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The Norwegian management of an introduced species: the Arctic red king crab fishery

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ABSTRACT

Introduced into the Barents Sea in the 1960s, the red king crab (*Paralithodes camtschaticus*) has been fished commercially in Norway since 2002. Because it is an introduced species, its management raises a number of concerns. Minimising the threats posed by non-native species that cannot be eradicated is a challenge facing nature management authorities worldwide. High concentrations of crab on fishing grounds in eastern Finnmark in North Norway have interfered with traditional gillnet and longline fisheries, prompting fishermen to demand compensation for lost income. Difficult trade-offs were posed by the dual management objectives, which included (i) preventing the geographical expansion of the crab and (ii) exploiting the resource to provide income to coastal communities. The Norwegian government, with the consent of Parliament, has developed a management regime that addresses both objectives: an open-access fishery west of 26°E to prevent further west- and southward expansion of the crab population, and a regular commercial fishery east of that longitude. This management regime commands wider consideration, owing to its handling of the dilemmas inherent in the management of introduced species.

1. Introduction

The red king crab was transferred from the Russian Far East and released in Kola Bay in the waters of the Soviet Union on several occasions during the 1960s and once during the 1970s [1]. The main purpose of the transfer was to establish a new stock of this valuable resource in the Barents Sea to enhance the food supply in north-western Russia and to increase the economic output of fisheries in the region.

The transfer was not reported to neighbouring countries. However, in negotiations between Norway and the Soviet Union, held in 1976–1977, on practical arrangements for fisheries in a then disputed area of the Barents Sea (The Grey Zone Agreement of 1978), a ban on fishing red king crab in the entire Barents Sea was agreed. Despite the explicit mention of red king crab in the agreement and bycatches of crab in Norwegian waters, the species, new and alien to Norway, attracted no particular attention. By that time, however, it had invaded most of the Kola Peninsula's coastal waters, crossed the Norwegian–Russian border, and become abundant in small inlets close to the border (Fig. 1).

The first known record of the red king crab in Norwegian waters was made in 1977 [2]. It was not until 1992, however, that the crab came to the attention of Norwegian management and research institutions, as a result of the problems it caused in local gillnet fisheries.

In the beginning, the red king crab existed mainly in areas of the Varangerfjord (Fig. 1), but the population gradually expanded farther west, causing problems related to bycatch for fishermen in the expanded area. At the same time, the crab became a significant fish resource in its area of distribution. The fishery increased gradually and, by 2015, it involved more than 500 vessels.

Until recently, the introduction of alien species into new environments was considered a nature management technique [3]. In the Soviet Union, for example, more than 900 different aquatic species were intentionally transferred between ecosystems as the result of a comprehensive, planned governmental policy [4].

The crab population adapted to the Barents Sea ecosystem by establishing an abundant self-reproducing stock. No management measures were applied prior to its establishment in Norwegian waters. Management of the red king crab was an issue considered by the Joint Norway–Russia Fisheries Commission for several years, until it was concluded that, from 2007 onward, each country would manage the crab fisheries separately. After that, Norway managed the red king crab based on its own assessment of management needs [5].

Concerns about the introduction of alien species and their impact on ecosystems have existed for decades [6], but nothing has been done until recently. Changes in the perception of

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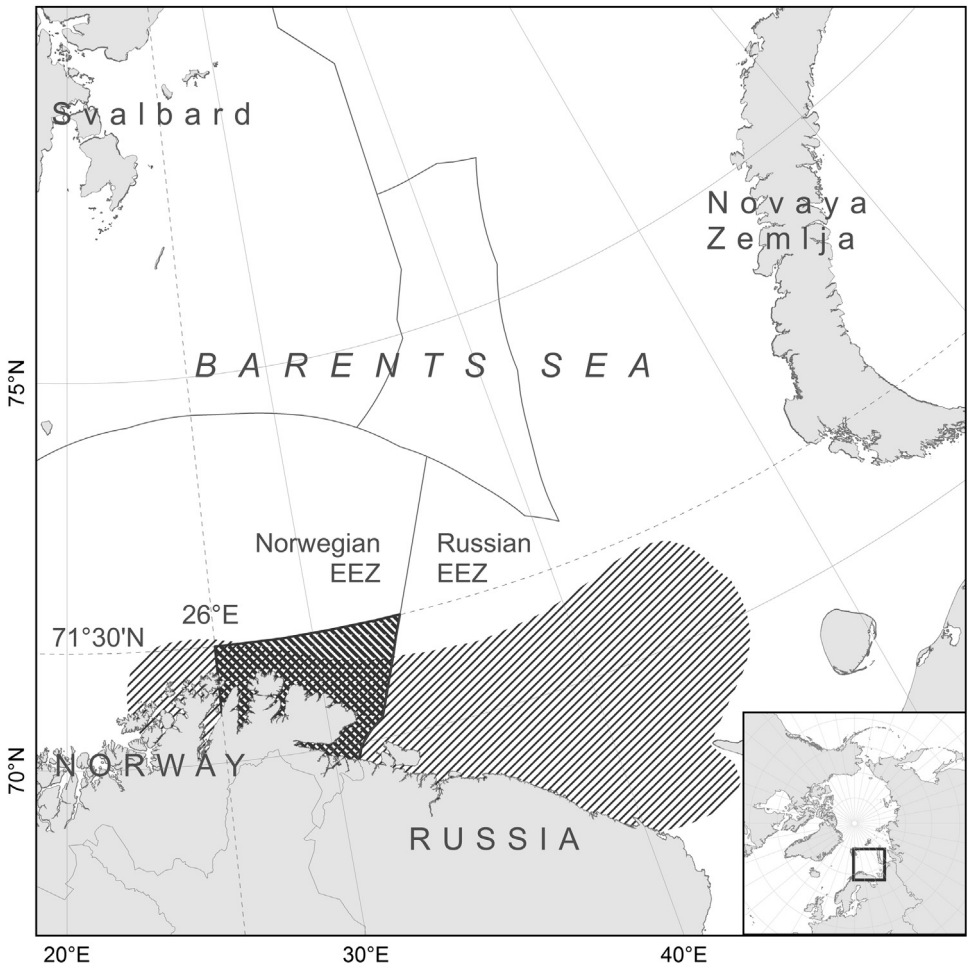

Fig. 1. Map showing the approximate distribution of the red king crab (*Paralithodes camtschaticus*) in the Barents Sea (light shaded), and the area of the quota-regulated area in Norwegian waters (double shaded).

introduced species have recast them as a threat to marine ecosystems [7]. The common policy response mentioned in scientific literature has advocated prevention by limiting vectors, early detection and rapid response (EDRR), and control or eradication [8]. International agreements, to which Norway is a party, require that populations of alien species introduced into local ecosystems be eradicated or, if this is not feasible, be limited to keep populations as low as possible [9]. However, emerging studies question the feasibility of eradication approaches and wonder how introduced species can be realistically managed [10]. Chew et al. [11], for example, suggest that conservationists should assess the impact of non-native species on the ecosystem, rather than focusing on the species' origin outside the ecosystem. Pearce [12] argues that ecosystems are constantly evolving, and non-native species could actually promote that evolution.

Also, the economic advantage of high-value alien species has shifted the perception of such species and their management. For example, the red king crab in the Barents Sea can fetch up to NOK 500/kg in the marketplace. The management regime adopted by the Norwegian government is, therefore, an interesting example of how an introduced species can be managed to benefit the fishing industry and coastal communities, while limiting the population's geographical expansion.

In this paper, the theoretical approach to the dilemma of managing a high-value introduced species will be discussed, in addition to how the management objectives for red king crab have been reconciled in practice. The paper discusses also how past and present management of the red king crab in Norway can lead to a more pragmatic approach to the management of non-native species that cannot be eradicated, for which the costs of keeping the population low are disproportionally high and substantial economic benefits for coastal communities exist.

2. Institutional issues

The 1982 Law of the Sea Convention is the fundamental global agreement for all marine governance. It lays down the ground rules for the jurisdiction, management, and use of the oceans [13]. The Convention provides for sovereign rights of coastal states over the natural resources in waters extending to a distance of 200 nautical miles, and stipulates rights and obligations for the coastal states in the management of living marine resources. Coastal state jurisdiction may extend beyond 200 nautical miles, depending on certain geologic criteria. Crab is a sedentary species and, according to the Convention, management authority over such species follows from its continental-shelf provisions [14].

A number of other international instruments are also relevant. In the development of a substantial body of legal and non-legal agreements on living marine resources and the marine environment over the past two decades, there has been an increasing emphasis on conservation and sustainable use and, therefore, on management of living marine resources [15]. Ecosystem approaches devised by the FAO are an important development, [16] as are other approaches described in academic literature [17] and those based on a precautionary approach to fisheries [18].

In addition, a number of international environmental instruments address invasive species. This includes the 1992 Biodiversity Convention's (CBD) position on in situ conservation, which states, in Article 8, Paragraph (h), that Parties shall "as far as possible and as appropriate … prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species." [19].

In the context of the Barents Sea, the Joint Norway–Russia Fisheries Commission was established in 1975. Its mandate is to manage fish stocks shared by Norway and Russia in the Barents Sea, including cod, haddock, and capelin. Greenland halibut was recently designated a shared stock. The red king crab appeared on the agenda of the Fisheries Commission for the first time in 1993 as a shared stock. However, as noted above, separate management regimes were put in place from 2007 onwards.

3. Biology, expansion, and development of the red king crab fishery

3.1. Biology and introduction

The red king crab, introduced into the Barents Sea, was caught in Russian waters in the Bering and Okhotsk seas, where it is endemic. It is a typical cold-water species preferring temperatures below 4 °C, but it is also found at higher temperatures [20].

Dominant prey groups include polychaetes, mussels, and echinoderms, but the crab also feeds on a variety of sedentary benthic animals, dead organic matter, and algae [21]. Therefore, the availability of prey does not seem to be a limiting factor in the crab's establishment in new areas.

Juvenile red king crab resides in shallow waters (<20 m) yearround and migrates to deeper areas as they grow into mature adults. Hatching, spawning, and mating also take place in shallow areas during spring (March–May), and both males and females migrate to deeper areas (>200 m) during summer to feed. The hatched larvae lives pelagic in the upper water column for up to two months and may be widely dispersed by currents before they settle in nearshore shallow areas (10–20 m) [22,23].

Determining the age of crustaceans is difficult owing to the lack of hard structures, like otoliths in fish [24]. However, currently ongoing work has revealed growth lines in some hard structures of crab, lobster, and shrimp, which may be related to age [25]. The applicability of this research has not yet been verified, and age determination of crustaceans is still based on estimates of moulting frequency and increments. Male and female red king crabs in the Barents Sea mature at an approximate carapace length of 110 mm, and the age at that size is estimated at 5–7 years [26]. Based on size and moulting frequency, the largest crabs in the Barents Sea stock may therefore be more than 20 years old.

Since its introduction, the red king crab population has expanded to most areas in the southern Barents Sea, from Kolguyev Island in the east to approximately Tromsø on the coast of North Norway in the west. In Norwegian waters, most of the stock is within 20–25 km of the coast, whereas in the Russian sector, it extends 90–140 km from the coast (Fig. 1). The difference in expansion in Russian and Norwegian waters remains unexplained but may be related to differences in the bottom topography of the Russian and Norwegian areas of the Barents Sea. Finnmark's coastal area descends to 200–400 m only 20–25 km from the shore, and depths of 200–300 m are found in the fjords. In the Russian area of the Barents Sea, however, such depths occur 90–150 km from shore. Because the red king crab apparently moves to deeper areas during part of the year, it must move farther offshore in the Russian waters than in the Norwegian waters.

3.2. Developments 1993–2002

During the traditional winter gillnet fishery for cod in the southern Varangerfjord in Finnmark, significant bycatches of red king crab were taken in winter 1992 [27]. This led to demands for research on the species' biology and distribution. In 1993, scientists at the Institute of Marine Research undertook research projects which, from 1994, included Russian colleagues. Regular ship-based surveys have been conducted since then.

The crab's expansion continued to cover most of the Varangerfjord during the late 1990s, and crab was found in the Tanafjord for the first time in 1995. As the population expanded westwards, initial observations were commonly made in the inner areas of the large fjords. Significant concentrations were not found in the outer coastal areas of eastern Finnmark during this period. At the beginning of 2000s, the red king crab had expanded westwards and entered the Laksefjorden, and was found farther west in the Porsangerfjorden for the first time in 2002.

In 1993, the Norwegian–Russian Fishery Commission decided to start an experimental fishery the following year and agreed to a per-country quota of 12,000 crabs. In Norway, research institutions were asked to organise the experimental fishery. In 1994, only four vessels were licensed for the fishery. It grew rapidly through the late 1990s, along with an increase in the annual quota (Fig. 2) reaching more than 120 vessels in 2002. Then, the growth of the red king crab stock, the fishing quota, and the number of vessels prompted the Fisheries Commission to establish a regular commercial fishery in Norwegian waters. The red king crab fishery in Russian waters continued as an experimental fishery until 2004.

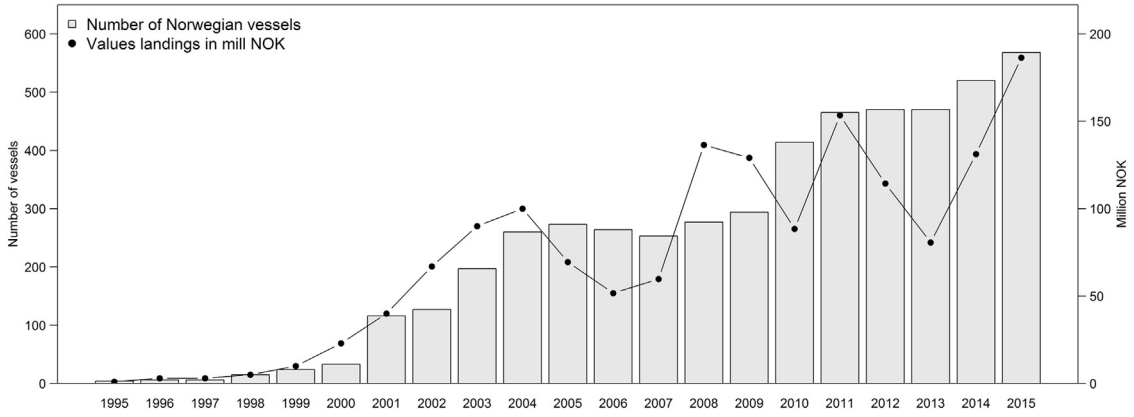

Fig. 2. Number of vessels participating in the Norwegian quota-regulated area for the red king crab (*Paralithodes camtschaticus*; grey bars), and the value of landings (black line) for the fishery from 1995 to 2015.

3.3. Developments 2002–2015

During this period, the red king crab in Norwegian waters did not move far offshore, and most of the species' expansion was westward in coastal waters. Monitoring of the expansion was therefore concentrated in fjords and coastal areas.

During the first years, the commercial red king crab fishery took place mainly in eastern Finnmark, Varangerfjord, and Tanafjord. However, as the crab stock expanded westwards, the fishery followed. A vociferous public discussion about limiting the westward expansion of the crab ensued. Conservationists and fishermen without license to fish the crab argued for its eradication in Norwegian waters, whereas those with access to the crab fishery and processing plant owners argued for managing the crab population as a sustainable fishery. At the time, Norwegian management of the red king crab had to be agreed by Russia because the population was considered a shared stock. In 2005, a western boundary for joint Norwegian–Russian management was agreed and set at 26°E (Fig. 1). To the west of that longitude, crab was regarded as Norwegian, and Norway could apply its own management regime.

Then, in 2007, the Fishery Commission decided that Norway and Russia were to manage their parts of the crab population in their respective waters, Norway established a national management regime for the stock. In a Report to the Parliament in 2007, the government defined the new management regime, ensuring the consent of Parliament.

Since 2008, Norwegian management of the red king crab has been divided between a quota-regulated area (QRA) in a defined area in Finnmark County and an open-access area (OAA) outside the QRA (Fig. 1). The main management objective in the OAA is to maintain high fishery pressure to limit further expansion as much as possible, whereas the management objective in the QRA is to maintain a viable, long-term fishery.

In the OAA, the only restriction on the fishery is that, from November to April, vessels larger than 21.35 m are not permitted to fish within 6 nautical miles of the baselines, and within 4 nautical miles from May to October. The value of landings and the number of participating vessels in the OAA fishery has varied (Fig. 3). Particularly in 2008 and 2009, the landings and the catches' value from the OAA were much higher than value of the quotas given in the QRA. This was mainly the result of the way the borders between the QRA and the OAA were set in the regulations. The borders were adjusted in 2010, and the extent of the QRA has remained the same since then. The northern boundary for the QRA now follows 71° 30′ N from 26°E to the boundary with Russia in the east. Everything outside this area is OAA. The landings from the OAA were large in 2011 and 2012, probably a reflection of the increase in crab abundance in local areas of the OAA.

The fishery for the red king crab in OAA can be described as an on-and-off fishery: a large abundance of crab in small localities, leading to a sudden increase in fishing effort, followed by an end of the fishery when the local stock is fished down to unprofitable levels (Table 1).

The first objective of the existing management regime is to limit further expansion of the population. It has therefore been important to monitor the development of the stock west of 26°E. Since 2011, annual surveys of the stock have been carried out by sampling at fixed stations in the area using traps. Fig. 4 shows a large variation in crab abundance at the sites monitored in the past five years. The absolute number of crabs caught at any one time has been low, usually 0–2 crabs at each station. An increase was seen at some stations in 2012, followed by a reduction in 2013, which can be attributed to fishing. In 2015, there were signs of a renewed increase. The catch per unit of effort, however, is lower than for the catches in the QRA (Table 1).

There is no indication of a significant northward expansion of the red king crab from the Norwegian coast. A discussion of whether or not the red king crab may expand northwards towards Svalbard continues. However, prevailing ocean currents along the northern Norwegian coast are east flowing. It is, therefore, unlikely that larvae could be transported by currents to Svalbard from existing hatching areas. This may change if, in future, larvae hatch farther west where the main, near-coastal current turns north, directly west of Svalbard [27].

The aim of maintaining a viable, long-term fishery in a limited area was to create a red king crab fishery that would compensate for the problems created by the crab for traditional groundfish fisheries in eastern Finnmark. Crab bycatches interfered with gillnet and longline fisheries for cod, haddock, and other fish in areas where crab was abundant [28]. In addition, a long-term fishery for the crab would help maintain a viable crab industry, which would also be able to handle crab from the OAA [5].

The total quota for male crab in the QRA with a carapace longer than 130 mm are set annually, based on scientific advice from the Institute of Marine Research. Traps are the only legal gear in Norwegian crab fisheries. This creates a demand for vessels safely equipped for this type of fishing.

Crab landings from the QRA represent NOK 100–150 million in annual landed value (NOK 141.6 million in 2015), and employ more than 500 small vessels (6–15 m; Fig. 2). The export value in 2015 was close to NOK 365 million.

4. Benefits and costs of the regime

The red king crab fishery is smaller than most other Norwegian fisheries. However, it is of considerable economic importance in

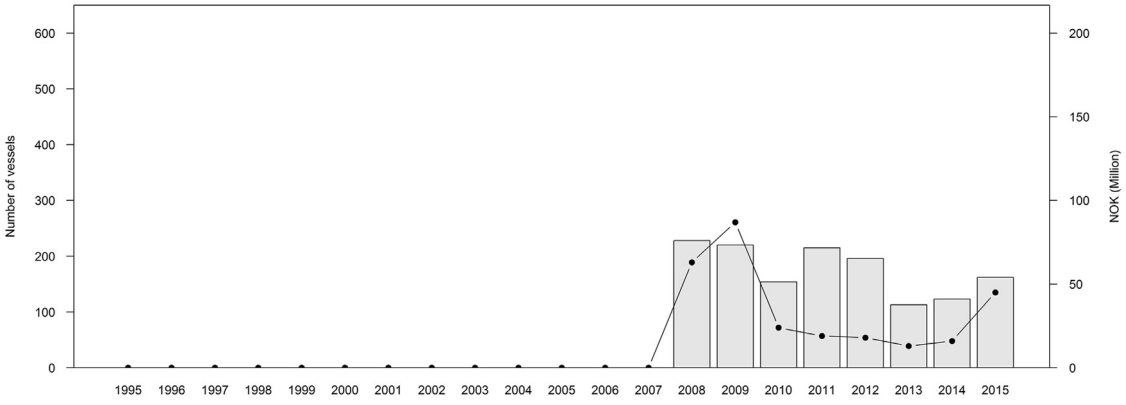

Fig. 3. Number of vessels participating in the Norwegian open-access fishery for red king crab (*Paralithodes camtschaticus*; grey bars), and the value of the landings (black line) for the fishery from 1995 to 2015.

Table 1
Mean catch of red king crab (*Paralithodes camtschaticus*), standard deviation (SD), and number of pot deployments during 24 h (PD) in an annual pot survey in the free fishing area (FFA) and in the quota-regulated area (QRA) during 2011–2015.

FFA:	2011	2012	2013	2014	2015
Mean	0.1	0.8	1.9	0.9	1.4
SD	0.6	4.0	12.6	2.6	3.5
PD	159	96	82	61	87
QRA:	2011	2012	2013	2014	2015
Mean	73	39	59	49	51
SD	112	35	87	47	28
PD	33	42	66	58	40

eastern Finnmark. The fishery and the industry it brings onshore contribute significantly to both the economy and employment in small coastal communities in the region. Importantly, income from the crab fishery also reimburses the economic losses caused by crab bycatch in gillnet and longline fisheries for other species. The bycatch problems seem to have been mitigated over time, mainly because the fishermen avoid areas with high crab concentrations and because fishing gears have been modified.

A well-regulated fishery for red king crab, based on the long-term perspective of maintaining an economically viable fishery in eastern Finnmark, helps maintain an onshore industry capable of handling all crab landed. This includes landings from the OAA. The fishery thus benefits the fishermen, fish processing plants, and local communities.

The profitable harvest of a non-native, invasive species such as the red king crab may encourage illegal introductions. It has been reported that, in the 1990s, the red king crab was illegally transferred to new areas. No further activity has been reported in recent years.

It can be argued that this management regime does not sufficiently address Norway's obligations under international agreements regarding the extermination and control of invasive species. However, these obligations are qualified in that they apply “as far as possible and as appropriate.” Although investigations have revealed that high densities of crab affect benthic communities, it is not known if the changes observed are reversible [29]. In addition, a relatively abundant crab stock in the QRA contributes to a continuous expansion of red king crab to other areas. However, the open-access fishery in the west appears to reduce the rate of expansion. From time to time, limited aggregations of crab appear in new areas, particularly in fjords farther west in North Norway. Such appearances, however, are likely to be kept in check by the open-access fishery. Years during which new concentrations are observed are usually followed by years during which a reduction in the number of crab is seen (Fig. 4). Also, given the large population of red king crab in Russian waters, there will always be an influx of crab from east to west, which would render Norwegian efforts at eradication futile.

One way to eradicate the crab in all Norwegian waters is to introduce an unrestricted crab fishery there, with the purpose of reducing the ecological impact on ecosystems by keeping the stock as low as possible. However, such a fishery would not be viable in the long run, because it would soon evolve into a “yo-yo” fishery: an initial Klondike fishery, followed by a collapse, resulting in lower stock levels and reduced profitability, ending in a halt to the fishing. Such breaks in production could last for several years owing to the crab's slow growth rate, which would put processing plants with the expertise and infrastructure for crab out of business. Also, the eradication of red king crab from Norwegian waters is impossible. It is not feasible to catch all crab in the area where it exists. In addition, most of the crab stock in the Barents Sea is in Russian waters, and Russian fishery authorities manage crab as a resource to be sustainably fished. Therefore, a continuous immigration of crab from the Russian area of the Barents Sea to Norwegian waters will continue, regardless of the management strategies chosen for the Norwegian waters.

5. Discussion

In general, non-native species are considered unwanted organisms for which the overall management objectives are eradication and prevention of expansion. However, an emerging literature discusses how to approach management of non-native species [30–32]. Eradication may be costly or unfeasible, deprive local communities of economic benefits, and even be counterproductive to the evolution of ecosystems. An example of this is the proposed management of the Pacific oyster (*Crassostrea gigas*) in the UK [33], where sustainable use is advocated for this non-native species when kept in cages, and eradication is suggested for oysters invading local marine ecosystems. This situation is analogous to that of the red king crab, a non-native species regarded as both a pest and a commercially important species.

Here we have discussed the dilemmas inherent in the expansion of the introduced species of red king crab. Balancing commercial exploitation of the red king crab in one region and eradicating it in another seem to constitute a pragmatic approach to the dilemma, yielding significant benefits to the local communities in the north. The present dual-approach management regime for the Norwegian red king crab fishery has been in effect for 10 years and appears to work as intended. The result of the international legal framework is that the coastal state has sovereign rights over the resource and is to manage it. Total eradication of the red king crab is neither possible nor desirable from a management point of view. So, the qualifier of CBD Article 8 regarding in situ conservation “as far as possible and as appropriate” applies [19].

The first objective of Norwegian management of the red king crab has been to limit further expansion to the west and south and minimise ecosystem impacts outside the QRA. The open-access fishery seems to meet that objective to a considerable degree. Monitoring of the crab stock west of 26°E since 2011 has revealed no significant increase in abundance, although the appearance of the crab in new areas farther west indicates that expansion continues [34]. There is no indication that the crab is spreading northwards. Along the coast of Finnmark, its major distribution is within fjords and near coastal waters.

Regarding the objectives of economic development and maintenance of a viable industry, most of the red king crab landed in Norway is exported. The export value in 2015 was almost NOK 365 million [35]. The value is likely to increase in the coming years as more of the catch is sold live.

A new challenge is now the expansion of the snow crab (*Chionoecetes opilio*) in the northern Barents Sea [36]. The crab's origin is not known. It may have migrated naturally into the Barents Sea from the Chukchi Sea off north-eastern Russia. In that case, the snow crab cannot be regarded as an introduced species but as a species extending its distribution area. The snow crab is a highly valuable species and was recorded for the first time in the Barents Sea in 1996 [37]. It represents a threat to the benthic ecosystems, but is a valuable fish resource in other regions [38,39]. The expansion of the snow crab is similar to the expansion of the red king crab in the southern Barents Sea, bringing the same management challenges.

As species extend their distribution areas, species' “nativeness” will increasingly be questioned, especially as such drivers as climate change, eutrophication, and human activity rapidly change local ecosystems. This is a challenge to the concept of species' native areas. There is, however, a substantial difference between

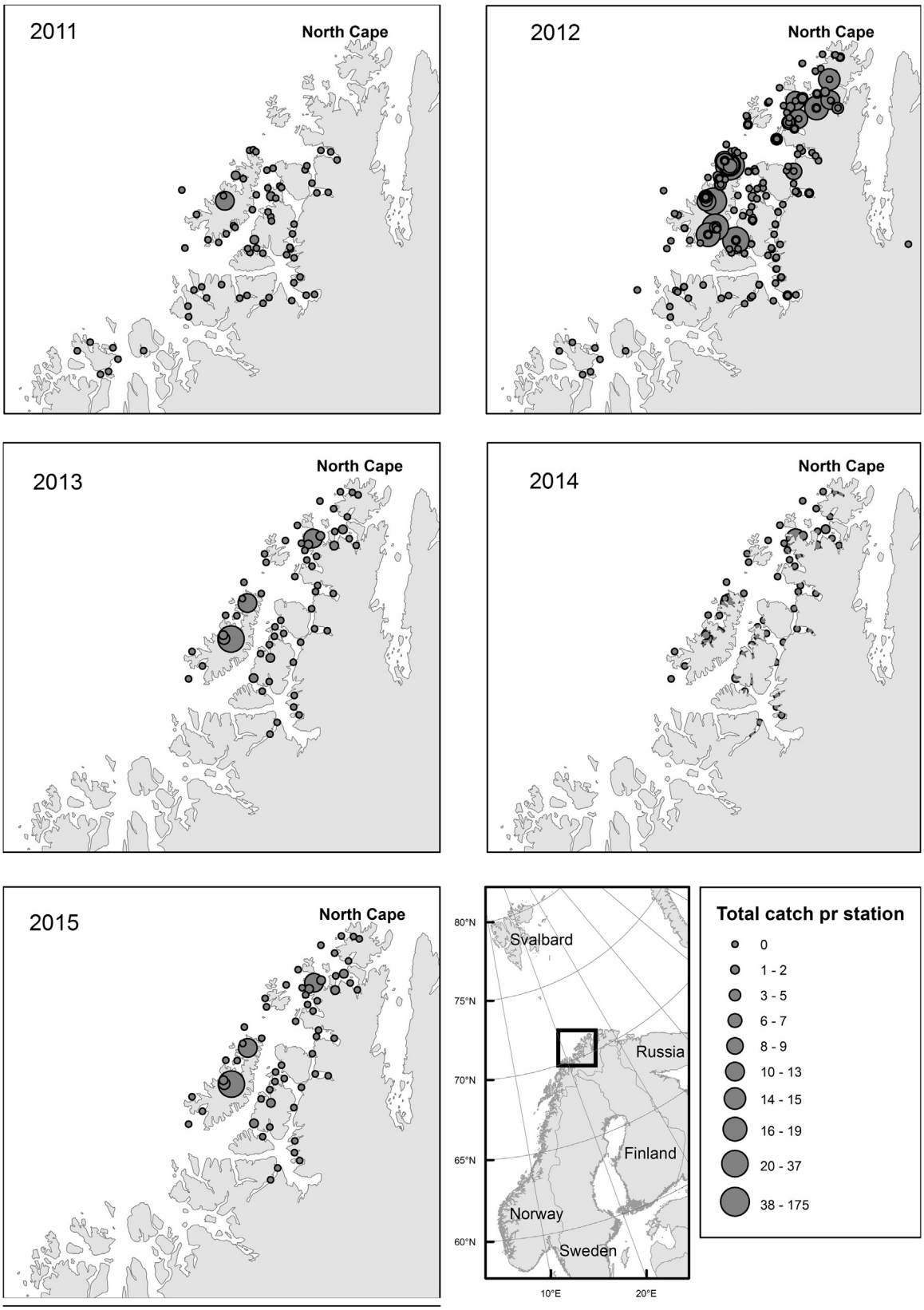

Fig. 4. Development of the catch of the red king crab (*Paralithodes camtschaticus*) in pots per day, based on surveys at stations in the OAA west of 26°E (North Cape) annually from 2011 to 2015. Catch size is indicated by the size of the shaded circles. Note that not all stations were visited each year.

species that are new as a result of an increase in their distribution area, and those introduced deliberately or by accident. The red king crab was deliberately introduced and will not be considered native to the Barents Sea. But the Norwegian approach to the management of this resource provides ideas for handling the management dilemmas that such species raise.

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Glossary

Introduced species: A non-native organism intentionally or accidentally transferred by humans.;
Non-native species: An organism occurring outside its natural past or present range and dispersal potential including any parts of the organism that might survive and subsequently reproduce.;
Gillnet fishery: Passive fishing activity by use of several types of gillnets.;
Long-line fishery: Passive fishing activity by use of baited angles.;
Open access fishery: Fishery with no restriction regarding participation.;
Population: All organisms of the same species, which live in a particular geographical area and have the capability of interbreeding.;
Stock: A management unit of a particular species; usually geographically limited.;
Bycatch: Marine species that is caught unintentionally while catching target species, or targeting sex or sizes of particular species.;
Ecosystem: A community of living organisms regarded as linked together through nutrient cycles or energy flow.;
High value species: Harvestable species of particular high market value.;
Sedentary species: Organisms which, at the harvestable stage, either are immobile on or under the seabed or are unable to move except in constant physical contact with the seabed or the subsoil (UNCLOS).;
Ecosystem approach: A strategy for integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way.;
Precautionary approach: A concept of proportionality of the risk and the cost and feasibility of a proposed action.;
Shared stock: A fishing stock shared between two or more nations.;
Prey group: A particular group of organisms preyed upon by other species.;
Benthic animals: Animals living close to or on the bottom, or in the bottom sediment.;
Juvenile crabs: Bottom dwelling (not larvae) not mature crabs.;
Otholiths: A calcareous structure in the inner ear sensitive to gravity and acceleration.;
Moulting: A periodic shedding of the old exoskeleton replaced by a new.;
Carapace: The dorsal section of the exoskeleton or shell in crustaceans.;
Eutrophication: An ecosystems response to the addition of artificial or natural nutrients to an aquatic system..