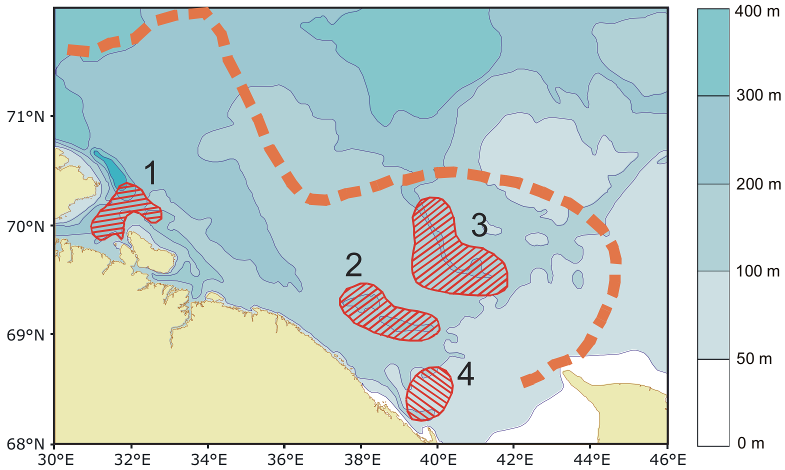

Figure 2.15. Areas of localization of the red king crab concentrations within REZ in autumn-winter. The areas are explained in the text. The red dotted line shows the boundary of the red king crab distribution.

Among the four areas, areas 2 and 3 (Figure 2.15) in the eastern part of the crab area, have the greatest commercial importance. It is well documented by the pattern of the fishery in 2003-2005, which distinctly marks the most abundant concentrations of the commercial male crab in the two area mentioned (Figure 2.16).

The comparison of crab concentration localization and the topography pattern showed that three of four concentrations are distributed in the areas with local descendings of the bottom, and underwater slopes with depths larger than 150-200 m, and the prevalence of soft silt and sand ground (Areas 1-3 in Figure 2.15). In all areas mentioned the concentration of large mature males makes up the commercial stock in the population. The exception is the shallow eastern coastal area, where, in some years, quite high concentrations of crabs were found in areas of Iceland scallop beds in the Svyatoy Nos area (Area 4 in Figure 2.15). However, unlike the deepwater aggregations, primarily adult mature females were concentrated here. According to the results from the trawl surveys and observations during scallop harvesting, few commercial males were caught here. The comparison of maps of crab concentrations and the main distribution of benthic species are shown in Figure 2.17.

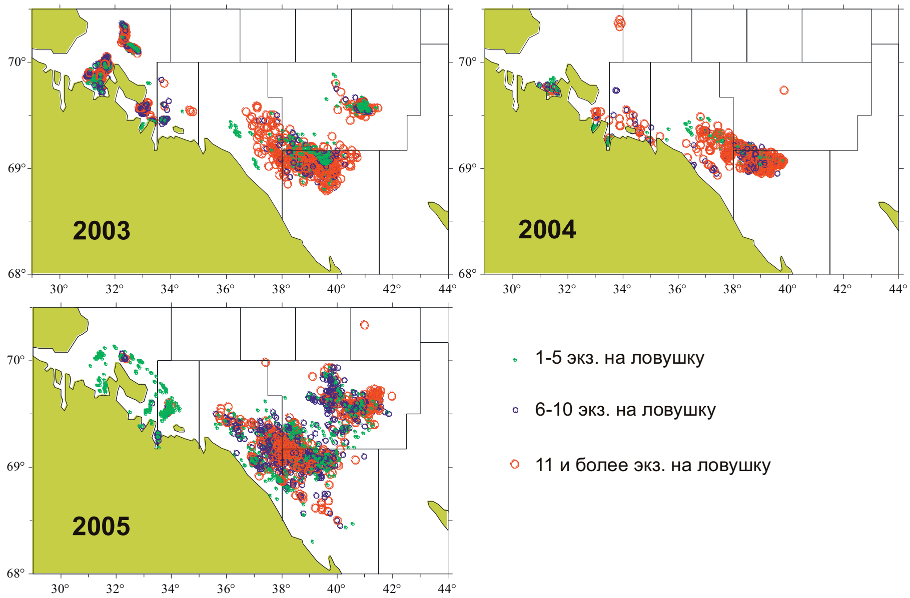

Figure 2.16. Distribution of commercial catches of the red king crab in EEZ RF of the Barents Sea in 2003-2005.

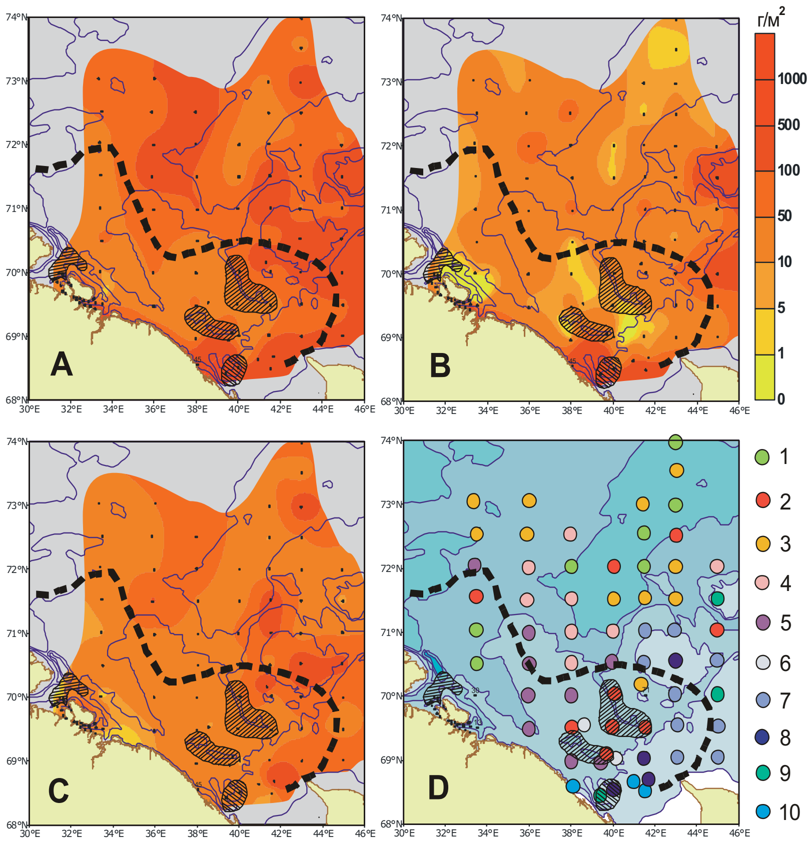

Figure 2.17. Location of the main concentrations of the red king crab within REZ and distribution of the main benthic species groups. A – total biomass of benthos, B – biomass of epifauna, C – biomass of infauna, D – distribution of benthic species groups. Categories of benthic groups:

1. *Molpadia borealis*, 2. *Spiochaetopterus typicus* and *Ctenodiscus cripatus*, 3. *S.typicus*, 4. *S.typicus* and *Astarte crenata*, 5. *Brisaster fragilis* and *A.crenata*. 6. *Scaphander punctostriatus* and *Dacridum vitreum*, 7. *Clinocardium ciliatum* and *Astarte borealis*, 8. *Serripes groenlandicus*, 9. *Chlamys islandica*, 10. *Balanus balanus* and *Asterias rubens.*

The species predominating in biomass are pointed out.

In the areas of commercial male king crab concentration, the biomass of benthos is within the range of the mean values, which are mean for the area studied (Figure 2.17A). None of the areas of commercial crab concentration coincide with the areas of prevalence and high density of epifauna (Figure 2.17B), despite these areas are usually considered to be more attractive for crabs as feeding grounds and a source of easily assessable and preferable food. The crab concentrations in areas of high infauna biomass were not found. All the areas of crab concentrations are characterized by the average abundance (Figure 2.17C).

Unlike commercial males, localization of female concentrations in autumn-winter is connected with shallower areas characterized by harder ground and prevailing density of epifauna. One such areas is the Svyatoy Nos (Area 4 in Figure 2.15).

The densest commercial concentrations of crabs are located in the distribution area of the community, with the predominance of the polychaete *Spiochaetopterus typicus* and sea star *Ctenodiscus crispatus*, which is typical for soft bottom in average depths (Figure 2.17D). Within the distribution of this community most of the large males forming the main commercial concentrations in the eastern area, in some recent years, are fed.

Thus, among the factors studied, only the pattern of topography and the benthic communities shows a certain relationship with the localization of crab concentrations. It is not excluded that in certain conditions of the southeastern Barents Sea, commercial concentrations of crabs in the autumn-winter period is not necessarily connected with the direct search for more productive feeding grounds, but by the behaviour where large males have feeding migrations toward larger depths.

2.2.2. Benthos as prey for the red king crab

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The attempts to estimate the influence of the red king crab on the local ecosystem due to consumption of benthos organisms have already been made and published in a number of papers (Gerasimova, Kachanov, 1997; Manushin, 2003). However, the calculations given in these papers are primarily based on data from literature and are of general character. The data obtained in the course of recent investigations allow calculations to be specified for an in situ situation observed in the crab concentrations.

The preliminary studies on the consumption of benthos organisms by crabs showed that, in 2001, the value amounted to the order of 15-20 thousand tons of benthos per year. That was considered insignificant compared to the total production in the coastal zone of Murman (33 mill. tons per year) (Manushin, 2003).

The studies during 2000-2007 indicated that, in some recent years, the peak of the red king crab population in REZ shifted from the western Murman to the east, where, at present, the total and commercial stocks are mainly concentrated. According to the data from the research trawl surveys, already in 2005, in the eastern part of the area, 92% of the total stock and 96% of the commercial stock were concentrated (Anon. 2005).

The crab stock is distributed unevenly in the eastern part of the area and forms two local concentrations related to the bottom lower parts in the southeastern part of the Murman Shallows, and the deep between the Murman Bank and the North Kanin Bank. This is the area of these local concentrations, where the maximal trophic pressure on the benthic communities from the commercial males of the crab can be expected. The situation in 2003, when the crab abundance in the eastern part in REZ was maximal, can be taken as example of this relation.

Data on the 2003 density of commercial males at the depths of more than 150 m in the areas of their fishing concentrations in the Murmansk Shallows were used in the calculations (Areas 2 and 3 in Figure 2.15) together with the quantitative data from 2003 on the structure of benthic communities in the same area. When calculating, an assumption that crabs did not feed for more than six months, was taken.

According to data from 2003 on crab concentrations, the mean benthos biomass converted to "live biomass" equaled to 78.8 g/m^2 in density of organisms, 5,535 ind./m^2.

To estimate the biomass of benthos being under the main feeding pressure from crabs, we chose the species which most often occur in the crab stomachs and have a positive selectivity index: *Astarte crenata*, *Bathyarca glacialis*, *Crenella decussate*, *Ctenodiscus crispatus*, *Macoma calcarea*, *Ophiocten sericium*, *Ophiura robusta*, *O.sarsi*, *Phascolion s. strombus*, *Siphonodenttalium lobatum*, *Spiochaetopterus typicus*, *Yoldiella intermedia* and *Y.lenticula*.
In converting to the mentioned species the biomass of preyed benthos in the analyzed area were 31.2 g/m^2 and its annual production – 157.5 g/m^2.

The density of commercial males in the studied area in 2003 was estimated to 1873 ind./km^2, on average, approximately corresponding to 0.002 ind./m^2. In order to show this, it can be pointed out that with this density and an even distribution, the distance between neighbouring crabs is about 26 m. With the average weight of a crab of 3200 g (according to catch statistics for 2003), the biomass of *Paralithodes camtschaticus* in the studied area was 6 g/m^2.

The mean water temperature for autumn-winter season in the area studied was set to 4ºC. Based on the equation of the dependence of food consumption by crab on water temperature and body weight (Manushin, 2003) the value of benthos consumption by an average crab was 3035 g/year that corresponded to a consumption of 7.5 g/m^2 preyed benthos organisms per crab during half year of they stay in the autumn-winter feeding area.

If we assume that real losses of benthos due to crab feeding exceeds, as a minimum, two times the weight of organisms estimated based on crab stomach content (the body parts of animals killed by crab which have not been eaten) the real consumption of benthos by crab in the feeding grounds may reach 15 g/m^2 a year. The obtained value is equal to almost half of the biomass of the benthos and one-tenth part of its annual production.

The comparison of the obtained data with analogous parameters (crab density and benthos biomass) from the western Murman and the native areas of the red king crab (the Far East), allows the level of trophic pressure from the red king crab on benthos in the areas of crab mass feeding to be approximately estimated.

According to the data from the trawl surveys, in the western Murman, the maximal density of crabs was registered at the depths lower than 150 m in 1998 and 200 m in 1999, and were 541 ind./km^2 and 315 ind./km^2 respectively. The greatest average fishing efficiency in the areas of the western Murman (the Ura Guba, the Varanger Fjord and the Motovsky Bay) was recorded in 1999 and equaled to 2-2.8 ind. Per a conic trap (Sennikov, 2003) that amounts to 600-850 ind./km^2 when converting to the fishing area (Moiseev, 2003). Thus, of the depths of the autumn-winter feeding, in these areas, by both estimates, the crab density was considerably lower than the mean indices, which were recorded in the eastern fishing concentrations in 2003. According to the data on benthos surveys in 1996 and 2003 (Frolova et al., 2003; Anisimova et al., 2005), at depths lower then 150 m, in the Motovsky Bay, benthos biomass was 75-96 g/m^2.That is comparable with the observed values at the same depths of the eastern Murman. Nevertheless further increase in crab density resulted in exceeding trophic environment capacity, which resulted in their active settlement outside this area and the transition to the alternative source of feeding as the residuals of fishery (Anisimova, Manushin, 2003).

On the other hand, in the Far East, where the crab abundance was evolutionally balanced with the local benthos production the density of the red king crab was quite comparable with those observed in the eastern Barents Sea in 2003, and even significantly exceed them in some cases.

According to the data of A.Klitin (2002), in the waters of the western Sakhalin, in the conditions like in the Barents Sea (low sublittoral biocenosis *Ctenodiscus crispatus*), at the depth of 170-200 m, the densities of the red king crab (commercial males) was close to the ones observed in the eastern fishing concentrations, in the Barents Sea, in 2003 (1200-1500 ind./km^2), were registered. On the other hand, in the mentioned community, benthos biomass is 176 g/m^2, on the average, that exceeds the Barents Sea values by more than 2 times.

According to the data by L.Vinogradov (1969), in 1958-1963, in waters of the western Kamchatka, the density of adult males was, on the average, about 1300 ind./km^2, the maximal – about 1770 ind./km^2. The density of adult males and females was estimated to 4 thousand ind./km^2, on the average, reaching 6-7 thousand ind./km^2 in some areas. From the data of A.Slizkin and S.Safonov (2001), in 1979-1988, in the most part of this area, crab density was 500-2500 ind./km^2 that, on the average, may be estimated to 1500 ind./km^2. But, in the western Kamchatka, benthos biomass is in the order of 150g./m^2 (Neiman, 1969), that is twice the value for the Barents Sea, obtained by the data from our research, as in the western Sakhalin.

As the abundance dynamics of crabs in the waters of the western Murman, the data on crabs and benthos ratio in native area give us the reason to assume that crab density observed in the eastern fishery concentrations in 2003 are either at the upper boundary of the environment trophic capacity of feeding grounds exploited by them, or even exceed it. In this respect, such dense concentrations are not likely for a long time.

The experience of the western Murman indicates that keeping the population abundance at the level of 2003 (for instance, due to full-value recruitment) would only be possible under the condition of extending the area of feeding due to either scattered of concentrations or transition of the part of population to alternative feeding sources, such as remnants from fishery, as in the western Murman. Variations in the feeding of crab in the eastern Murman from 2002 to 2005 indicate that this part of the crab population was adapted to the conditions of local food supply this way. In the waters of the eastern Murman, during three years (from 2002 to 2005), the portion of fish in the crab diet rose from 5 to 75% (Figure 2.15 in Section 2.1.1.).

Lately, as a result of natural dynamics of the year-class abundance dynamics and the lack of valuable recruitment the reduction in abundance of commercial part of the crab population is observed in this area. In the process, not only natural, but anthropogeneous factors, such as the press of the legal fishery, a great catch by poachers and by-catch of crabs in bottom fishery play a certain role in this process.

One can forecast the variations of benthic community structure in the places of the densest crab concentrations towards the reduction in the abundance of the species consumed by crab, the increase in total indices of non-preyed object abundance and total reduction in community. It should be noticed that this process will hardly have a negative impact on the food supply of benthic feeding fish, since these are the small objects wholly swallowed by fish which is the bulk of their bottom diet. The decrease in total benthos biomass is highly improbable, since this parameter is determined, to a great extent, by the quantity of food , which is accessible for benthos organisms (primarily, detritus, seston and plankton), which does not depend on the change of order of species predominance in community or the appearance of additional predator in it.

The experience of the Far East indicates that the productivity of crab populations is highly dependant on strong year-classes (Levin, 2001), which appearance periodicity is determined by the climatic factors of the planetary scale and is equal to on the order of 5-10 years. Besides the natural reasons, the main factor of reduction in abundance is also the enhancement of fishery press, abruptly growing in the periods when a strong year-class enters the commercial part of the population. Thus, inevitable fluctuations of the red king crab abundance may work as a natural factor favouring the recovery of the food supply in the crab feeding grounds and broken structure in bottom communities.

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2.2.3. King crab feeding activity

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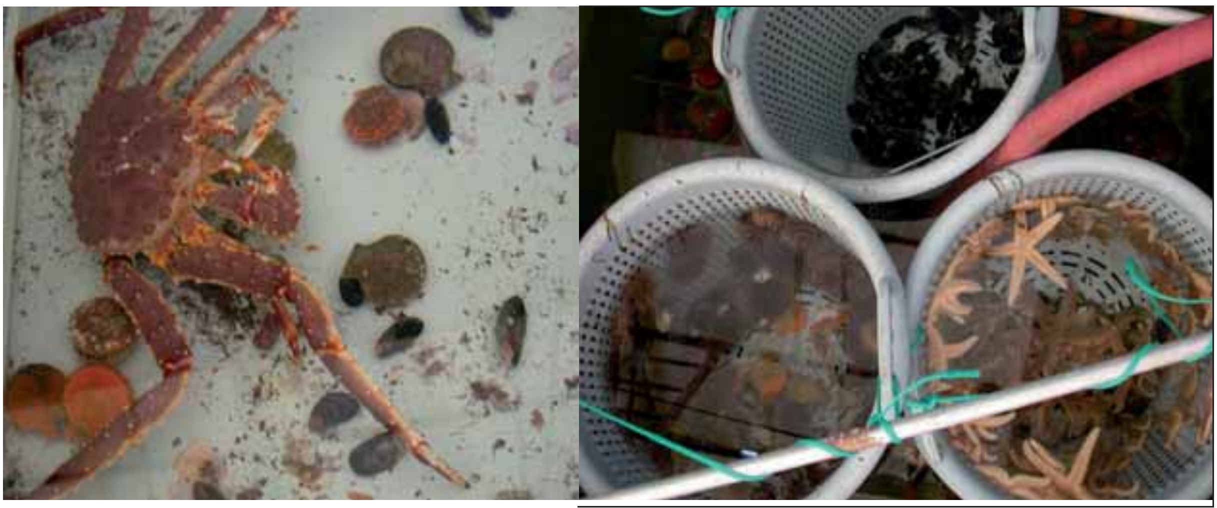
It appears that king crabs have two distinct methods of feeding: 1) grasping and tearing apart larger evertebrate organisms, and 2) filtering organisms with the third maxillipeds from substrate scooped up by the lesser chela. Adult king crabs are opportunistic, omnivores (Cunningham 1969) using the most abundant benthic organisms as food. At least one species group tends to dominate their diet, and diet composition is usually area-specific (Jewett and Feder 1982). Food consumption depends on life stages. The larvae are plankton feeders consuming both phytoplankton and zooplankton (Bright 1967). The bottom settled juvenile crab in the coastal regions of the west Kamchatka shelf feed on hydroids, the dominant epifaunal component of the refuge substrate within the region (Tsalkina 1969). From other areas diatoms, foraminifera, sponge spicules, bryozoans, polychaetes, ostracods, and harpacticoid copepods together with sediment was reported from stomachs analyses. The approximately 86%, by weight, of the major food categories ingested by the adult king crabs consisted of animals which possess calcareous shells, namely ecinoderms (*Ophiura sarsi*, *Strongylocentrotus* sp and sanddollers) and mollusks (*Nuculana radiata*, *Clinocardium californiense*, *Chlamys* sp, Buccinidae and Trochidae) (Cunningham 1969). An increase in the consumption of calcareous benthic animals is found in connection with ecdysis (Herrick 1909; Logvinovich 1945; Feniuk 1945). Kulichkova (1955) suggests that crabs need to replace calcium carbonate lost during molting and those young clams and barnacles in shallow waters represent an abundant resource to fulfil this need.

Foraminifera, minute molluscs, and amphipods in the stomachs suggest feeding upon small evertebrates which borrow in or move upon the substratum. Scooping of sand was often observed during periods where no evident food material was immediately available, although the significance of this behaviour is obscure, it suggests an alternate method of feeding when larger prey is unavailable (Cunningham 1969).

Low densities of benthic food organisms may not necessarily limit feeding activity of the king crab. The king crab posses adaptations as long and slender periopods which allow rapid and efficient movement in the vast open regions of the deep sea (Somerton 1981). It appears that speed and mobility of king crabs would allow them to exploit considerable areas of sea bottom (Cunningham 1969).



Photos: Lis Jørgensen

In the Barents Sea the non-native king crab seem to reflect much of the same behaviour as in the native areas of Bering Sea and Northern Pacific. This behaviour includes the main prey categories eaten such as bivalves, echinoderms (spring and summer) and polychaetes (in autumn and winter) (Gerasimova 1997), with a principal diet on the sea urchin *Strongylocentrotus droebachiensis* (Gudimov et al 2004). Gerasimova (1997) writes that food appears to be the solely factor which could limit the increase in abundance of king crabs within the Southern Barents Sea, with its mean depth of 230m. Recent data on food preferences have been obtained through quantifying the gut contents of king crabs collected by trawling on soft-bottoms, and subsequently with soft-bottom invertebrates as the main food items (Sundet et al. 2000). Analyses of the king crab stomach content show that the crab feeds on a variety of resident organisms. This includes a diverse range of molluscs, and other echinoderms (Jewett et al. 1989), crabs, worms (polychaetaes and sipunculides) and fish (Gerasimova 1997; Sundet et al. 2000). But positive identification of food items is extremely difficult. Decapods rarely swallow whole animals, but tear pieces from the main portion. The pieces passes to the gastric mill which thoroughly masticate food items, effectively reduce the prey to an amorphous mass. Fragments of food items may be scattered and lost entirely before the transfer to the mouth. Moreover, crustaceans possess a small oral opening and whole ingested animals are necessarily small, their body axis is generally long.

Feeding experiments in laboratory

The commercial scallop *Chlamys islandica* (O.F. Müller) has been observed as a preferred prey items when offered to the red king crab in feeding experiments in laboratory (Jørgensen 2005; Jørgensen and Primecerio 2007). These experiments demonstrates high walking activity of the crab and when prey touched the fringes of hairs on the inner edges of the chelipeds and maxilipeds it was drawn in under the body towards the mouth. When feeding on bivalves, the smaller prey is easily crushed outright by the right larger claw. Once the shell has been crushed, flesh is torn out by the left smaller chela directed to the mouth-parts and ingested. Larger flattened bivalves such as scallops were edge-chipped, the valves grasped by the chela and pulled open in order to expose the flesh. Identification of bivalve species from stomach analysis, using flesh, would be a challenge if not impossible. The laboratory results demonstrate the susceptibility of native scallop (*Chlamys islandica* Müller, 1776) bed communities to king crab predation (Jørgensen 2005; Jørgensen and Primicerio 2007). Mature (~3000g; 1700g) and immature (~500g) king crabs are capable of killing ~300g and ~150g prey (scallops, *Strongylocentrotus droebachiensis*, *Asterias/Henrisia*, *Modiolus modiolus*, *Astarte* sp, *Buccinum undatum*) daily, respectively. The data set suggests a mature crab preference of prey sizes larger than 3 cm, and for round/arch prey-bodies a maximum of 6cm height/diameter. Larger round/arced bodies which, after a period, could not be crushed were abandoned for another prey. Flattened prey-bodies as scallops and *Asterias* sp had no upper limitations and probably no size refuge from predation when both mature and immature crabs are present. Both mature and immature crabs left valves on the bottom as fragments or as edge-chipped (fingerprints) after tearing the bivalve flesh into pieces and consuming it. The laboratory results demonstrate that abundant king crabs could have significant effect on Norwegian scallop beds (500-1000g scallops/m^2). But it is yet to investigate if the actively moving king crab, is capable of not only crushing bivalves, but also picking soft animals and scooping meio- and microorganisms from sediment, will have a non-reversible effects on the bio-diversity of native benthic communities.

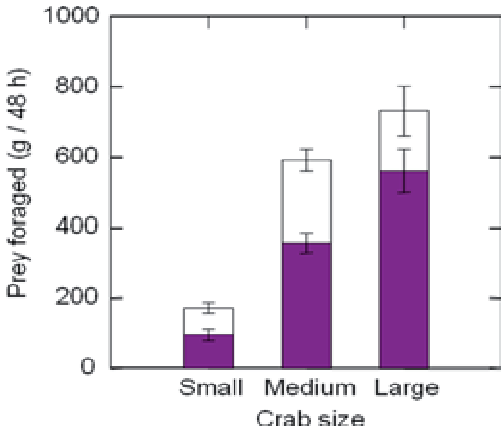


Figure 2.18. Results from laboratory investigation on foraging of scallops (*Chlamys islandicus*) (colored column) by three sizes (small ~500g , medium ~1500g and large ~3000g) of red king crab when also offered alternative prey (white column) of blue mussel (*Mytilus edulis*), sea urchins (*Strongylocentrotus droebachiensis*) and sea stars (*Asterias rubens*).

Conspicuous native epibenthic species such as the scallop *Chlamys islandica* (30 year lifespan, maturation after 3-6yr (Vahl 1981) are particularly exposed to risk of local extinction. It is of high priority to follow and quantify the potential impact of the king crab promoted by its exploitation and disturbance of native benthic communities along the coast of northern Norway. In year 2001 fields of non-invaded scallop beds, located in Porsanger fjord in Northern Norway, was chosen as an object of long-term monitoring. Although their distribution within this area has not been thoroughly measured, abundance varies between approximately 400-1200 g scallops per m^2. In order to track a possible impact on the scallop population, the scallop bed has to be followed with methods which are easily obtained, but still statistical robust (Jørgensen et al. in prep).

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2.2.4. Alteration in soft bottom fauna in Varangerfjord after the red king crab introduction

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Background

Several investigations have shown that benthic fauna constitutes the most important food organisms for the red king crab (Takeuchi 1967, Feder and Paul 1980, Sundet et al 2000). Generally larger sedentary and slow-moving organisms are preferred. It may therefore be assumed that benthic ecosystems with a high amount of sedentary species may be pronouncedly affected when the crab enters into a new area.

The red king crab invaded the Varanger fjord area in the early 1990s, and became abundant in the southern part of the fjord during the first half of the decade. The stock increased strongly in the second half of the decade, when the crab became established all over the fjord area (Anon 2007). The Varanger fjord is characterized by small bights and relatively narrow side-fjords, which apparently are favorite areas for the king crab.

The ecological impact of the crab was not a hot issue during the early years of the invasion. It also contributed to the low focus that “pre-king crab” knowledge of the benthic ecosystems was very scarce, especially quantitative information on species assemblages and natural gradients. However, as a consequence of the increased crab abundance and the continued spreading of the crab to new areas, the need for knowledge about ecosystem effects has become apparent. Recently, comparisons of benthic fauna in fjords with dense crab populations and fjords close to the dispersal front have therefore been made. These studies suggest that larger organisms of bivalves and echinoderms have been significantly reduced in the areas where the crab has been present for several years.

In the Varanger fjord area, quantitative data on soft-bottom infauna exist from a few previous studies, carried out respectively in the southern side-fjord Bøkfjorden and at Byluft in the innermost part of the fjord (Skei et al. 1995, Holte et al. 2004). These studies allow direct before and after crab invasion comparisons to be made for species assemblages in areas which presently hold dense crab populations. By chance, both areas were sampled in 1994 just prior to the strong abundance increase of the crab. The study in Bøkfjorden (Skei et al. 1995) was principally focused on possible effects from mining industry, which were found to be none in the outer part of the Bøkfjord, whereas the study at Byluft (Holte et al. 2004) was performed for establishing reference data for environmental investigations.

In august 2008 sampling stations from both 1994 studies were revisited in order to describe the present fauna. We here report some preliminary results from the investigations. In particular, the present catch of larger easily observable species like mussels, worms and echinoderms is compared with the results from 1994 to indicative the status of these groups. In Bøkfjorden, a few stations were revisited in 2007 in a separate study, giving an indication of changes in the fauna (Skaare et al. 2007).

Material and methods

In total five stations in Bøkfjord (206-375 m depth) and four stations at Byluft (10-110 m depth) were sampled (Figure 2.19). At each station four replicate samples were taken using a 0.1 m^2 van Veen grab. The samples were sieved through 5 and 1mm round mesh screens and fixed in buffered 4 – 6% formaldehyde solution. Subsamples of surface sediment for analysis of particle size and organic content were taken at each station.

Figure 2.19. Benthos sampling stations (grab) in Varangerfjord, August 2008.

Results

Bøkfjord

The most striking observations were a total absence of the mud sea star *Ctenodiscus crispatus* and a significant reduction of brittle stars (Ophiuroidea). In 1994 *Ctenodiscus* was present in a density of 10-15 ind/m^2 (Skei et al. 1995). The present low occurrences of echinoderms are corroborated from tows with bottom sledges and dredges in the same area (pers. observations, Skaare et al. 2007). It also seemed that several species of bivalves and bristle worms, which were quite frequent and abundant in the 1994-samples, were reduced or absent. Most bristle worms and bivalves are of small and moderate size, however. The study of Skaare et al (2007) showed similar results and suggested that larger bristle worms were reduced in addition to the echinoderms.

Byluft

As in Bøkfjorden, large specimens of biologically important taxa were reduced or absent. For instance, no brittle stars of any species were observed at all in this year samples and very few specimens of the sea urchin *Strongylocentrotus droebachiensis* were found, which were common in 1994. The bivalves *Mya truncata* and *Macoma calcarea* were highly reduced, and only some few larger specimens were found. It also appeared that smaller bivalve species such as *Yoldiella lucida* was reduced or absent. Among the bristle worms, *Harmothoe imbricata*, which was abundant at the shallowest station (10 m depth) in 1994, seemed to be totally absent in 2008. The same holds for *Nothria conchylega* which were common at the two deepest stations in 1994 and not recorded in 2008. In addition, sedentary tube-building worms, as for instance *Nicomache quadrispinata* and *Maldane sarsi,* were apparently reduced in abundance in 2008.

Preliminary conclusions

The estimated king crab stock has increased about ten-fold during the period from 1994 to 2008 in the Varangerfjord area (Anon 2007). To our knowledge, there have been no other major ecological changes in the fjord area in the same period which could explain the changes in the soft-bottom species assemblages as presently observed. The mining industry previously had a major impact on benthic communities in the inner part of Bøkfjorden (Skei et al. 1995), but the activity stopped in 1997 and the species assemblages in the impacted areas have largely been restored (Skaare et al. 2007). We therefore conclude that the observed changes are likely to be caused by feeding activities from the king crab.

Complete results from the investigation will be published as soon as all material has been analyzed.

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2.2.5. Seasonal depth distribution of the red king crab (*Paralithodes camtschaticus*) in Varangerfjorden

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Introduction

One can arbitrarily group adult red king crab (*Paralithodes camtschaticus*) seasonal movements into two categories: the mating-moulting behaviour and feeding behaviour. The shoreward migration to shallow waters takes place in late winter and early spring were they mate and breed (Marukawa, 1933; Wallace et al. 1949; Powell and Nickerson, 1965; Bright, 1967; Stone et al. 1992). Larval hatching is also associated with these events and the hatching process extend over 32 days in average (Stevens and Swiney, 2007). The shoreward migration is followed by migratory feeding movement to deeper waters, and then the migration happens independently regarding the sex. The sexes are not found together until the following mating and moulting season (Cunningham, 1969).

Sexually immature crabs generally remains in shallow water and are seldom associated with mature crabs in the deep water (Wallace et al. 1949). The immature crabs of the same size groups are known to form pods, and the pods are composed of both sexes. The pods are identifiable population units composed of juvenile, sub-adult and adult red king crabs of both sexes (Dew and McConnaughey, 2005). The podding behaviour causes the red king crab to be spatially distributed within their habitat as dense aggregation both when resting and foraging. Such behaviour increases the fraction of the total population and will lowering the probability of capturing crabs (Dew and McConnaughey, 2005).

The purpose of this study was to describe the seasonal depth and distribution of mature and immature female and male red king crabs in the Varangerfjorden area.

Material and methods

The crabs were caught by baited traps in an area close to Vadsø in Varangerfjorden in the period September 2004 to August 2005. The sampling was done each month at the same five stations. The traps were set at 50, 100, 150, 200 and 235 m probably on sandy and muddy bottom substrates. At each station one string, consisting of 3 square traps baited with herring, were used. Average soak time was 27.2 h (±12.6 h s.d [standard deviation], minimum 8.3 h, maximum 66 h). All crabs captured in the traps were counted and measured. For each, carapace length (CL) was measured to the nearest millimetre by using a vernier calliper. The collected data have been separated in two classes, mature female and male crabs (CL ≥ 110 mm) and immature female and male crabs (CL<110 mm). The data is presented for each month, the percentage distribution of the four categories (mature female and males, immature female and male) are presented for each station (depth).

Results and discussion

Mature females

The catches of mature females were either large (N>100 individuals) or small (N<50 individuals). Large catches were observed in January, February, September, November and December (Table 2.5). This could be explained by the aggregative behaviour mature females have (Stone et al. 1993), and the overlap between the stations and availability of females in the same area. Low catches were observed from March to August and in October.

Table 2.5. Catch data from the sampling period September 2004 to August 2005. Number of crabs caught per month divided in mature and immature female and males. Mean soak time (h) per month is presented.

	Mature (CL≥110 mm)		Immature (CL<110 mm)		
Month	Females	Males	Females	Males	*Soak time (h)*
January	158	66	3	0	25.9
February	100	63	5	1	24.8
March	38	80	26	15	25.7
April	14	49	15	15	24.4
May	24	36	71	61	26.4
June	5	164	189	234	25.1
July	46	200	21	30	10.0
August	19	112	18	23	23.0
September	253	221	28	31	25.6
October	7	135	9	10	66.0
November	240	70	73	70	26.0
December	216	26	7	3	24.0
Total catch	1120	1222	465	493	

From June to December, the major number of females was caught at stations deeper than150 m (Figure 2.20A). In January and February they were either found on the shallow station (50 m) or on the deepest station (235 m). This could indicate an onset of migration to shallow water areas. In March about 50 % of the females were caught at the shallowest station and in April the few females were caught at the deep stations (200 and 235 m). Some of the female crabs caught in March were hatching. All female crabs with roe caught in April had new extruded roe, so they had probably started to migrate into deeper water again after the mating period. New laboratory studies has shown that primiparous females (carrying their first clutch of eggs) moult and mate earlier than multiparous (carrying their second or later clutch of eggs) females (Stevens and Swiney 2007). So catches of females in both shallow and deep water in the period January to May could be explained by this extended hatching period.

Some are on the move into shallow water to mate and some are moving into deeper water again after mating. We did not differentiate between primiparous and multiparous females in this study.

Mature males

The catches of mature males were large (N>100 individuals) from June to October (Table 2.5). In this period the mature males were caught at the deepest stations (150 – 235 m). In November and December we started to catch large mature males at the shallow stations at the same time as we caught them at the deep stations. From January to March the major number of males was caught at the shallow stations (Figure 2.20). This could be explained by the male moulting and breeding behavior. They migrate to shallow waters to achieve protection using shallow habitat, with hiding places. These males do not necessarily participate in the mating season this year (Braxton and McConnaughey, 2005). Our results indicate that mature male crabs starts to move to shallow waters already in November. In December and January all males were caught at the shallow stations.

The mature female crabs were dominating in deeper waters in the same period. In February, the females had either shallow or deep distribution, indicating that females may have started the movement to shallow waters (primiparous females), while others were still in deeper waters (multiparous females). Females caught in shallow stations in March had started hatching. In April females caught at the deepest stations had new roe, and has probably newly left the spawning ground. Low catches of females from April to August could indicate that the ovigerous females have a more aggregated behavior and is difficult to catch with traps, while the mature males are behaving more solitary. The ovigerous females actively seek optimal conditions for incubation of eggs (Loher and Armstrong, 2005). The males migrate to deeper water to find the most advantageous feeding grounds. This separation in depth could be seen in September, when all females were caught at the intermediate station and the males were caught at the deepest stations. The traps attract crabs from unknown distance and they therefore provide poor information on the micro scale distribution of the crab and their distribution by habitat and depth (Zhou and Shirley, 1997).

Juvenile crabs

The most obvious pattern observed among the juvenile catches is that there was no clear difference between the sexes. When catching juvenile crabs, the sex ratio is almost 1 to 1. The number of crabs caught were also varying between months, from very small catches (N=3) to large catches (N=423) (Table 2.5). The juvenile crabs use all depths and show no apparent distributional pattern (Figure 2.21). The smallest crab caught was 54 mm CL. The large catch of juvenile crabs in June, could be a result of soaking the traps close to a large assemblage of crabs, since it is known that crab of the same sizes forms social functioning groups. This behavior will increase the size fraction of a population in the area, and may explain the different catchability for juvenile crabs.

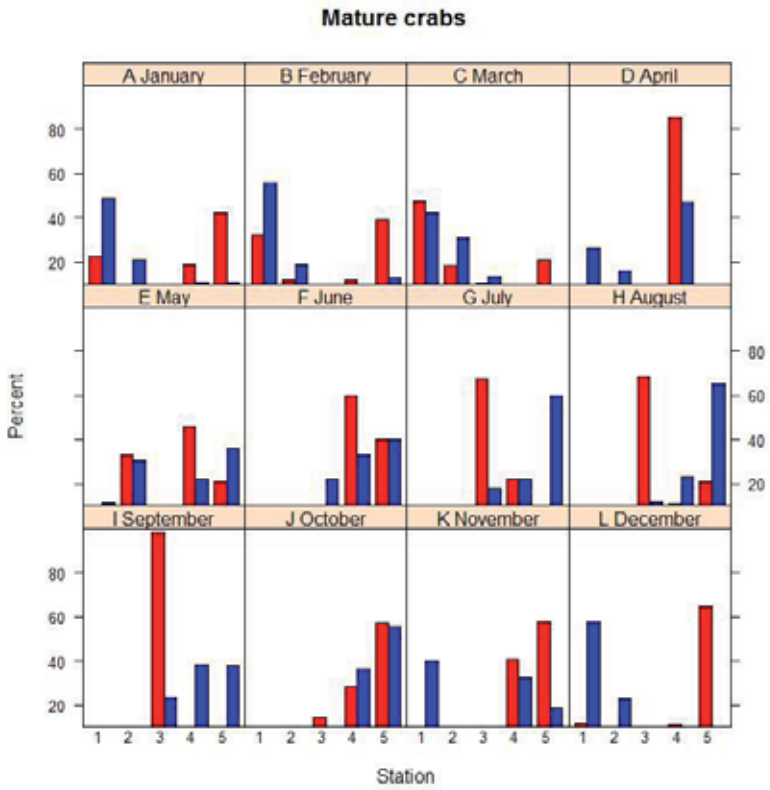

Figure 2.20. The depth distribution (%) of mature female (red bars) and males (blue bars) per station per month. Station 1 = 50 m, station 2 = 100 m, station 3 = 150 m, station 4 = 200 m and station 5 = 235 m.

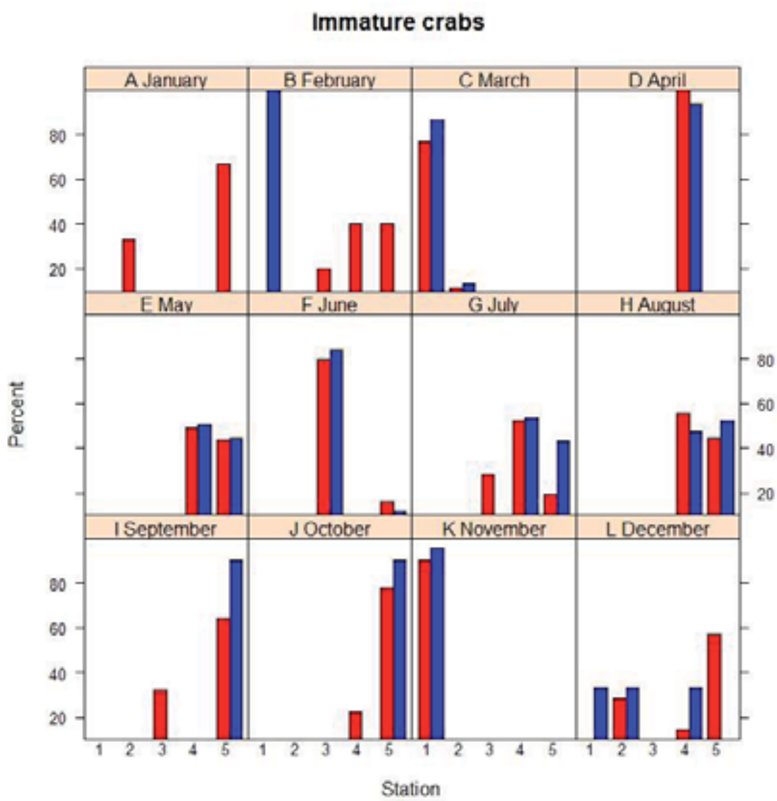

Figure 2.21. The depth distribution (%) of immature female (red bars) and males (blue bars) per station per month. Station 1 = 50 m, station 2 = 100 m, station 3 = 150 m, station 4 = 200 m and station 5 = 235 m.

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2.3. Spreading of the red king crab

2.3.1 Dispersal history in the Norwegian Economical zone

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Background

Neither Norwegian authorities nor Norwegian scientist were informed about the transfer and introduction of the red king crab to the Barents Sea during the 1960s and 70s (Orlov and Ivanov 1978). Although the first crab was caught in 1977, there was no focus on this introduced species in the Norwegian fishery management or among scientists until it became abundant close to the Russian border in 1992 (Kuzmin and Olsen 1994). Due to this it has been difficult to document the dispersal of the crab in this first period it invaded Norwegian waters.

The Norwegian research on the king crab was initiated in 1993 and almost all effort was diverted to establish knowledge on the crab being a valuable commercial fishing resource. It was not until 10 years later the scientific challenges about the king crab being an introduced species were given high scientific priority, of which the speed and pattern of dispersal became one of several issues to be investigated.

Methods

Most recordings were highlighted in local and national newspaper when king crabs were caught as bycatch in gillnets or trawl. Newspaper articles and information from other media has therefore been the main sources to describe the appearances of the crab in new areas of the Norwegian zone, the first years. Later, when routine scientific surveys were established and the consciousness about the crab increased in all parts of the society, it was much easier to confirm all new recording of the crab as it spread to new areas along the coast of Northern Norway. However, the first record of the red king crab in a new area was commonly done by others than scientists.

Results

Figure 2.22 shows the year of first observation of the red king crab in several spots along the coast of Finnmark. Single crabs may have been caught before this date, since we only got incidental information about findings, and usually when the crab caused problems in the local gillnet fishery. The catches west of North Cape (Figure 2.22) are only of single specimens.

Figure 2.22. Spreading of the red king crab in Norwegian waters. Year of first observation are shown in oval rings. Years with question marks indicate probable man-aided movement. Shaded area in section map indicate approximate distribution area in the Barents Sea today.

A massive occurrence of crabs close to the Russian border in the south Varanger area in 1992 led to major problems for the fishermen operating gillnet. They in turn, alerted scientists who initiated investigations on the crab in 1993 and regular cruises for the crab started in 1994. In 1995 abundant numbers of the king crab was observed at several locations further west and common for all these new recordings was that they were all done in the inner parts of fjords. This pattern of establishments in new areas has also been observed in most areas since.

Although one single finding was done outside Tromsø in 1999, the king crab did not reach areas west of North Cape until 2000 in significant numbers. The year before, several crabs were caught at the inner part of Porsangerfjord. On a number of instances during the late 1990s we received unverified oral reports about fishermen that brought live king crabs from Varangerfjord and released them on several spots along the coast off Troms county. We therefore believe that the single crab caught outside Tromsø in 1999 probably was released from such activity. Additionally, within a period of 6 months several single observations of adult king crabs of both species were caught in the vicinity of Tromsø in 2005. Most probably these crabs also were released from a vessel which had brought them from eastern Finnmark. Two other recordings of king crabs that are thought to be released from fishing vessels, one in Lofoten islands in 2003 where two crabs were caught, and one caught in Trøndelag (6444^o N 1104^o E) in 2005 (Figure 2.22).

In 2002 four female crabs were caught on long-line at about 7230^o N 2207^o E and 7150^o N 2802^o E (Figure 2.22). These crabs have most likely moved off shore from the coast of Finnmark. In the recent 2 – 3 years the crab abundance have increased in the more off shore areas (> 12 nm) outside the coast of eastern Finnmark, while it earlier were almost exclusively found in small bights and inlets in this part of the coast. Bycatch in trawl surveys and a special crab survey out to 60 nm off shore, indicate only occasional occurrence of the king crab outside 15 nm off shore.

In spite of single crab recordings in areas west of North Cape and far off shore, we believe that the main distribution area of red king crab in the Norwegian waters are limited in west at about Hammerfest and along the 12 nm border in north (Figure 2.22).

Discussion

Confirming new records of the king crab as it spread to new areas in Norwegian waters have been a difficult task since most of these findings have been done by local fishermen not familiar with this species at the time of first findings. In the reports to us about king crab findings there have always been a misjudgment between large northern stone crabs (*Lithodes maja*) and the red king crab. Therefore, all findings of the king crab by others had to be verified by a qualified person before it entered our records. Thus, the red king crab might well have invaded new areas in the Norwegian waters long before our first records.

The spread of the king crab in Norwegian waters has typically been in coastal waters with few recordings off shore. This pattern is in contrast to the situation in the Russian part of the Barents Sea (Pinchukov, this report). The dispersal of the crab is dependent on factors such as movement and behavior of adult crabs, spread of larvae, availability of food, predators etc. These factors have not been studied yet, but the most striking difference between the Norwegian and the Russian coastal areas along the Barents Sea is the coast line shape and bottom topography. In the Russian part, there are no fjords or large inlets and the depth increases smoothly from the coast to off shore areas, while the coast of Finnmark is characterized by large and deep (>200 m) fjords.

Investigations on the red king crab in its native areas have revealed that it occupies areas of shallow waters during spring and deep water in winter (Stone et al 1992). The movement to deeper areas seems to be adapted by the crab in our waters (see Hjelset and Sundet, this report), and if this is a conditional behavior, the crab may reach deep areas (> 200 m) within the large fjords of Finnmark. In contrast, the crab has to move far off shore to find the same depths in the Russian part of the Barents Sea.

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2.3.2. Red king crab settling and conditions of habitation in Russian waters of the Barents Sea

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Settling, alongside with birth and mortality rates, is one of the most important biological parameters determining the population growth and density (Odum, 1975). Settling is highly dependent on natural conditions, as well as on the mobility, i.e. the inborn ability of organisms to move. Settling ability of marine bottom invertebrates is strengthened by pelagic development of larvae due to their transport by currents (Mileikovsky, 1977).

Natural obstacles for species extension are determined by the threshold conditions of their habitat. The abiotic conditions of the red king crab habitation in the Far East seas are described well in literature. In the northern Pacific Ocean the crabs occur in a wide temperature range. Different authors note that, in natural conditions of this region, the crabs are distributed at 2-500 m depths, with –1.7 - +18.2 water temperature and 28-35 ‰ salinity (Vinogradov, 1941; Galkin, 1960; Rodin, 1985; Maslennikov et al., 1999; Klitin, 2001). It was noticed that the crab optimal temperature range was 0.5-1.5° C and salinity not less than 32 ‰ (Chebanov, 1965). At early stages of life, the conditions of species habitation significantly differed from above-mentioned. So, the larvae of the red king crab from the Posjeta Bay (the Japanese Sea) are registered at water temperature of 3.5-20° C, salinity - 27.22-33.85 ‰ and oxygen content – 5.98-8.18 ml/l (Fedoseev et al., 2001).

According to a few data on habitat of the red king crab in the Barents Sea area, which is new for the crabs (Kuzmin et al., 2002; Berenboim, 2003), it is known, that the whole year around they face positive water temperature of 0.4-7.0° C at the depths to 300-350 m.

By now, many data on distribution and temperature conditions in the habitat of the red king crab in Russian waters of the Barents Sea have been accumulated which allow us to specify our concepts on peculiarities of crab settling since the period of introduction till forming the current area.

The paper uses data on red king crab distribution obtained in annual trap and trawl surveys for the species in 1995-2007, as well as those ones on crab by-catches in trawl fishery of bottom fish in 2001-2005 as initial. The research covers Russian waters of the Barents Sea from the border with Norway in the west to the Kolguev Island in the east, from the coast in the south and to 70°30'N in the north, from 20-30 m –335 m depths. In the catches, crabs were represented by individuals of 60-270 mm carapace width.

To analyze the conditions of crab habitation we used hydrographic data on the Kola Section for 1960-2006 and deepwater hydrographic observations of the Polar Institute in the Barents Sea in August-September 1995-2006.

To estimate water temperature and single out the long-term periods of warming and cooling on the Kola Section used was the classification proposed by V.Tereshchenko (1985) where the values of root-mean-square deviations of temperature were taken as a quantitative indicator.

Transoceanic movement of the red king crab from the Pacific Ocean to the Northeast Atlantic was executed in 1961-1969 in order to replenish bioresources of the Barents Sea. The crabs delivered from the Russian Far East were released at the coastal areas of the Kola Bay and in the adjacent waters between the Motovsky Bay and the Kildin Island (Figure 2.23).

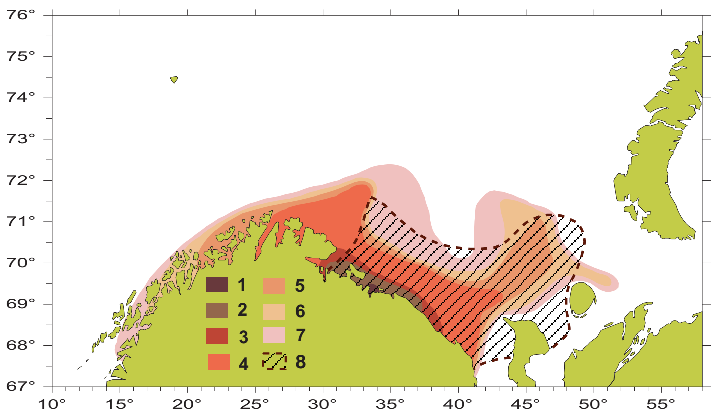

Figure 2.23. Distribution of red king crab in the Barents and Norwegian Seas:
1 – areas of species introduction in 1961-1969;
2 – boundaries of distribution in1977;
3 – in 1990;
4– in 1994;
5 – in 1995;
6 – in 1997;
7 – in 2002 (Berenboim, 2003);
8 – boundaries of distribution in Russian waters in 2005-2007.

In the Barents Sea, the 1960s were not favourable in respect of preferred the temperature conditions of habitation by the red king crab. The second half of that decade was, on the whole, characterized by the common cooling trend manifesting itself in the temperature decrease of the main currents in the Barents Sea with the minimum in 1966 (Bochkov et al., 1987) (Figure 2.24). In that period, crabs were not found.

Cooling finished in 1972, and later in 1976, the water temperature increased. In particular, significant positive anomalies of water temperature were registered for all branches of warm currents on the Kola Section. In respect of temperature, those years were considered as warm (Figure 2.24). By the middle of the 1970s, the data on the new species found in Russian waters of the Barents Sea started to be obtained. Already by the end of the 1970s, in Russian coastal waters, crabs settled eastwards, to the archipelago of Seven Islands (37º30'E), and westwards rounding the Rybachy Peninsula, in the southeastern part of the Varanger Fjord.

In the following period, from 1977 to 1988, anomalous decrease in the temperature of the main streams of the Barents Sea warm currents, with local warming in 1983-1984, was observed. On the Kola Section, the lowest values of water temperature negative anomalies were recorded in the deep layers. During that period, the boundaries of the red king crab area were not extended significantly. Crabs inhabited coastal waters from the boundary with Norway in the west to the Nokuev Island in the east (38º30'E).

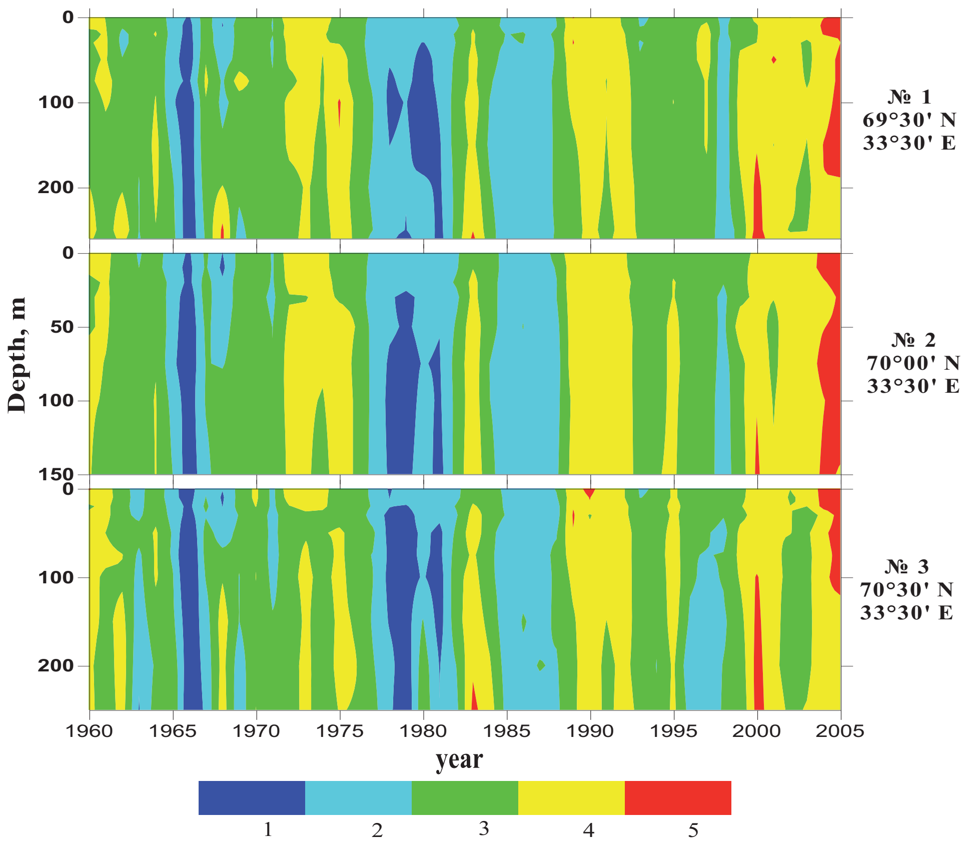

Figure 2.24. Water temperature at Stations 1-3 of the Kola Section in 1960-2005 (Karsakov, in press): 1 – anomalous cold; 2 – cold; 3 – normal; 4 - warm; 5 – anomalous warm years.

Since 1989, the warming period started in the Barents Sea.. On the Kola Section, that period was characterized as warm and anomalous warm, with minor cooling in 1997-1999 (Figure 2.24). In that period, on the section, the maximal temperature was registered in 2004-2005

(Karsakov, 2007). In those years, crabs started active distribution outside the coastal waters to the north (up to 71º20' N), to the Finnmarken Bank in the west and the southern slope of the Goose Bank in the east. To the east, the boundary of crab distribution shifted to the Kolguev Island (51º E). In the coastal waters, crabs reached the Voronka of the White Sea.

In 2003-2004, the position of crab area boundaries in Russian waters of the Barents Sea became stable. In 2005-2007, it remained to be quasistationary (Figure 2.23). According to data from catches by dredges, mature females and juveniles of both sexes were found in the Voronka of the White Sea, within 67º40'-67º50' N and 41º00'-42º15' E (Zolotarev, personal information), in 2007.

Analogous to that mentioned above, there was quantitative redistribution of species population commercial part from the western area part to the eastern one. Figure 2.25 shows the dynamics of total Russian catch of the red king crab in the western (to the west of 35º E) and eastern Murman (Russian waters) in per cent.

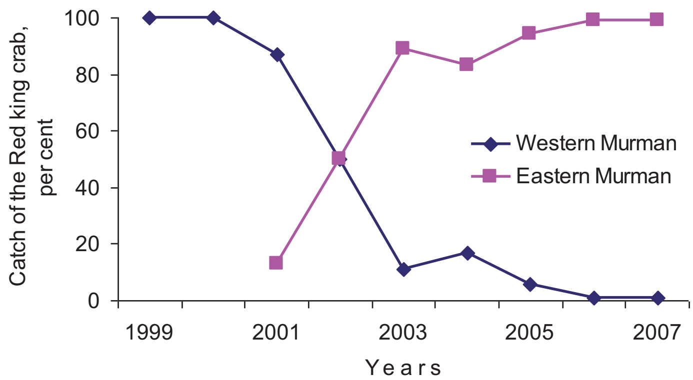

Figure 2.25. Variation of total Russian catch of the red king crab in Russian waters of the Barents Sea in per cent.

Before 2001, almost all crabs were caught in the western Murman, in 2002, they were taken in equal parts in the western and eastern Murman, since 2003 crabs has been harvested in the eastern Murman.

The analysis of our data shows that adult males were the first to inhabit the new areas in the offshore waters, in the east and north of the area. However, in the following year, adult females appeared in those areas. They, obviously, were the first to inhabit the new parts of the coastal waters.

According to our data, in Russian zone of the Barents Sea, red king crab occurs from the coastal shallow down to 335m depth, within the temperature range of –0.81 - +8.47º C. In spring, in April-May, the crabs form concentrations of both sexes, within 0-2º C temperature range. In August-September, crab concentrations are usually of different sex. Males form concentrations within 4-6º C temperature range, females – within 5-7º C temperature range.

Conclusions

1. In Russian waters of the Barents Sea, red king crabs occur from the coastal shallow down to 335 m depth, with –0.81 - +8.47º C water temperature in the bottom layer.
2. The temperature conditions of crab habitation during the introduction in the 1960s are characterized as unfavorable, with a pronounced trend to cooling. There is no information available about crab findings in this period.
3. Water temperature was softening since the beginning to the middle of the 1970s and considered as warm. In that period, the first data on red king crab recordings were received. Already by the late 1970s, in Russian coastal waters crab had settled to the east, up to the Seven Islands, and to the west, in the southeast of the Varanger Fjord.
4. Since the last quarter of the 1970s to the late 1980s there was anomalous reduction in water temperature. During that period, the area of red king crab has not been widened significantly.
5. Since the late 1980s to the end of the first decade of the 21st century, water temperature was characterized as warm and anomalous warm. In those years, crabs actively distributed northward, to the Finnmarken Bank, and the southern slope of the Goose Bank, and to the east, to the Kolguev Island. In 2003-2004, the position of area boundaries became stable.
6. The widening of red king crab area in Russian waters of the Barents Sea was more intensive against the increase in temperature of the Atlantic currents. It allows us to assume that water temperature is the main limiting physical factor.

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2.3.3. Potential spreading of red king crab larvae by currents along the North Norwegian coast

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The larvae of the Red King Crab develop in the near-coastal zone and succeed through four pelagic stages in approx. 60 days. The larvae are passive pelagic drifters during this period and can potentially be transported large distances by currents. For survival and furthermore recruiting to the stock, the larvae must be transported to favourable settling habitats.

In order to fully understand the evident linkage between passive RKC drifters and water movement, it is essential to identify the spatial and temporal dynamics of the prevailing current systems in this region.

Along the Norwegian coast, two major current systems dominate (Figure. 2.26). These are the Norwegian Atlantic Current (NAC) and the baroclinic Norwegian Coastal Current (NCC). Outside Troms County, the NAC splits and the inshore branch changes name to the North Cape Current. One branch follows the shelf edge northwards while the other flows around Tromsøflaket and continues along the Norwegian coast along with the NCC. The current system along the coast of North Norway is complex, and rich in mesoscale features, e.g translating and semi-stationary eddies. This is mainly due to an intricate bathymetry, windpatterns, phaselag of the barotropic tidal signal, baroclinic instabilities etc. However, the general current direction is towards northeast - southeast.

The spreading potential of RKC larvae has been investigated through model simulations. A combination of an Individual Based Model, an advection scheme and a hydrodynamical model was used.

The main direction of transport of larvae was between 60° and 90° in an eastward/north-east direction for 1998 -2000 (Figure 2.27). However, a certain fraction of the population exhibited a net westwards motion. In 1998, 22 % were advected westwards, while the numbers are 33 % and 34 % for 1999 and 2000. Maximum net distances advected were 247 - 314 km. Those advected eastwards followed the NCC. The westward transport is due to minor nearshore local current systems, and we also believe that westwards branches of eddies are used as conveyorbelts for larvae. There is also an offshore transport into the Barents Sea of RKC larvae during all three years. A major fraction of objects leave the coast along well defined “departure highways” (previously seen in hydrodynamical simulation), while particles released in semi-enclosed regions like fjords, tend to remain there. Such a feature is seen north of the Tanafjord, where a vast number of objects leave the coastal region and are advected northbound into the central and eastern Barents Sea.

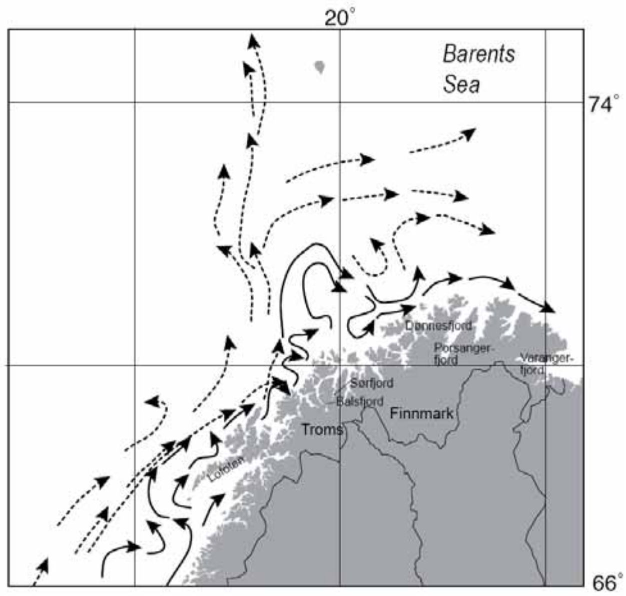

Figure 2.26. Current systems along the coast of North Norway.

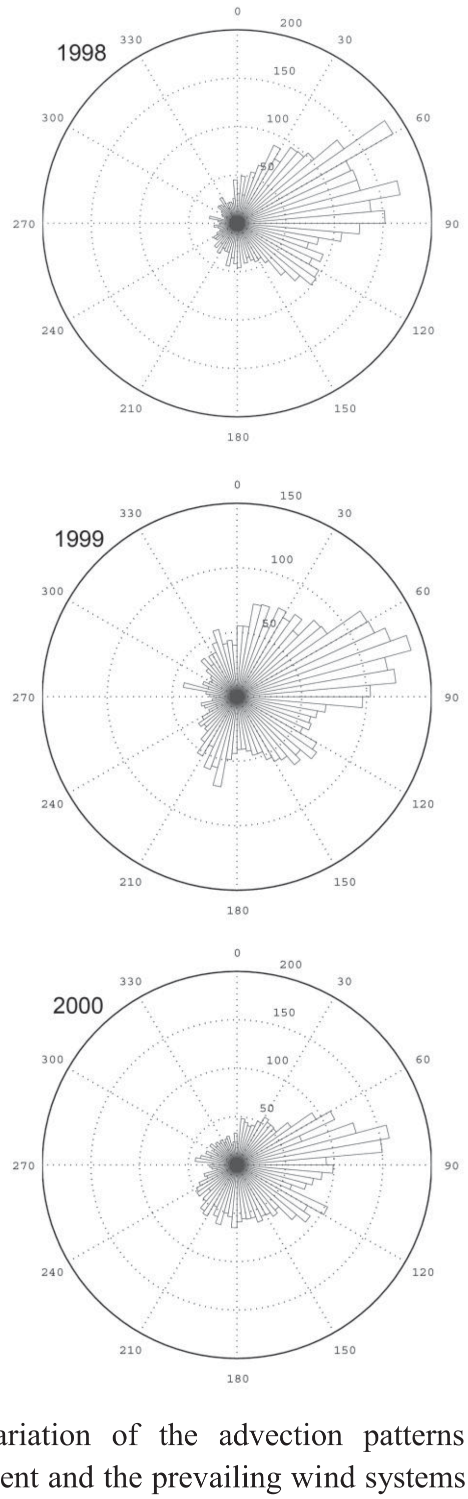

Figure 2.27. Modelled advected direction of Red King Crab larvae in 1998, 1999 and 2000. The concentric circles indicate number of larvae.

There is significant interannual and intra-seasonal variation of the advection patterns modelled. This is due to the variability of the coastal current and the prevailing wind systems during the 2 month pelagic phase. The upper 50 m layer, also known as the wind-driven layer, is subjected to wind-stress, and is has been seen that certain wind conditions can almost entirely block the northward/eastward propagation of this layer. This will obviously effect the larvae dispersal. Also the amount of eddies acting as retention bodies and transporting agents is variable, and will affect the transport.

What is still poorly understood is how larvae are able to utilize small-scale coastal current variations and mesoscale features, the population effect of these anomalies and how near-shore stationary retention areas effect the distribution of larvae.

2.3.4. Preliminary results from experimental studies of temperature preference and tolerance in Barents Sea red king crab (*Paralithodes camtschaticus)*

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[2)] University of Tromsø, Norway

The temperature preference displayed by adult red king crab was investigated in a temperature gradient ranging from 1-14 ºC. We tested seven females with roe (range in carapaxe length: 129-159 mm), seven females without roe (range in carapaxe length: 100-115mm and twelve male crabs (range in carapaxe length: 108-121 mm). All crabs were tested under both feeding and starving conditions at the ambient light conditions of 70 °N from March to May. The crabs were individually tagged with an iBTag data storage fish tag of the type iBkrill-temperature logger attached to the carapace and the ambient temperature was logged each minute for a period of > 48 h. This provided us with a final data set of > 2880 temperature registrations per crab. During the entire logging period the crabs were left undisturbed in the gradient after which the logger was removed and the data downloaded to a PC for subsequent statistical treatment. The results showed that the roe-bearing crabs selected a higher temperature zone (4-6 °C) than both the females without roe and the mature males (2-4 °C) (Figure 2.28).

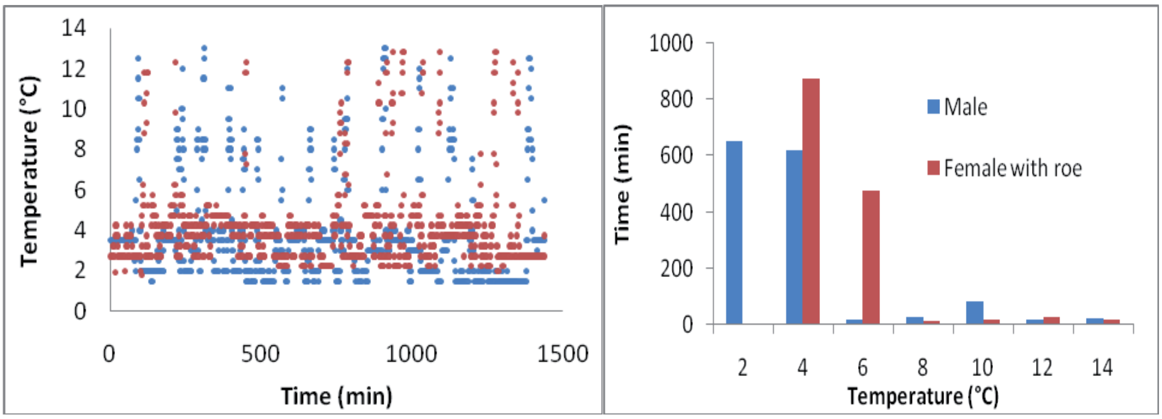

Figure 2.28. A graphic exemplification of temperature registrations (24 h) for a male (blue) and a roe-bearing female (red) crab. The panel to the left show the raw data obtained from the two loggers whereas the panel to the right show the time spent at given temperatures in the gradient by the respective crabs.

The absolute temperature tolerance, i.e. the temperature causing 100% mortality, was investigated in red king crab larvae. About 9000 larvae were collected immediately after hatching and acclimated in incubators at 4 (ambient), 8 and 14 ºC. The acclimating larvae were fed *ad lib* and the duration of the specific planktonic stages was registered. We conducted 150 short-term temperature challenge tests covering the developmental stages: Zoea I – IV and the glaucothoe (G). For each challenge test, 20 intact larvae at a given stage and acclimation temperature were acutely exposed to temperatures ranging from -1.7 to 30 °C for 55 h using a water bath (Heto HMT 200/CBM 18-30).

The results showed that the tolerance towards high-end temperatures increased significantly both with the larval stage (i.e. from Z1 to G) and the acclimation temperature (i.e. from 4 to 14 °C) prior to the challenge tests (Table 2.6). Hence, the G-stage was the most temperature resistant (absolute mortality at 24.2 °C) compared to the Z1-stage which succumbed already at 21.5 °C. Interestingly, absolute mortality was not observed for any of the larval stages at subzero temperatures close to the freezing point of seawater (-1.7 °C). This may suggest a potential for a successful dispersal of red king crab larvae to the north in the Barents Sea and into the Arctic Ocean.

Table 2.6. Absolute lethal temperatures for larval red king crab after 55 h of exposure. The larvae were acclimated to either 4, 8 or 14 °C prior to the challenge tests.

Stage	4°	8°	14°	average
ZI	21,5	21,5	21,5	21,5
ZII	19,6	21,5	22,5	21,2
ZIII	22,5	20,1	23,3	22,0
ZIV	21,5	23,3	23,3	22,7
G	23,3	22,5	24,2	23,3

2.3.5. Movements of adult crabs in Varangerfjord – tag-recapture experiment

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Background

The crab stock in the Barents Sea was earlier regarded as a shared stock between Norway and Russia, and was managed jointly by the two countries where each national quota was derived from the stock size in each national zone. In 2006, this regime was terminated and national management regimes were implemented.

In Norway there is a public agreement that the spreading of the king crab along the coast of Northern Norway should be stopped. There is also some that claims it should be eradicated since we are dealing with an introduced species. The chosen management of the crab in Norwegian waters implemented in 2008 includes a limited area where the crab will be managed as a sustainable fishing resource. Outside this area there is an unlimited free fishery in order to prevent further spread of the crab (Anon. 2007). These two oppositely aimed management regimes entail different challenges, particularly when it comes to movement patterns of the crab in our areas. Therefore we want to use results from tagging experiments with the red king crab in the Varangerfjord area to reveal questions such as does population density affect the rate of emigration from an area, and how long distances does the king crab move during a certain amount of time. We also question if there are differences in movement patterns between sexes.

Tagging experiments and data sources

Crabs were tagged and released at two sites, twice annually in the period from 1994 to 1998, and once in 1999, in the southern part of the Varangerfjord. Sampling was carried out using traps, Agassiz-trawl, diving and gillnet. In addition, we tagged and released some specimens caught in the commercial fishery. Different sampling gears and methods may catch crabs of different sizes and sex. A paper scrutinising the sampling of king crabs in the Barents Sea is in preparation (Sundet and Nilssen, in prep .).

Tagged crabs were released at two sites (Figure 2.29). Since the release position were not exactly the same every year, the width of each site is set to a circle with a diameter of four nautical miles around the two positions; site 1: 69^{o} 53,1' N 29^{o} 59,8' E and site 2: 69^{o} 47,5' N 30^{o} 45,5' E. In this study we have chosen a time at large between 12 and 18 months.

Figure 2.29. Map of the Varangerfjord indicating the two release sites (1 and 2) of tagged king crabs.

The major parts of the recaptures were caught during the research fishery in autumn each year, and recaptures is therefore dependent on the effort of the crab fishery in the different areas. Recaptures were also taken during our annual surveys, while only a minor part of recaptures were reported from leisure fisheries in the area.

It is well documented that the red king crabs perform seasonal migrations between shallow (spawning and mating areas) and deep waters (feeding areas). Therefore, it was only recapture of crabs between 12 and 18 months at large that was recorded as movements out of the release area if they were caught more than four nautical miles from the two release site positions.

Results

The number of crabs tagged at each cruise, vary from only to 509 in 1994 to 1990 in 1999 (Table 2.7), dependent on the number of crabs we were able to catch during each cruise. More crabs were tagged during the autumn cruises than in spring because the availability of crabs was higher in autumn and that a large part of the catches during spring was soft-shelled females not suitable for tagging.

Table 2.7. Total number of tagged and released male and female crabs during Norwegian cruises in the period 1994 – 1999.

	Number tagged			Number recaptured		
Year	Males	Females	Total	Males	Females	Total
1994	187	318	505	16	23	39
1995	468	778	1246	111	163	274
1996	823	797	1620	269	253	522
1997	633	1093	1726	33	131	164
1998	1228	1467	2695	38	83	121
1999	1025	963	1988	1	1	2

Most recaptures of tagged crabs was done during the annual research fishery carried out by commercial vessels, but some recaptures were caught during scientific cruises. The recaptures of tagged crabs being at large between 12 and 18 months are shown in Table 2.8. This shows that there are relatively more recaptures from area 1 than from area 2, and slightly more females than males recaptured in both areas (Table 2.8).

Table 2.8. Number of male and female red king crabs tagged and released, and recaptured after 12 – 18 months at large each year at two different release sites in Varangerfjord. Numbers in brackets and italics are percent recaptures.

	Site 1		**Site 2**		**Site 1**		**Site 2**	
Release Year	Tagged Males	Tagged Females	Tagged Males	Tagged Females	Recap Males	Recap Females	Recap Males	Recap Females
1994	188	318	0	0	0 *(0)*	1 *(0.3)*	0	0
1995	304	293	177	486	23 *(7.6)*	21 *(7.1)*	10 *(5.6)*	39 *(8.0)*
1996	599	556	284	301	54 *(9.0)*	48 *(8.6)*	12 *(4.2)*	15 *(5.0)*
1997	230	422	222	698	1 *(0.4)*	5 *(1.1)*	0 *(0)*	5 *(0.7)*
1998	578	734	664	763	5 *(0.9)*	18 *(2.4)*	6 *(0.9)*	14 *(1.8)*
1999	610	582	411	386	1 *(0.2)*	0 *(0)*	1 *(0.2)*	0 *(0)*

Crab movements direction from the two release sites are shown in Figure 2.30 a and b. Crabs released at site 1 seem to move mainly in two directions. A large part of the recaptures was done NW of the release site, to the inner parts of Varangerfjord. These were areas with lower density of king crabs throughout the whole period of investigation. In addition, a significant part of tagged crabs have moved southeast, inside the small fjords close to the release site (Figure 2.30 a). The one exception is a female crab that was caught across the Varangerfjord northeast of the release site. Tagged crabs released at site 2 were recaptured west of the site, further inside the Varangerfjord, and east of site 2 in the Russian zone. A few were captured in a small fjord close to the site (Figure 2.30 b). Male and female crabs seem to have the same pattern in movement directions at both release sites.

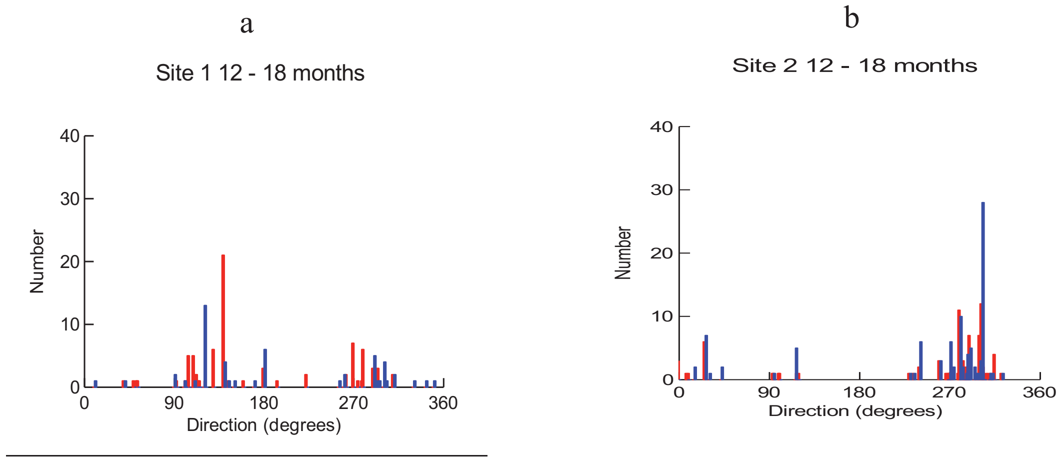

Figure 2.30. Movement direction of male (blue) and female (red) red king crabs released at site 1 (a) (134 crabs) and site 2 (b) (391 crabs) in Varangerfjord , being at large between 12 and 18 months.

In general, both sexes of king crabs recaptured after 12 – 18 months at large, have moved only short distances (Figure 2.31 a and b). Except for a large batch of males (22 crabs) released at site 2, and caught in one occasion by a fisherman (Figure 2.31b), there are mostly female crabs that has moved further than about 20 nm from the release site (Figure 2.31a).

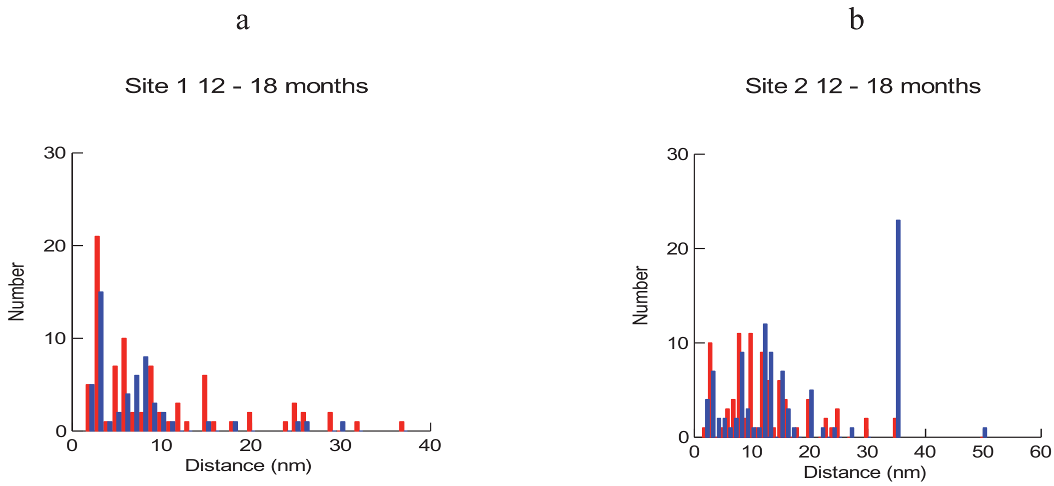

Figure 2.31. Movement distances of male (blue) and female (red) red king crabs released at site 1 (a) and site 2 (b) in Varangerfjord, being at large between 12 and 18 months.

Conclusions

The two release sites differ in concentrations of crabs and movement directions indicate that crabs moves from areas of high to areas of lower crab concentrations, as the movements from site 2 were mainly westwards (~ 300^{o}). At site two crabs seem to move most possible directions, mainly following the mainland orientation (east – west direction).

Our results indicate that the king crab does not move significantly out of an area when first established. Of all crabs tagged at site 1 and 2 staying at large between 12 and 18 months, only 8.2 and 12.6 % were respectively recaptured more that 4 nm from the release site, and a majority of these recaptures moved less than 20 nm within this period (Figure 2.31 a and b).

The results may indicate a higher frequency of movement out of the release areas by females compared to male king crabs.

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2.4. Parasites

2.4.1. The effects of the red king crab acclimatization in the Barents Sea - parasitological aspects

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The Polar Research Institute conducted parasitological studies of the red king crab caught at the Kola Peninsula coast in 1996-2001. One of the main objectives of the above studies was to detect a possible incidental invasion of parasites foreign to these waters that could have a negative effect on the native fauna. Examination of different organs and tissues of 111 crabs resulted in the detection of parasites as follows: thorny-headed worms of four species - *Polymorphus botulus* l., *Corynosoma strumosum* l., *Echinorhynchus gadi, Acanthocephalus* sp. (location - stomach, intestines, body cavity); *Nematodes* of four species - *Anisakis simplex* l., *Pseudoterranova decipiens* l. (stomach, hepatopancreas, body cavity) and two unidentified species (stomach, egg clutch); *Monogenea* (hepatopancreas), *Cestoda* (stomach) and *Turbellaria* (gills), a single specimen each, which were not identified to species. Wide occurrence of fish leech *Johanssonia arctica* on exoskeleton of crabs and a single instance of leech *Crangonobdella fabricii* were noted (Bakay et al., 1998; Bakay, 2003).

Among the above indicated parasites of the red king crab in the Barents Sea there were no species found by N. Nechaeva (1964) during the crab studies in the Far East prior to its acclimatization. To reveal possible carrying of leeches, their species composition on crabs was examined in the Strait of Tartary (the Sea of Japan), the area close to the sites of the crab capture for transportation. The majority of leeches sampled from crabs in this area were identified as *C. fabricii.* This parasite was many times found in the Barents Sea also before the introduction of the red king crab (Epshtein, 1961; Sawyer, 1986). The leech *Notostomum cyclostomum*, common for different crab species in the Strait of Tartary, was not encountered in the Barents Sea. No parasites dangerous for crabs such as crustaceans of the *Briarosaccus* and *Sacculina* genera residing in the Pacific were observed either. Therefore, the results of the studies show that the introduced red king crab has not become the source of invasion of parasites foreign to the Barents Sea.

Norwegian researchers also have no data that cast any doubt on the conclusion made (Jansen et al., 1998). However, some of them (Hemmingsen et al., 2005) mention an increase in the occurrence of flagellates *Trypanosoma*, a blood parasite in cod, at the Northeast coast of Norway (Varangerfjorden) in autumn 1999-2001 caused, in their opinion, by an increase in abundance of the red king crab spreading the leech *J. arctica* being a potential intermediate host of blood parasites in fish.

We carried out our own research and made an analysis of the information available on this issue. In 1999-2000, blood of several hundreds of cod individuals caught in bays of the West Murman, where the red king crabs occur in great numbers, was examined. In these cods, mostly aged 3-4 years, the flagellates were not detected. In December 2005, *in vivo* examination of blood in 390 cods of different age in the southern Barents Sea, where the densest concentrations and the most part of the red king crab stock is located, was made. Prevalence of infestation with *Trypanosoma* made up 23.1 % at a low average relative density of the parasite (0.7 individuals over the area of the cover glass of 18x18 mm) (Bakay and Karasev, 2006). The results show the occurrence of *Trypanosoma murmanensis* in cod in this area to be still kept at the background level (26.7 %) recorded in the beginning of the XX century (Nikitin, 1927).

In the result of the experiment with leeches gathered from fish at the coast of Norway it was found that different species of leeches, *Johanssonia arctica* and *Calliobdella nodulifera,* communicate morphologically different *Trypanosoma* to fish. Taking into account the stringent leech-specificity inherent to *Trypanosoma* (Khaibulaev, 1970) it was determined that flagellates *T. murmanensis* are associated with leech *C. nodulifera* (Karlbakk, Nylund, 1999). According to our data, the leech *C. nodulifera* being a boreal species occurs in cod rarely and only in the western (warmer) part of the Barents Sea, where the red king crab do not reside. However, the leech *J. arctica* being a commensal to the crab and an arctic species, do not occur on the crabs at the northern coast of Norway and in the Norwegian Sea, and is not found in cod anywhere (Bakay, 2003; Karlsbakk, 2005).

Data from Norwegian researchers showed that in the area distant from the king crab habitat, i.e. in warm waters of the southwestern coast of Norway, 20-59 % of cod and 67 % of haddock individuals examined were infected with *Trypanosoma.* Nevertheless, in the period of maximum occurrence (at the end of 1990's) of the leech *J. arctica* on the crab, when the leech was the most abundant in the Barents Sea in the western (Norwegian) part of the Varangerfjorden, the blood parasites were detected only in 10% of cod individuals in this fjord (Karlsbakk et al., 1999; Bakay, 2003).

The extent to which fish are affected by flagellates must be judged from the blood condition (hemogram) of individuals invaded, as the presence of the parasite, in itself, is not pathogenic for the host. It is important to be confident that flagellates are identified to species correctly that is quite problematic at present due to flaws in their description and taxonomy. When evaluating the effect of blood parasites on fish, it should be kept in mind that acquired immunity to a repeated infection may be formed. The presence of the blood parasites in fish under natural conditions does not cause a disease or death (Khan, 1991).

Thus, there are no grounds to believe that a short-term and local increase in infestation of cod blood with *Trypanosoma* observed by Norwegian researchers is caused by the red king crab expansion and the leech *J. arctica* associated with the crab. Possible increase in invasion of fish by the blood parasites under natural conditions does not mean a direct detriment to their health.

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2.4.2. Report on trypanosome infections of cod in the southern Barents Sea

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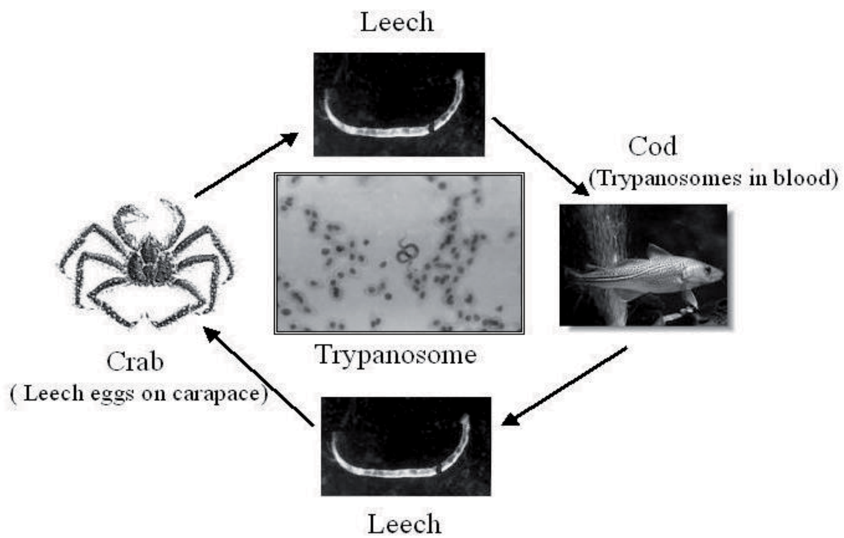
Introduction

Trypanosomes are protozoan parasites of vertebrates which require blood-feeding invertebrates to serve as vectors. For trypanosomes infecting fish the vectors are leeches. The marine leech *Johanssonia arctica* has been shown to be the vector for *Trypanosoma murmanensis* — a blood parasite of marine fish first reported from cod in the Barents Sea (Nikitin, 1927) and subsequently from cod and other fish species off the Atlantic coast of Canada (Khan, 1977). *T. murmanensis* is capable of killing juvenile cod (Khan, 1985) and heavy infections are likely to have debilitating sublethal effects on adult cod and other fish. The life history of marine leeches involves a stage when they must leave the fish host and lay their eggs on a hard substrate. In the case of *J. arctica* the favoured substrate is the carapace of the red king crab *Paralithodes camtschaticus* (see Figure). Since the introduction of this crab to the Barents Sea from its native North Pacific in the 1960s by Russian scientists (Orlov and Ivanov, 1978), a rapidly growing and disseminating population has become established in coastal areas of the southern Barents Sea (Kuzmin et al. 1996).

The present survey was undertaken in response to concerns over one of the possible effects of the burgeoning population of king crabs — that it will lead to an increase in the population of the leech *J. arctica* and consequently to an increase in the level of trypanosome infection in cod. For comparative purposes the survey included areas where red king crabs were common and areas to which they had not yet spread.



Materials and methods

Cod were caught by bottom trawl during cruises of the research vessel *Jan Mayen* in October of 1999, 2000 and 2001 along the coast of Finnmark from the border with Troms county to Varangerfjord. Blood samples were taken from a total of 1254 cod from 28 stations and smears made on microscope slides. Smears were air-dried, fixed in methanol and stained with Giemsa's stain. A standard area was then scanned at a magnification of x125 and the number of trypanosomes in the area was counted. Levels of infection used were prevalence (number of cod infected divided by the number examined, expressed as a percentage) and intensity (number of trypanosomes per infected cod).

Results

We found that in every year the prevalence of infection was significantly higher in Varangerfjord than in any other area. Infected cod from Varangerfjord also had significantly higher intensities of infection than any of the other areas, whereas none of the other areas varied significantly from one another.

Discussion

We suggest that the burgeoning population of red king crabs in the southern Barents Sea is indirectly responsible for increased transmission of trypanosomes to cod by promoting an increase in the population of the leech vector. The introduction of the crab to the Barents Sea may thus be having a detrimental effect on the health of the native cod population. An important factor in the present situation is that although the red king crab has a natural distribution confined to the North Pacific, the leech *J. arctica,* and possibly the trypanosome it vectors, have circumpolar distributions. In the Barents Sea it seems that the parasites have been able to exploit the increased probability of successful transmission provided by the introduction of the red king crab.

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3. Methods for reducing by-catch of red king crab in other fisheries

3.1. How to avoid catches of red king crab in a cod trawl

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Abstract

To develop methods for reducing bycatch of red king crab in cod trawl, four different approaches has been tested. Observation of the behaviour of the crab after entering a cod trawl suggests that there is no active escape behaviour, and therefore the trawl should be rigged so that the entering of would be minimized. Three different rope arrangements in the bottom panel right behind the ground gear seem to have no effect of crab bycatch. A rigging experiment where the fishing line of the trawl is set 0.3 m in front of the rockhopper does not sort out enough of the crabs. One of the rope panels and the forwarded fishingline gave decreased efficiency for the target species of roundfish. Carapax injuries for crabs that had passed under the rockhopper gear were almost 16 % in the standard gear, 11.5% in the gear with forward fishingline. The difference was not significant.

Introduction

Bycatch of red king crab (*Paralithodes camtschaticus*) is well known from Russian and American waters. Norwegian vessels, especially when fishing in Russian zone, are also reporting this kind of problems. Bycatch of red king crab (RKC) and anecdotal reports of "red bags" seems to be a growing problem in coastal waters from Nordkynn and eastwards. The large amounts of crabs become difficult to handle, and fishing vessels must leave the area. In Norwegian waters, the largest bycatches of RKC in the cod trawling is normally in May. Occasionally, large amounts of RKC are also taken at trawl stations in the Norwegian surveys, and also in these data, the number of hauls with crab present is increasing.

Bycatch of RKC in trawl may have a large effect on the total stock if the spawning and breeding areas of the species are trawled (Dew and McConnaughey, 2005).

Experiments to avoid bycatch of RKC has shown that the task is not straight forward, (Highliners association, 1988) and the problems often involve loosing target species. The patchiness in distribution of the crab necessitates total sampling of the catch, and may still give problems when statistical modelling of inter-haul variance is adopted (Millar *et al*. 2004). Reports of behaviour of RKC after it has entered into the trawl are not known. The design of a proper escape panel or shoot must be based on such knowledge. The main purpose of these investigations have been to develop devices for excluding RKC before it clog up the sorting grid in the belly of the trawl.

Materials and methods

Two Norwegian (2005 and 2006) and one Russian (2005) cruise have been carried out.

Video observations, standard gear with collecting bags

The first experiment was conducted in May 2005. In the first Norwegian cruise the behaviour of RKC when entering the trawl was filmed in every second haul. A commercial stern trawler, M/Tr Eilifson, (40 m, 1623 kW) was hired and video-observations of RKC and catch comparisons were made. The trawl used was a Maxi 400 with a rockhopper 21´ ground gear. The trawl was equipped with an auxiliary net below the fishing line in the mid section of the ground gear to capture crab and fish that entered under the fishing line of the net. Five videocamera systems were used to identify the behaviour and escape mechanism of the crab.

Fishing experiments with exit windows behind the ground gear

In autumn 2005, an experiment was conducted in the Russian part of the Barents Sea. The vessel, Yaroslavec, used a rockhopper gear of similar size and tested different types of modification of the trawl net. The first modification tested was a rope grid (0.5 m and 0.7 m long squares) behind the rockhopper. A second ropepanel configuration with 6 squares of 1.0 x 0.4 m that gave larger exit windows was also tested in the Russian part of the experiment. The total numbers of fish and RKC and injuries frequencies of RKC were analysed.

Fishing trials with the groundgear slacked behind the fishing line

Based on the observations in 2005, a rigging with the rockhopper slacked 0.3 m behind the fishing line was tested against a standard rigged trawl in 2006. Both trawls were rigged with bags to collect fish and crab that passed under the fishing line. The idea was that if the crab hit the gear and went over it, it would be led under the bottom panel and under the trawl body. Based on the assumption that the catch in the codend and the collecting bags equals the setup in a cover codend experiment, i.e. that crab in the collecting bags corresponds to catch in the cover in a cover codend setup. There was no subsampling of RKC in this experiment. Length dependent capture probability of the net was estimated using a logistic model with interhaul variance.

For the classification of injuries we used a system approximately like the one decribed by Rose (1999), but we registered both abdomen and carapax injuries as carapax injuries. Since RKC can autotomize (drop) injuried legs, crabs with fresh autotomy were classified as leg injury. Healed aututomies were not classified as injuries. Multiple injuries were classified as the most serious injury. The same system was used in the Russian trials with exit windows behind the gear.

Results

Video observations, standard gear with collecting bags

A total of 13 hauls were done with this rigging, and in these hauls a total of 4085 RKC was caught. The depth range of the stations was from 40 to 120 m. The RKC than went under the fishing line was smaller than the crabs that entered the trawl, and most of the crabs went under the fishing line (Table 3.1).

Table 3.1. Mean size (carapax, mm) and mean number of crabs (both sexes pooled).

	♀♀ size	♂♂size	Number per haul
Codend	111	132	63
Bags	102	106	117

After 13 hauls the trawl had to be abounded, and the rest of the experiments was conducted without collecting bags with a Selstad 400 155 trawl. 10 more hauls were done, and in the codend a total of 338 RKC were caught. Observations of the behaviour of the RKC in the trawl opening showed that the RKC has very weak, if any, avoidance reactions towards the approaching trawl. When hit by the ground gear, the size of the crab, together with the degree of the bottom contact of the gear, seem to decide if the animal entered under or over the fishingline of the trawl. We observed crabs hanging at the ground gear after being hit by it, but never saw crabs being active inside the trawl by walking at the net or searching for escape possibilities. After entering over the groundgear the animals were tossed into the water column, out of orientation. They were actually seldom in contact with the netting panel at all. These observations suggested that to avoid bycatch of RKC the crabs need to be selected out from the trawl mouth before it has actually entered it.

Fishing experiments with exit windows behind the ground gear

The Russian experiments with rope panel of 0.5 and 0.7 m in the bottom panel was designed with four experimental hauls and four control hauls with standard rigging. The total number of crab, proportion of crab with injured legs and proportion of crabs with injured carapax was tested with Cruskal-Wallis test. There were no significant differences between standard and experimental setup for any of the counts when rigging with a 0.5 m rope grid. A set of haul was done with extra length (0.7 m) of the rope grid. No significant difference in the number of RKC caught, the proportion of injured crab or the total catch of fish could be shown.

When testing the rope panel with large open squares in the front part of the bottom panel, there was no difference in catch of crab or the injuries proportion of the crab. However, there was significant less fish caught with the rope panel rigging.

Fishing trials with the groundgear slacked behind the fishing line

Catches of a crab-rigged trawl with slacked groundgear (crab-rig) compared to the standard rigged trawl shows that larger cod escape under the fishing line with the crab-rig. In the standard rigging, significant smaller cod (mean length 39 cm) escaped under the fishing line than over it (mean length 54 cm). For the special crab rig, there was no difference between the cod that went over or under the fishingline. For haddock and saithe no length effect was significant.

In both riggings, the part of crabs that was injured was largest in the crab that ended up in the collection bags under the fishing line. The total number of crabs caught was 890. The depth range of the trawling stations was from 16 (!) to 400 m.

The proportion of carapax injuries is significant higher in the collection bag for both standard and crab rig. The observed injuries of crabs in the codend are not significant different between the riggings (Table 3.2).

Table 3.2. Observed percentage of injured crabs

	Under gear		Codend	
	Std	Crab-rig	Std	Crab-rig
Carapax	15,7	11,5	3,1	0,5
Leg	11,3	5,3	14,1	7,4

Mean number of crabs per haul (Table 3.3) suggest that the crab rig sort out more RKC than the standard rig. The proportion of RKC in codend compared to total catch for each haul was 0.45 for the crab-rig and 0.56 for the standard rigging. The difference is not significant, but an important result.

Table 3.3. Mean size (mm) and mean number of RKC in each haul for both riggings.

	Std-rig			Crab-rig		
	♀♀ size	♂♂size	Number per haul	♀♀ size	♂♂size	Number per haul
Codend	122	143	14.8	123	145	10.1
Bags	115	122	9.7	112	135	14.6

A model for length dependent logistic selection curves incorporating interhaul variance (Millar *et al.* 2004) was applied to the data for standard and crab-rig. However, the model did not converge with the given length distributions.

Discussion

Temporally and spatially variability in RKC distribution is a major problem when testing different bycatch reducing riggings. In 2006 both the area searched, the number of stations and the depth range of the trawl stations were larger than in the experiment in 2005. Still, less than 22 % of the amount of crab was found in 2006. Several hauls with no catch of crab reduce the power of the statistical testing.

Crab panels where the crab should "fall down" have been tested by Highliners association (1988), and also a "crab chute" where one expected the crab to move along it and passed out while the fish passed over it. A reduction of 50 % of RKC bycatch was achieved with the panel compared to each ton of target species, but the overall efficiency was also reduced. The crab chute could not be shown to reduce the number of RKC in the study.

None of the riggings that were tested in this report gave a satisfactory reduction of catches of RKC. Using the collection bags below both standard and crab-rig has shown that 56 and 45 % respectively of the crab end up inside the trawl, in front of the sorting grid, or in the codend. A length based catchability could not be fitted to our data. One of the most important factors in catchability of the crab is the size, height and bottom contact of the groundgear. Weinberg *et al.* (2004) found the mean capture probability for 95 mm males to be 72 %, and 70 % for 90 mm females. However, the ground-gear of the 83/112 Eastern bottom trawl used by Weinberg *et al.* is a 5.2 cm diameter footrope, and hence increasing the probability of fishing a larger part of the total length distribution.

The percentage of injured crabs that passed under the gear was 15.7 and 11.5 for the two riggings (Table 3.2). This is almost double the frequency of carapax and abdomen damage found by Rose (1999) when he compared rockhopper with other gears. However, the gear used by Rose had a diameter of 38 cm, and since the rubber is almost buoyant in water, the weight of the gear in water will be determined by the number of steel-spacers and the dimensions of the chains, and may vary considerable between vessels even when using the same size of rockhopper. The towing speed and bottom substrate may be equally important when it comes to injuries of crab.

Separating a species with major behaviour differences compared to the target species is a challenge, and maybe the approach must be to utilize the differences more by stimulating the most active species away from the escape openings made for RKC.

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