ICES Cooperative Research Report

Rapport des Recherches Collectives

No. 277

September 2005

The intentional introduction of the marine red king crab *Paralithodes camtschaticus* into the Southern Barents Sea

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Recommended format for purposes of citation:
ICES. 2005. The intentional introduction of the marine red king crab *Paralithodes camtschaticus* into the Southern Barents Sea. ICES Cooperative Research Report No. 277. 18 pp.

The document is a report of an Expert Group under the auspices of the International Council for the Exploration of the Sea and does not necessarily represent the views of the Council.

ISBN 87-7482-040-0

ISSN 1017-6195

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Abstract

The red king crab (*Paralithodes camtschaticus*) was intentionally transferred from areas in the Northern Pacific Ocean to the Russian Barents Sea during the 1960s (1961–1969), to create a new and valuable commercial resource. A reproductive population in the receptor region was evident ten years later and from this time the species has continued to spread both north and east in the Barents Sea and southwards along the coast of Northern Norway. Ecological impacts upon the native fauna are investigated through, among others, analysis of the diet of the crab, as molluscs, echinoderms, polychaetes and crustaceans are frequently found as prey items.

Problems following the invasion of the red king crab are displayed as bycatch of crabs in gillnet- and longline-fisheries. The crab is regarded as a commercial resource both in Russia and Norway. Management of the red king crab is undertaken as a joint stock between Norway and Russia through the Joint Russian-Norwegian Fishery Commission.

1 Introduction

The red king crab *Paralithodes camtschaticus* (Tilesius, 1815) (Reptantia, Lithodidae) is native to the Okhotsk and Japan Sea, the Bering Sea, and the Northern Pacific Ocean. On the Asian side of the Pacific, crabs are found from Korea, along the eastern coast of Siberia and down the coasts of the Kamchatka peninsula. In the Northeast Pacific and Bering Sea the red king crabs are distributed throughout the Aleutian Island chain, north to Norton Sound, Alaska, and southeast to Great Bay in Vancouver Island, Canada (Figure 1). Russian scientists intentionally introduced larvae, juveniles, and adults of this species from the western Kamchatka peninsula to the southern Russian Barents Sea over the period 1961–69. Ten years later, in the 1970s, a reproductive population of red king crabs had become established in the receptor region (Orlov and Ivanov, 1978). Its spreading from this location may have been due to both natural dispersal of larvae by coastal currents and by adult migration. This review describes some of the current knowledge of the species in its home range and the introduced population.

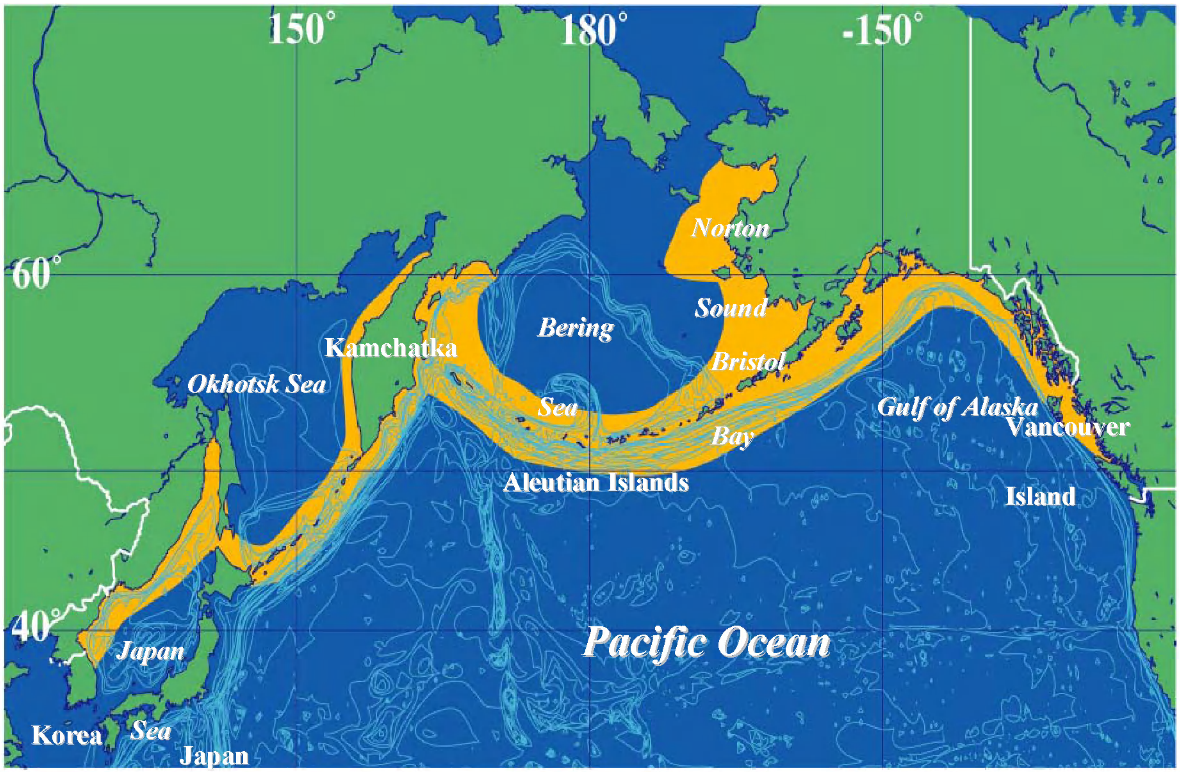

Figure 1. The native distribution of the red king crab (orange shading) along the coasts of Korea, Japan, Russia, Alaska, and Canada.

2 Identification

King crabs are among the world's largest arthropods, having a crab-like morphology and a strongly calcified exoskeleton (Cunningham *et al.*, 1992). Furthermore, they have a fused head and thorax, an asymmetrical abdominal flap, one pair of chelipeds, three pairs of walking legs, and an array of antennae and mouth parts (mandibles, maxillae, and maxillipeds). *Paralithodes camtschaticus* is one of several species of the genus present in the subarctic areas of the North Pacific Ocean and the Bering Sea (Table 1).

Table 1. Taxonomy of the crabs cited in the present paper.

CLASS	CRUSTACEA	
SUBCLASS	Malacostraca	
ORDER	Decapoda	
FAMILY	Lithodidae	
GENUS	Lithodes	Paralithodes
SPECIES	*Lithodes maja*	*Paralithodes camtschaticus* *Paralithodes platypus* *Paralithodes brevipes*

Characteristics distinguishing the three species *P. camtschaticus* (red king crab), *P. platypus* (blue king crab), and *P. brevipes* (Hanasaki crab) include the shape and number of spines on the posterior and postero-lateral margins, the cardiac and branchial regions of the carapace, and the rostrum (Figure 2). *Lithodes maja* is morphologically similar to the King Crab group, but is distinguished from adult *Paralithodes* by the comparatively smaller body size and the bi-fid rostrum. It ranges from the Barents Sea southwards along the coast of Norway and Greenland and to the south coast of Ireland and England.

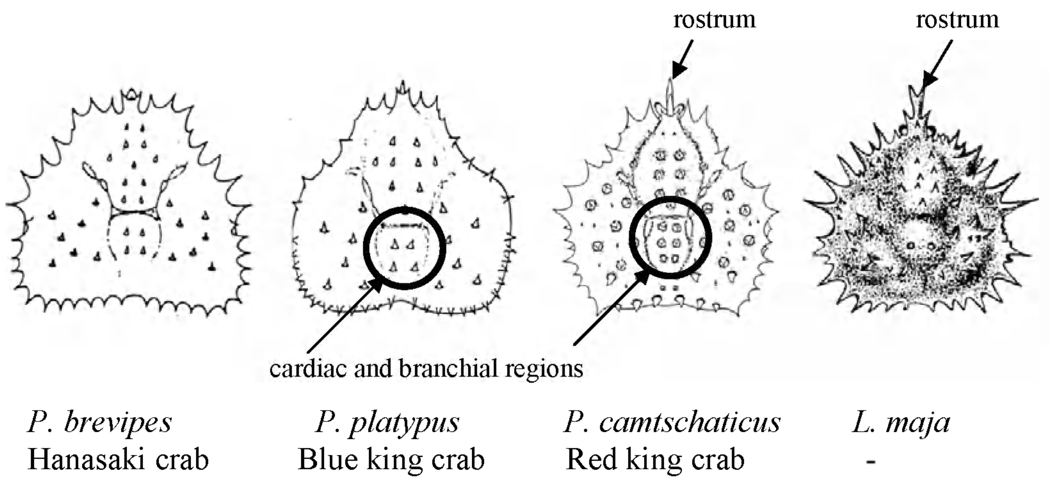

Figure 2. The carapace of four different Lithodidae crustaceans, where *Paralithodes platypus* (blue king crab) and *P. brevipes* (Hanasaki crab) inhabits the subarctic North Pacific Ocean and Bering Sea, while *P. camtschaticus* (red king crab), in addition, is recorded in the Barents Sea (*L. maja* ranges: see above).

3 Biology in the native range

3.1 Some basic features

Based on the three largest, reproductively independent, and most productive populations in West Kamchatka, West Okhotsk Sea, and Bristol Bay, Rodin (1989) defined some basic factors. These factors include the complex of biological, geographical, and oceanographic features of the habitat of these crabs. The larvae of the red king crab develop in the coastal zone. After hatching into a brief prozoea stage lasting only a couple of minutes, the larvae pass through four pelagic stages, followed by a settling stage (megalopa), in about two months. The larvae may be transported considerable distances by currents. For survival of the young, the larvae must be transported to favourable habitats. Successful recruitment of the benthic juvenile crab will depend on a well-developed sessile community with dense concentrations and large areas of hydroids, bryozoans, and sponges; this is an environment that will support a massive settlement of larvae. The habitat must be temporally synchronised with the spring phyto- and zooplankton peaks in the upper 15 m of the water column (Shirley and Shirley, 1989). The survival in one-year-old red king crab is directly related to availability of cover, while dependence on the epifaunal community apparently decreases as crabs grow older (~2 years).

3.2 Seasonal migration

P. camtschaticus has two migrations, a mating-molting and a feeding migration (Figure 3). The patterns of behaviour are similar off the coasts of Japan, Russia, and Alaska (Marukawa, 1933; Vinogradov, 1941; Powell and Reynolds, 1965). The shoreward migration to shallow waters (10–30 m) takes place in late winter and early spring where they mate and breed (Marukawa, 1933; Wallace *et al.*, 1949; Powell and Nickerson, 1965) with the subsequent hatching of larvae at the short prozoea stage (and further transition into the first zoea stage (Stone *et al.*, 1992)). The termination of spawning activities is followed by migratory feeding movements, of both male and female crabs, towards progressively deeper water (300 m). Sexes are not found together until the following season (Cunningham, 1969).

Sexually immature crabs (smaller than 120 mm in carapace length, CL), generally remain in shallow water along the coast at 20–50 m depth (Wallace *et al.*, 1949) and are seldom associated with adults in deep water.

3.3 Salinity and temperature

Little is known of the salinity tolerances of the red king crab. In its northern-most range (Nome, Norton Sound in Alaska) the crab occurs in the shallow coastal water when ice is present but is, however, absent in the ice-free period (Jewett and Onuf, 1988). The bottom salinity and temperature beneath the ice was 34 ppt and –1.8°C (Hood *et al.*, 1974), while it ranged from 22–24.5 ppt and 8.8–11°C in the ice-free period (Rusanowski *et al.*, 1987). This suggests that salinity may be a factor for their absence during ice-free periods.

The red king crab is known to tolerate temperatures of –1.7 to +11°C (Rodin, 1989) and this varies according to the life history stages. The West Kamchatka red king crab sub-population overwinters on the continental slope where the warmer Pacific Ocean water mixes with the colder waters of the shallow shelf. The migration period from the over-wintering area to shallow water depends on increases of bottom water temperatures, as well as on the physiological conditions prior to spawning and molting (Rodin, 1989). The geographical extent of the sub-zero temperatures influence the time of their shoreward migration. In spring, normally May–June, high densities of adults accumulate at 10–15 m where temperatures are approximately 2°C. Following reproduction in June and July adults forage at around 50-m depth at roughly 2°C. In cold years, where the females are unable to penetrate through the cold-water layer (–1 to –1.7°C) and into the coastal zone, the release of larvae takes place at depths of 80 to 120 m. In these cases the larvae are transported to unfavourable areas and larval mortality is high (Rodin and Lavrentev, 1974). Red king crab populations at the West Kamchatka shelf have strong year classes appearing at approximately 5–7 years intervals (Rodin, 1989). Once temperatures decrease the crabs disperse to deeper water where they overwinter (Rodin, 1989).

Fecundity, size and age of maturity, and average annual growth varies throughout its native range. In the northern areas of the Pacific, the red king crab undertakes a spring-spawning migration from depths of 200–300 m to shallow water (10–50 m). Here little moulting takes place over the winter, and the hatching of the larvae occurs when the majority of crabs reach the coastal zone in June. In southern areas with higher temperatures the situation is different: the spring spawning is widely distributed from the shore to 100- to 120-m depth, winter molting of males is normal, and hatching takes place when females aggregate in May.

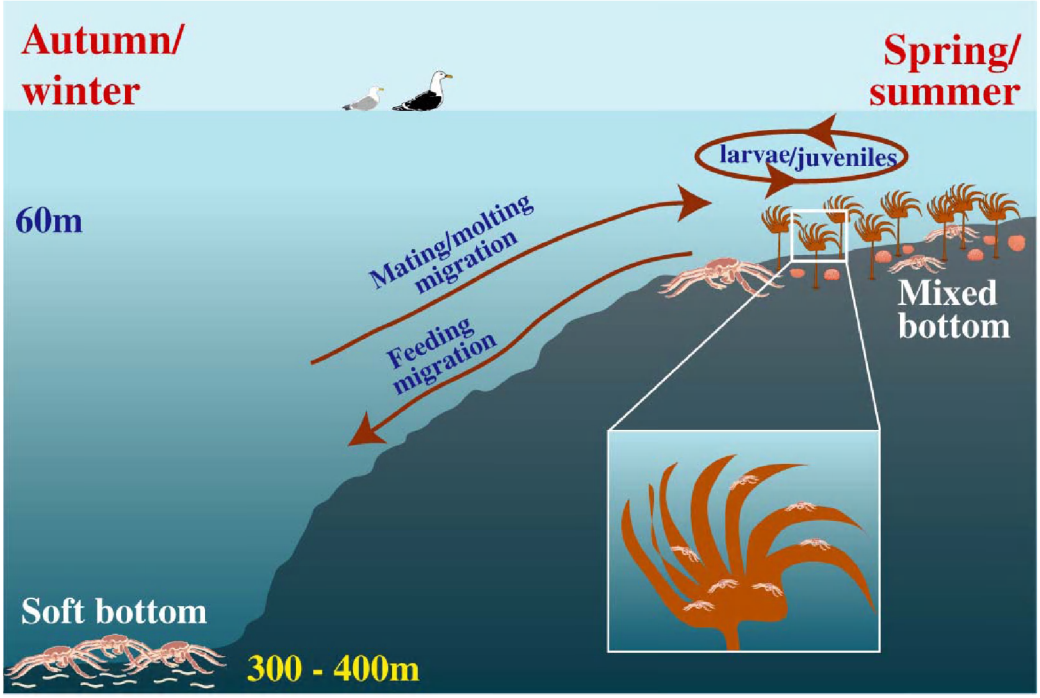

Figure 3. Seasonal migration of *Paralithodes camtschaticus*: the mating-moulting migration in the spring/summer period to various substrates with benthic communities principally composed of calcified prey organisms, and a subsequent feeding migration in winter/autumn to soft substrate where annelids occur (enlarged picture: juvenile red king crabs associated with kelp).

3.4 Life stages and habitat

Settlement of larvae in shallow waters (<20 m) usually takes place on sponges, bryozoans, and macroalgae (Marukawa, 1933). Red king crabs smaller than 20 mm carapace length (CL) have no podding behaviour and remain solitary the first year as cryptically living beneath rocks and stones and in crevices. In the second year (20–25 mm CL) podding behaviour is seen (Dew, 1990). After the first two years they migrate to deeper water (20- to 50-m depth) where they congregate in large, tightly packed groups, often referred to as pods (Powell, 1974).

Adults occur on sand and mud substrata (Vinogradov, 1969; Fukuhara, 1985) and aggregate according to size, life history group, or to sex. Extensive aggregations, where both sexes occur, are made during the spring spawning season. After this period, the sexes form separate aggregations for the remainder of the year (Fukuhara, 1985). The regions where these spawning aggregations occur can also be found in shallow water where kelp occurs (Powell and Nickerson, 1965). The kelp may provide some protection for the females following moulting ecdysis and make them less vulnerable during mating (Jewett and Onuf, 1988). Red king crabs may live 20 years (Kurata, 1961) and can reach a carapace length of ~220 mm and a weight of ~10 kg (Wallace *et al.*, 1949).

3.5 Feeding activity

The nature of the food consumed varies according to the life history. The pelagic larvae consume both phytoplankton and zooplankton (Bright, 1967) and once settled feed on hydroids, the dominant epifaunal component of the refuge substrate within the Kamchatka shelf region (Tsalkina, 1969). Dew (1990) reported that small red king crabs (>20 mm CL) feed on sea stars (50–200 mm), kelp, *Ulva* sp., molted king crab exuvia, *Protothace staminea* (clam), *Mytilus edulis* (mussel), nudibranch egg masses, and barnacles. Occasionally crabs were observed dragging around large sea stars during the entire nightly foraging period. These stars were sometimes left near the base of the pod in the morning, and taken up again upon pod breakup.

Post-larvae show three different behaviour patterns: 1) remaining cryptic during daylight and foraging as solitary individuals at night (0- and 1-year-old crabs); 2) less obvious feeding pattern at night and aggregating (1- to 2-year-old crabs); and 3) feeding either during daylight or night, but principally at night and remaining in groups or becoming solitary (Tarverdieva, 1978). Adults are opportunistic, omnivorous feeders according to what is most readily available in the benthos (Cunningham, 1969). They normally use the most abundant benthic organisms as food, and usually one food group or species is dominant and varies according to region (Kun and Mikulich, 1954; Kulichkova, 1955; Jewett *et al.*, 1989). The weight of food consumed includes approximately 86% of taxa that have calcareous shells. These are echinoderms (*Ophiura sarsi*, and *Strongylocentrotus* sp.) and molluscs (*Nuculana radiata*, *Clinocardium californiense*, Buccinidae and Trochidae) (Cunningham, 1969). An increase in the consumption of calcareous benthic animals is found in connection with moulting (Herrick, 1909; Fenyuk, 1945; Logvinovich, 1945). Kulichkova (1955) suggested that crabs need to replace calcium carbonate lost during molting and that the young clams and barnacles in shallow waters are an abundant resource to fulfil this need. Crabs contain significantly more food in their gut during spring-early summer (Takeuchi, 1959; Jewett *et al.*, 1989) when compared with the late summer-fall-winter months (Jewett and Feder, 1982).

It appears that adult red king crabs have two distinct methods of feeding: 1) grasping and tearing apart larger invertebrates, and 2) sieving organisms using the third maxillipeds following the scooping-up of sediment by the lesser chela. Logvinovich (1945) referred to the frequent occurrence of sediments in the stomach and intestine of crabs. Foraminifera, minute molluscs, and amphipods found in stomachs probably result from the sieving method of feeding, as these prey either burrow in or occur on sediments. Remote cameras have shown that the scooping of sand frequently occurred even when there was evident food available (Cunningham, 1969).

Observations on the degree of gut fullness would indicate that crabs browse on food as it is encountered (Cunningham, 1969). At times of moulting, during growth and at times of reproduction, the food intake declines, but such pauses do not normally last more than two to three weeks (Kulichkova, 1955) and thereafter they feed avidly (Takeuchi, 1967).

Adult crabs are active and consequently, where there are low densities of available food, they may swiftly migrate, by walking rapidly on the long legs, to a different and less exploited region where food is more abundant (Somerton, 1981). This ability to range over long distances by walking, from 3 to 13 km per day (Marukawa, 1933; Vinogradov, 1941) and 172 km in six months (Hayes and Montgomery, 1963) or 426 km during a year (Simpson and Shippen, 1968), enable the adult crabs to exploit considerable areas of the sea bottom (Cunningham, 1969).

4 Non-native distribution

4.1 Date and mode of arrival

During the period 1961–1969, 1.5 million zoea I larvae, 10 000 1- to 3-year-old juveniles (50% females and 50% males) and 2609 5- to 15-year-old adults (1655 females, 954 males) of the species *P. camtschaticus* from West Kamchatka were released intentionally in the Kolafjord in the east Barents Sea (Russia) to create a new and valuable fishing resource in the region (Orlov and Karpevich, 1965; Orlov and Ivanov, 1978). Since then, the crab has spread both east along the Kola Peninsula, and westwards into the Norwegian zone (Figure 4).

In the Russian part of the Barents Sea the highest densities were observed on both sides of the Rybachi Island during the late 1980s and early 1990s. Then during the late 1990s crabs became abundant on the eastern part of the Kola Peninsula. The range up to 2002 included Cape Kanin and the entrance of the White Sea to the east. Further northwards the crab was found on the Kanin Bank and at the Goose Bank. Russian scientists believe that the red king crab in the Barents Sea has reached the limits of its eastern distribution (probably due to salinity and temperature).

It was not until 1992 that the crab became abundant in Norwegian waters, first occurring in the southern areas of Varangerfjord. The general rate of spread of the distribution along the coast of Northern Norway is shown in Figure 5. By 1994 the red king crab had spread to the northern side of the fjord, and it was caught in Tanafjord for the first time in 1995. At that time it had almost certainly established breeding populations in the coastal waters between Vardø and Tana. Further range extensions were noted in Laksefjord and Porsangerfjord in 2000, and by 2001 fishermen caught several adult crabs west of Sørøya and west of the North Cape. In 2002 crabs were captured close to Hammerfest and three crabs were caught by a longliner at about 120 nautical miles off the North Cape.

Figure 4. The distribution of the red king crab (orange shading) in the native northern Pacific, Otkhotsk and Bering Sea and the non-native distribution in the Russian and Norwegian southern Barents Sea.

BOX 1. Future management options in Norwegian waters

Due to the fact that the red king crab has become well established in the Barents Sea over a period of about 40 years, it would be unrealistic to believe that it could be eradicated. We therefore see three management options for the crab in future:

I. Continuation of today's management regime where the crab is managed as a valuable fish stock, and the annual TAC (total allowable catch) is set aiming at a long-term sustainable harvesting.

II. Keeping the crab stock at a minimum level through deliberate actions. A non-regulated fishery has been proposed to reduce the crab stock in Norwegian waters. We are, however, reluctant to recommend such a method due to the fact that only large males are of any commercial value. It therefore seems necessary to introduce economical incentives such as a reward system to keep the crab stock at the lowest possible level.

III. The Joint Russian-Norwegian Fishery Commission has asked Norwegian and Russian scientists to submit a suggested western border for the distribution of the crab in the Barents Sea, based on scientific knowledge. Unless it proves too difficult to realize the management implications of such a border, this may well constitute a third option.

4.2 Natural history in receptor region

4.2.1 Larvae

Laboratory studies have shown indications of better larvae survival at temperatures of 6°C when compared with 1–3°C (Larsen, 1996). This counts in favour of *P. camtschaticus* becoming a successful invader of Norwegian waters.

4.2.2 Adults

In Norway immature and mature crabs generally migrate westward. Large egg-carrying females are often the first individuals to be caught in new areas (own observations: J. H. Sundet). The release of brood by these females may greatly enhance the rate of spreading of this species. Results from tag-recapture experiments carried out in the Varangerfjord reveal that adult crabs here move only short distances (2–15 nm, nautical mile; 1 nm = 1852 m) over a three-year period. It would appear that as the abundances of crabs increases they range further; nevertheless, tagged individuals have been found to move over significant distances over short periods of time.

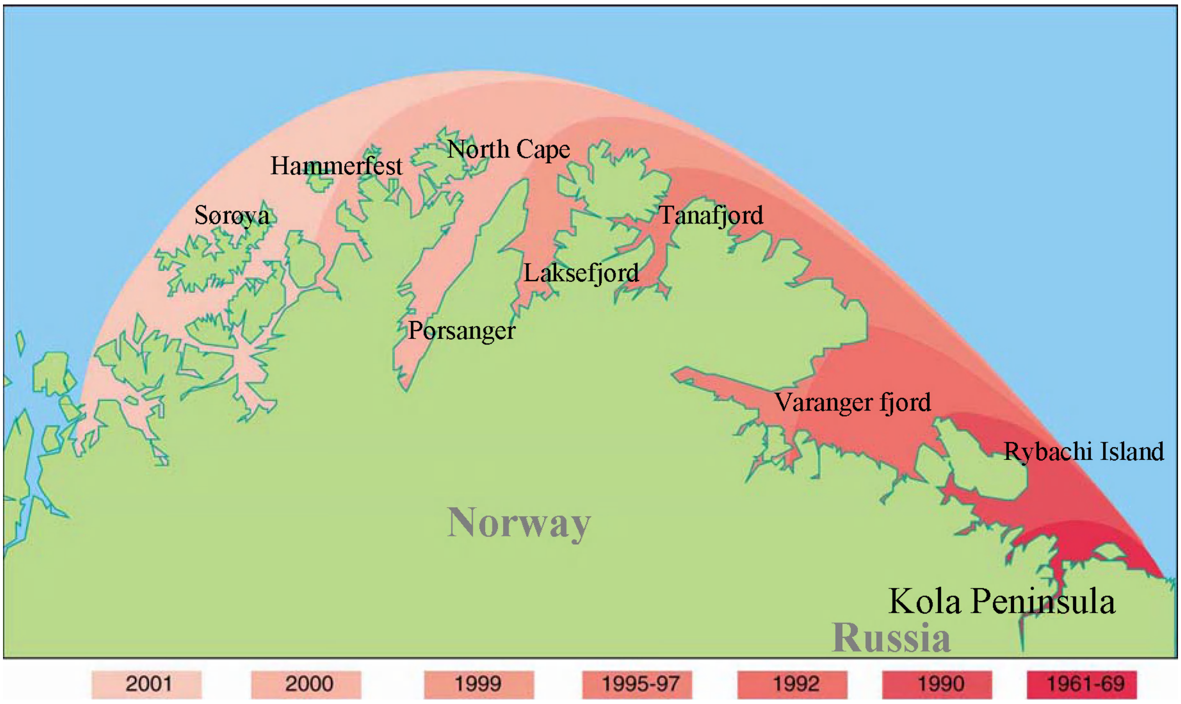

Figure 5. Generalised distribution and spread of the red king crab from its release region in the Barents Sea.

4.2.3 Temperature

In the Okhotsk Sea, the bottom temperature at 100–300 m is ~0°C. In the Barents Sea and the northern part of the Norwegian Sea at 100-m depth the temperature varies from 0 to ~+6°C in winter. The temperature increases with a southward progression along the coast of Norway. However, temperatures remain low around Svalbard and in the Northern Barents Sea. Laboratory studies have shown a temperature preference in immature red king crabs to temperatures below 4–6°C (Hansen, 2002). Hansen (2002) speculated that the crab will spread to elsewhere in northern Norway and may extend further south, as the uppermost temperatures are likely to be limiting but remain unknown. He also indicated a northward spread to Svalbard.

4.2.4 Food

The red king crab in the Barents Sea region feeds on bivalves and echinoderms in the spring and summer and polychaetes in the winter, in a similar way as native populations, and the availability of food for the crab would appear to be the most important factor in limiting its distribution in its new environment (Gerasimova, 1997).

The total index of stomach fullness (organic stomach content (g)/crab weight (g)) (Table 2) of the red king crab in the Barents Sea (Manushin, unpublished data) is similar to the red king crab population from the North Pacific Ocean (Tarverdieva, 1976; 1978) and indicates that the food availability in the Barents Sea is presently sufficient to support the existing population. However, there appear to be some changes in the diet from echinoderms to fish over the period 1997–2000, which is probably a result of crabs feeding on fish discarded from fishing vessels (Figure 6).

Consumption of benthos species in the Murmansk region at depths >100 m (calculated as daily stomach content and energy balance of the crab) ranged from 15 000 to 20 000 tonnes per year (Manushin, unpublished data). These data are based on daily consumption for all crab size groups scaled up to a year and includes an estimate of 20% of the food handled not being consumed.

Manushin (unpublished data) indicated a calculated daily ingestion of 6 g organic food for a 3000 g crab and 1.7 g for a 500 g crab at a temperature of 3°C, while the similar values at 6°C were 16 g and 3.5 g, respectively.

Zhou *et al.* (1998) demonstrated laboratory studies which indicated a daily ingestion rate of more than 70 g and ~20 g wet weight organic food (squid) per day for 3000 g and 500 g crab, respectively (temperature 5.4–9.4°C).

Laboratory studies at temperatures of 5–6°C by Jørgensen (unpublished data) on mature (1700–3000 g) and immature (~500 g) crabs, foraging on calcified epibenthic prey species ranging in size from 3–6 cm, show they can kill ~300 g and ~150 g prey (*Chlamys islandica*, *Strongylocentrotus droebachiensis*, *Modiolus modiolus*, *Astarte* sp., *Buccinum undatum*, *Asterias* sp., or *Henricia* sp.), respectively, per day.

Positive identification of food items within stomach analysis may be difficult. Decapods rarely swallow entire animals, but normally tear away pieces using their chelipeds. The pieces are crushed by the gastric mill, and so, are pulped on entry to the stomach, making food identity difficult. While feeding, fragments of prey may be scattered and lost before reaching the mouth. In laboratory studies, the valves of large bivalves remained on the tank floor following feeding. Should large molluscs be included in the diet following moulting in shallow water, the numbers they destroy in the course of feeding may be underestimated if the volumes in the gut are back-extrapolated.

AREA	TOTAL INDEX OF STOMACH FULLNESS	PREDOMINANT FOOD ITEMS	REFERENCES
The Kola Bay	7	Echinoderms	Kuzmin, Gudimova, 2002
The Barents Sea	4–7	Echinoderms	Gerasimova, 1997
The Barents Sea	4–7	Fish	Manushin, unpublished
Western Kamchatka	3.8–18.6	Molluscs	Kulichkova, 1955
Southern Sakhalin	1.3–4.9	Echinoderms	Kulichkova, 1955
The Bristol Bay	4.7	Echinoderms	Tarverdieva, 1978
The Bering Sea	7.0–7.7	Echinoderms	Tarverdieva, 1976
Southern Sakhalin	3.8–4.3	Molluscs	Klitin, 1996

Table 2. Index of stomach fullness (organic stomach content (g)/crab weight (g)) of king crab in different areas.

4.2.5 Feeding behaviour

Feeding observations from laboratory studies demonstrate 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. As also stated by Zhou and Shirley (1997) vision appeared to pay little role in foraging. When feeding on bivalves the right larger claw easily crushes the smaller preys outright. 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 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 from bivalves, would be a challenge; furthermore, red king crab foraging may be underestimated when stomach content is correlated to benthic biomass *in situ*. The laboratory results may demonstrate the susceptibility of native scallop (*Chlamys islandica* Müller, 1776) bed communities to red king crab predation (Jørgensen, unpublished data). The data-set suggest a mature crab preference of prey sizes larger than 30 mm, and for round prey-bodies a maximum of 60 mm height/diameter. Larger round-shaped bodies that, 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 after tearing the bivalve flesh into pieces and consuming it. The laboratory results demonstrate that abundant red king crabs could have significant effect on Norwegian scallop beds (500–1000 g scallops m^{-2}, Jørgensen, unpublished data). The actively moving red king crab may be capable of not only crushing bivalves, but also picking up soft animals and scooping meio- and micro-organisms, which will have non-reversible effects on the bio-diversity of native benthic communities.

4.3 Field assessments of environmental impacts

Scallop beds along the Norwegian coast are used as models for benthic shallow water communities with high availability of calcified prey species recorded from red king crab stomach analyses. The scallop beds may represent a potential food reservoir in spring/summer (May–July) for mature migrating red king crabs that are increasing food ingestion to replace recently expended energy. A principal challenge posed in field assessments of environmental impacts is to isolate the effect of interest (predation from red king crab) from noise introduced by natural spatial and temporal variability. One way is the Before-After, Control-Impact (BACI) analysis presented by Underwood (1992). This design uses comparison sites with one putatively impacted and several (minimum two) randomly selected control locations, which do not necessarily have to be identical. The sites are monitored at repeated, random intervals of time from before to after the putative impact starts. The logic of the design is that an impact in one site should cause the mean abundance of animals there to change more than expected on average in undisturbed sites. Impacts are those disturbances that cause mean abundance in a site to change more than is found on average. If the magnitude of change in the population is within the resilience of natural populations, the impact gives no cause for concern. Two fjord localities that may be impacted within the next few years were localised and have been monitored since 2001. We may need to include at least one more field station to get enough control sites for the monitoring program.

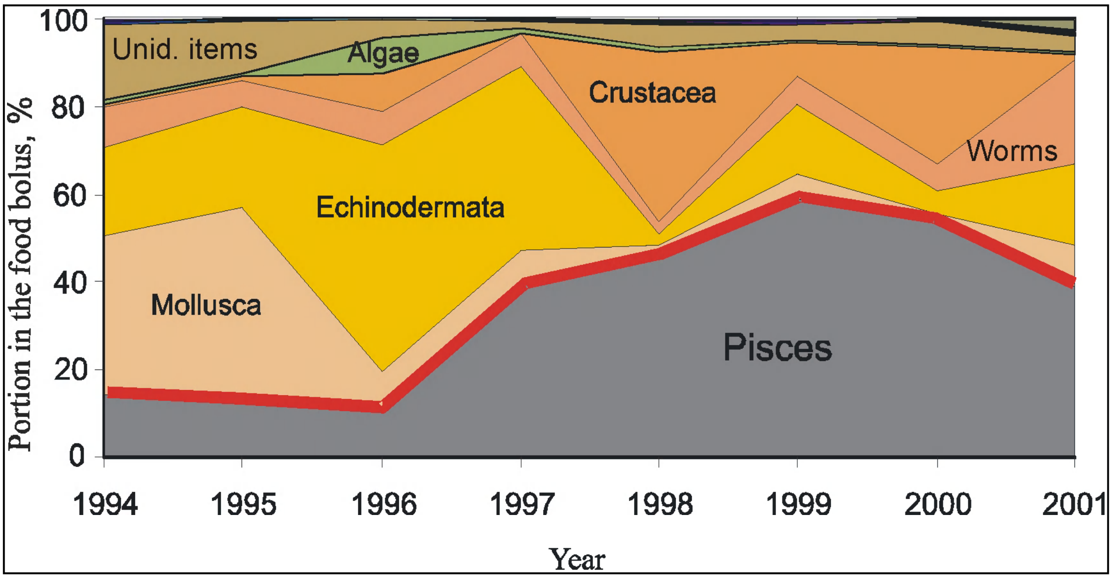

Figure 6. The proportion (%) of fish, molluscs, echinoderms, worms, crustaceans, algae, and unidentified items in adult crab stomachs over the period 1994–2001 from depths greater than 100 m (Manushin, unpublished data).

5 Fishery and management

5.1 Fishery

The Joint Russian-Norwegian Fishery Commission initiated the fishery for the red king crab in the Barents Sea as a research fishery in both national waters in 1994, and at the same time surveys of the crab stock started. Only male crabs larger than a fixed carapace length were legal for catch. Today, the agreed minimum legal size is 132 mm, but a minimum legal size of 137 mm is practised in Norwegian waters. An overview of the total allowable catches (TAC) and legal stock estimates is shown in Figure 7. The research fishery for the crab continued until 2002 and the TAC was, during that period, divided equally between Russia and Norway. In 2002 new agreed fishery regulations were introduced and in Norway the king crab fishery became an ordinary commercial fishery with a Norwegian quota of 100 000 crabs. A total of 124 Norwegian vessels participated in this fishery in 2002. In Russia the king crab fishery is still a research fishery and is carried out from large vessels (~130 m length).

5.2 Bycatch and socio-economic effects

For centuries coastal fisheries in northeastern Norway have been carried out with gillnets and longlines. Today, the typical small-scale fisher uses gillnets, operated from small vessels in fjords and the near-shore fisheries for all available species. The concurrent increase in the red king crab stock in recent years has resulted in huge bycatch problems, particularly in the gillnet fishery. The crabs impact the longline fishery by removing bait from hooks, thereby reducing catches of targeted fish. The bycatch of crabs increased steadily from 1997 to 1999, but in 2000–2002 the bycatch rate decreased, and the estimated number in 2002 was only 30% of that in 1999. This is probably due to a reduction in the cod gillnet fishery. Low abundance of cod have forced the fishers to move further west along the coast of northeastern Norway in search of cod, and this has subsequently minimized bycatches of crab.

Some available size distribution data for crabs caught in the gillnet fishery shows that few juvenile red king crabs are caught. Most crabs seem to be larger than 120 mm CL. More than 60% of the crabs caught in gillnet fishery for cod in Varangerfjord are females, while large males dominate the bycatches in the lumpsucker gillnet fishery in early summer.

In order to compensate for the loss of fishery and equipment (gillnets, longliners, etc.) caused by the invasion of the red king crab, the criterions for participation in the annual crab fishery are set in favor of the local small-scale fishers. This is generally acknowledged by fishers from other parts of Norway, since the presence of the crab directly influences the conditions of the local fishers.

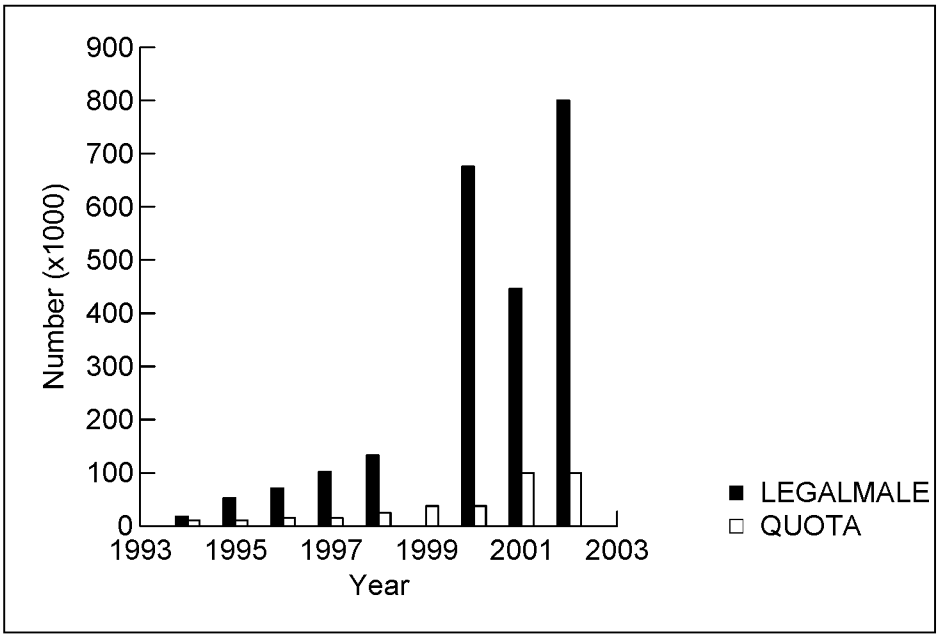

Figure 7. Estimated stock of legal male (i.e. the amount of crabs that can be caught legally) red king crabs (filled bars) and the Norwegian annual quota (open bars) in the Norwegian part of the Barents Sea.

5.3 Management

The red king crab in the Barents Sea is managed as a joint stock between Norway and Russia, and the main body deciding upon management actions is the Joint Russian-Norwegian Fishery Commission. Therefore, all research on this species is performed in cooperation between the two nations' scientists. The Commission sets a common TAC limit, which is divided between the two nations dependent on the standing stock in each economic zone.

Up to now, the main goal of the crab management has been to perform a long-term sustainable harvest of the stock, and this has in many ways influenced the research undertaken.

Box 2: Ongoing and future research in Norwegian waters

The Norwegian Ministry of Fisheries has decided to launch a comprehensive research and surveillance program on the ecological impacts of the king crab in Norwegian waters in 2003. The research will be carried out by the Institute of Marine Research in cooperation with other research institutions in Norway. The program is planned to last for at least ten years and the available cost for 2003 is set at NOK 4.7 mill. All planned research will be closely cooperated with Russian research activities in the same field. The research program is structured as follows:

I. Basic biology
- Environmental demands of the crab as temperature preferences, habitat preferences, etc.;
- Potential for spreading based on the environmental conditions in the northeastern Atlantic, including coastal Norway;
- Studies of population biology of the crab, including development of population models;
- Bioenergetic studies of the crab.

II. Distribution and spreading
- Development of larvae drift models;
- Migration studies of adult crab and developing of models;
- Risk analyses for spreading of the crab via ballast water;
- Continuous surveillance of the distribution front;
- Studies of migration pattern throughout the year.

III. Direct and indirect effects on habitats
- Establish time-series on zoobenthos composition on soft and hard bottom, both in areas with and without crab. Isolated studies of effects of the crab on bottom fauna;
- Interaction with other (native) species:
  1) Qualitative and quantitative effects of food competition,
  2) Study effects of the crab on fish stocks with demersal eggs.

IV. Genetic studies
- Comparison with crabs from the origin site (Okhotsk Sea);
- Studies of genetic drift in Barents Sea king crab.

V. Observational methodology and data analysis
- Development of new methods (sample design);
- Methods for estimating stock size (acoustic, UTV, etc.).

VI. Diseases
- Reveal the role of the crab as a vector for spreading new diseases or diseases harmful for the native fauna.

VII. Parasites
- Study the parasite fauna associated with the king crab in the Barents Sea;
- Reveal the role of the crab as a vector for spreading native or introduced parasites that may be harmful for the native fauna.

VIII. Translation of Russian literature relevant for the crab as an introduced species.

IX. Workshop 2003
- A workshop was arranged in Tromsø in June 2003 with invited experts on introduced species. The main aim of the workshop was to draw upon the experience with other introductions in the future management of the crab in Norwegian waters.

5.4 The future

Concise scientific answers to questions about the future impacts of the red king crab in the southern Barents Sea cannot be given. So far, indications point in the direction of continuous migration both further north in the Barents Sea, as well as a southwards spreading along the coast of Norway. Due to the pelagic phase of the crab larvae, the possibility of ballast water being a vector of spreading is likely. The fact that ship traffic (oil and gas transportation) both in the Barents Sea and in the Northern Norway is likely to increase in the near future, emphasize the possibility of ballast water spreading of the species to other areas in the Atlantic Ocean (e.g. the American east coast).

6 Acknowledgements

The authors wish to thank Dan Minchin for valuable and constructive criticism of the manuscript. In addition our acknowledgement goes to the participants of the ICES WGITMO-meeting in Cesenatico (Italy) 2003, for their comments to the manuscript and discussions on the invasion of the red king crab.

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