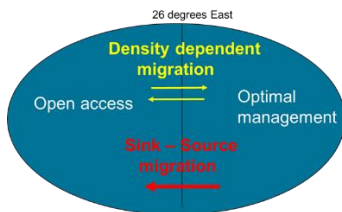


Management of invasive crabs in Northern Norway

Researching perceptions of the risks, opportunities and values of different management regimes.



PICO

PARTICIPATORY MODELLING
OF INTEGRATED
ECOSYSTEM-BASED MANAGEMENT
REGIME FOR
INVASIVE CRABS

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Figures from top to bottom: (1) The red king crab fishery has become of interest to the young generation of fishers in Northern Finnmark. Photo: B.T. Forberg (2) Bioeconomic modelling of the red king crab management with spatial spread (3) PICO stakeholder workshop, Tromsø, October 2022. Photo: J. Falk-Andersson.

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Sammendrag

Mange tenker på invaderende arter som en trussel mot arts mangfold og en plage som medfører kostnader for samfunnet. Men noen invaderende arter kan også være til nytte, og dette kan gjøre det utfordrende å finne den riktige måten å forvalte dem på. Forskningsprosjektet PICO (Participatory Modelling of Integrated Ecosystem-Based Management Regime for Invasive Crabs) har utforsket den norske forvaltningen av kongekrabbe (*Paralithodes camtschaticus*) og snøkrabbe (*Chionoecetes opilio*). Prosjektet har undersøkt hvordan innspill og deltakelse fra interesserte parter og allmennheten kan integreres og gi nye innsikter og kunnskap. Hvordan kan ulike former for risiko, preferanser og perspektiver tas i betraktning og veies mot hverandre?

Her oppsummerer og presenterer vi undersøkelsene og de vitenskapelige funnene fra PICO og hva dette kan innebære for ressursforvaltning.

Kongekrabbe og snøkrabbe er nye arter som har spredd seg raskt i norske områder. Begge er grunnlag for verdifulle fiskerier, men representerer samtidig dilemmaer for forvaltningen. Kongekrabben er ansett som en invaderende fremmed art, og man går ut fra at spredning innebærer svært høy risiko for negativ påvirkning av økosystemer. Samtidig er kongekrabben en etablert og viktig økonomisk ressurs, både i fiskeri, foredling og turisme.

Fisket etter kongekrabbe er delt i to soner, på hver side av linjen 26°Ø. For å begrense kongekrabbens utbredelse og påvirkning er fisket i vest fritt, og har i perioder vært støttet av subsidieordninger. Øst for linjen er fisket kvoteregulert og adgangsbegrenset, og målsetningen er et beskatningsnivå som maksimerer profitten i fisket. Fisket har hatt høy deltagelse senere år, og en utvidelse av det regulerte området vestover har vært diskutert.

I motsetning til kongekrabben har snøkrabben ikke lengre status som en fremmed art, men forvaltes i økende grad som et ordinært, regulert fiskeri. Snøkrabben antas å ha spredd seg til norsk område uten menneskelig hjelp og forvaltes i forhold til denne antagelsen, selv om det er faglige uenigheter rundt dette. Ettersom den ikke er klassifisert som en fremmed art, er den heller ikke risikovurdert i Fremmedartslisten for 2023. Den var tidligere vurdert som potensielt høy risiko. En større bestand kan gi store økonomiske gevinster, men spredningen av snøkrabbe kan også innebære skadevirkninger på økosystemet i større områder. Kunnskapen om disse virkningene er mer usikker enn for kongekrabben, og snøkrabben har fått en mindre sentral rolle i forskningsprosjektet. For begge arter er endringer i forvaltningen for tiden til vurdering.

Begge artene representerer et dilemma for forvaltningen: Beslutninger må tas mens det fremdeles råder betydelig usikkerhet omkring både fremtidig spredning og hvilke virkninger på økosystemer man kan forvente over tid. Usikkerhet formidles ofte i form av ekspertuttalelser om sannsynlighetsfordelinger eller risiko for gitte utfall, men dette kan være problematisk: Usikkerhet kan dreie seg om ufullstendig kunnskap, om konsekvenser som ikke kan forutses, eller om ulike fortolkninger. Dette er vanskelig å fange opp og formidle i et risikoestimat.

For å kunne gi et bredere grunnlag for å forstå og avveie usikkerhet og ulike hensyn har PICO-prosjektet vært orientert mot å samle inn et større tilfang av synspunkter og vurderinger, og innlemme disse i modeller for forvaltningen av disse to krabbeartene. Workshops med gruppearbeid og deltagelse fra eksperter og interessenter fra offentlig forvaltning, organisasjoner og næringsliv har hatt som mål å danne en felles grunn for å diskutere

prinsippene og dilemmaene som ligger til grunn for forvaltningen av kongekrabben. Gjennom dette har PICO også kartlagt viktige synspunkter, forhåpninger og bekymringer knyttet til forvaltningen av krabbefiskeriene, og brukt innspillene i utforming av forskning på hvordan dette kan hensyntas i forvaltningsråd. Mot slutten av perioden ble det arrangert dialog- og innspillmøter der foreløpige resultater ble lagt frem for diskusjon.

Hvordan ser vanlige innbyggere, eksperter og ulike interessenter på risiko og virkninger av videre spredning av kongekrabben sørover og vestover? Dette ble belyst gjennom en spørreundersøkelse. Vi fant at forskere og fiskere vurderer både faren for videre spredning og skadelige virkninger på økosystemer og fiskebestander annerledes enn befolkningen ellers. Innbyggere i Finnmark og Nord-Troms vurderer risikoen betydelig høyere enn forskere og fiskere. Samtidig vurderer de også kommersielle utviklingsmuligheter i fiskeri og turisme for å være mindre.

Verdien av å hindre videre spredning av kongekrabbe vest for Nordkapp ble undersøkt gjennom et valgekspesiment. Ekspesimentet måler betalingsvilje for tiltak for å oppnå begrensning i spredning, og gir dermed grunnlag for å vurdere nytten av tiltak som kan redusere spredning og dermed unngå skadelige effekter på økosystemer. Undersøkelsen rettet seg mot et representativt utvalg av hele den norske befolkningen. Resultatene viser en tydelig preferanse for bevaring av artsmangfold i bunnfauna og god marin miljøkvalitet, og en villighet til å bære kostnader for tiltak. Disse resultatene er viktige for å kunne veie ulike verdier mot hverandre i et felles beslutningsrammeverk.

Den geografisk todelt forvaltningen av kongekrabbe byr på særlige utfordringer:

Målsetningen om minst mulig spredning og skadevirkninger vest for grensen må avveies mot et beskatningsnivå som sikrer mest mulig lønnsomhet i øst («optimal beskatning»), samtidig som de to påvirker hverandre. Ved å innpasse biologi og økonomi i en bioøkonomisk modell, kan betydningen av ulike reguleringer og menneskelige aktiviteter på den ene siden og bestandsmodeller på den andre sees i sammenheng.

To ulike modeller har vært utforsket for hvordan bestanden sprer seg på tvers av grensen. Enten kontinuerlig spredning i retning av områder med relativt lavere tetthet, eller enveis spredning vestover, fra kilde i øst. Når modellene utvides utover direkte økonomisk verdi ser det ut til at området for regulert fiske av kongekrabbe ikke bør flyttes vestover: Verdien av å begrense videre spredning er altså her beregnet til å være langt høyere enn nettoverdien av å utvide det optimalt beskattede området. Subsidiert fiske i vest kan redusere spredning, men risikerer samtidig også å skape økte insentiver for fusk og dermed økt kontrollbehov. Fangst på tettere bestander i øst kan for eksempel rapporteres i vest, og slik omgå kvote og samtidig motta subsidier. Erfaringene fra et slikt todelt forvaltningssystem kan inneholde viktige lærdommer for mulige løsninger med differensierte soner for fisket etter snøkrabbe.

En rekke mer spesifikke utfordringer ved dagens forvaltning ble også fremhevet av interessenter, sammen med ønsket om en fornyet, inkluderende og helhetlig vurdering av forvaltningssystemet for kongekrabbe.

Introduction

Most people think of **invasive species** only as a nuisance with **negative impacts** on biodiversity and costs to society. However, some invasive species may **also bring benefits**, making it difficult to decide on the management strategy.

PICO

PARTICIPATORY MODELLING
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The PICO project explores the management systems of the red king crab (*Paralithodes camtschaticus*) and the snow crab (*Chionoecetes opilio*) in Norway. It aims to provide useful insights that can assist the management of the species under an ecosystem approach, where a diversity of risks, human preferences, perspectives among various interest groups, and international obligations need to be considered



Management of the red king crab, integrating natural and social science perspectives² Image: N. Falk-Andersson.

The project has been funded by The Research Council of Norway, project number 302114

Running between 2020 and 2024, the project involved an interdisciplinary group of researchers in the fields of natural resource management, economics, and social and political philosophy. This report presents key findings of the project (orange box headings). Additional information can be consulted at the [PICO project website](#) and in reports and published articles referenced at the end of this document. Some background information is also provided to the reader (blue box headings).



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² Falk-Petersen, J., 2012

The **red king crab** is considered an invasive non-native species in the Barents Sea³. It is rated as a severe ecological risk species with documented negative impacts on benthic fauna. The red king crab has become a significant source of income to fishers in Finnmark where harvest-limiting quotas have been allocated. The red king crab also contributes to a growing tourism industry.



The red king crab (*Paralithodes camtschaticus*) Photo: Havforskningsinstituttet.

The **snow crab** is a species with no evolutionary history in the Barents Sea that after establishment has also evolved into a valuable fishery, attracting interest from commercial fishers both in Norway and Russia. Its introduction pathway and scale of ecological impacts remain uncertain to date, but it is currently regarded as a species that has migrated on its own to the region.



The snow crab (*Chionoecetes opilio*) Photo: Havforskningsinstituttet.

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³ Soto et al., 2024

1. Background

1.1 Dilemmas in the red king crab fishery

The red king crab is a highly valued species that has become an important **source of income** to fishers in the region. Yet, the red king crab is classified as an alien invasive species having a **negative impact** on the ecosystem.

The red king crab as an invasive species

The red king crab is classified in the Norwegian risk assessment of alien species as a “*severe impact species*” with a high invasion potential and a large ecological impact⁴.

Prevention, eradication, and reduction of risks are the premises that – according to international and national regulations⁵ – should inform the management of invasive species, mainly because of their negative impacts.

Invasive non-native species

Invasive non-native species are organisms that have established in an area to which they are not native and are expanding their range on their own accord⁹.

Invasive non-native species can affect native ecosystems for example through being predators and prey of native species, compete for habitat, or change the architecture of the natural habitat.

While the red king crab is considered a non-native (or alien) invasive species, there is uncertainty about the introduction pathway for the snow crab and the scale of its ecological impacts, although these are clearly significant¹⁰. The snow crab is now classified as “not evaluated” in the Norwegian list of alien species (see more below)¹¹.

The red king crab as a profitable fishery

The red king crab shifted from only being a nuisance in traditional fisheries (by-catch of crabs in the gillnet fishery, damage to nets, eating the bait in the long-line cod fishery)⁶ to also becoming an important economic resource in the region through a fishery on this species⁷.

Being highly profitable (high export value), the regulated Norwegian fishery of the red king crab represents key economic opportunities for communities (small-scale fishers, landing and processing industry). It is also the basis for tourism activities and, through government support programs, provides opportunity for young fishers to enter the fishery⁸.



The red king crab fishery has become of interest to the young generation of fishers in Northern Finnmark. Photo: B.T. Forberg.

⁴ Agnalt et al., 2023a

⁵ The *Convention on Biological Diversity* (CBD) to which Norway is signatory, and the 2005 *ICES Code of Practice on the Introductions and Transfers of Marine Organisms*

⁶ MFC, 2007

⁷ Kourantidou, 2018

⁸ Falk-Andersson et al., 2024

⁹ Soto et al., 2024

¹⁰ Zakharov et al., 2021

¹¹ Agnalt et al., 2023a

Impacts on benthic organisms are known for the red king crab. For example, large mussel and echinoderms (e.g. starfish) have been reported to have disappeared from areas of high red king crab density, with the soft-bottom fauna now being dominated by small individuals¹². The red king crab predated on commercial species like lumpsucker and capelin roe and Icelandic scallop and is associated with parasites which may negatively impact the cod fishery¹³.



Benthos, bottom sea dwelling organisms, are an essential component of the marine ecosystems. (Strelkova and Jorgensen, 2020) Photo: P. Leopold.

The architecture of both soft-bottom and rocky substrate habitats is also affected by the red king crab. Structurally complex scallop beds in invaded areas have seen a decline, and removal of sedimentary organisms has resulted in a degradation of the sedimentary environment.

Nevertheless, uncertainties regarding their impacts persist and **positive impacts on ecosystem services have been recognised.** For example, the red king crab may contribute positively to the preservation of kelp forests through predation of sea urchins which graze on kelp. Kelp forests also provide shelter which is crucial for many other marine species¹⁴.

¹² Fuhrmann et al., 2015

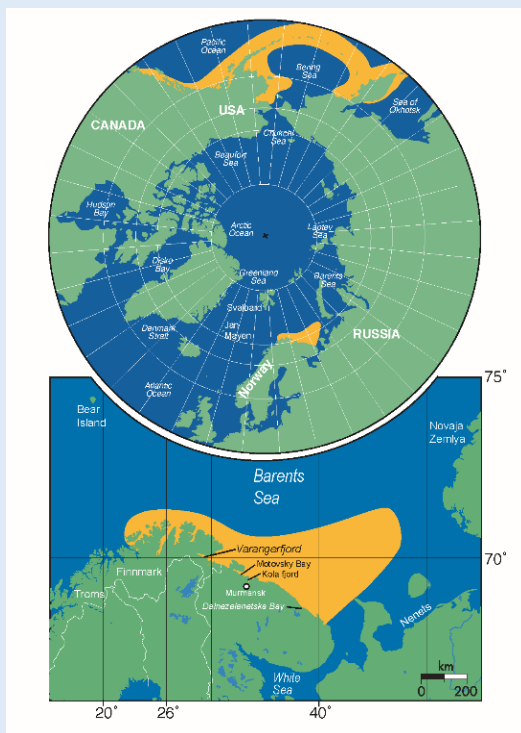
¹³ Mikkelsen and Pedersen, 2012; 2013; Jørgensen and Primicerio, 2007; Kourantidou and Kaiser, 2019

¹⁴ Falk-Petersen et al., 2011; Oug et al., 2018; Falk-Andersson et al., 2024

Uncertainty is large when it comes to potential ecosystem effects of the red king crab, and even scientific experts do not agree on which effects are larger and which are smaller.

Introduction of the red king crab

The red king crab was introduced into the Eastern Barents Sea in the 1960s by scientists from the then Soviet Union with the intention to create a commercial crab fishery. Migration of the crab from Russian waters would make any attempt to control this invasive species in Norway a continuous effort.



Red king crab's distribution in the Barents Sea (yellow area) (Falk-Petersen et al., 2011)

Snow crab: introduced or migrated?

First registered in the Eastern Barents Sea in 1996, the snow crab was presumed to have been accidentally introduced into the Barents Sea through ballast water. More recent findings suggest it may have migrated gradually from the Chukchi Sea.

The snow crab has quickly expanded its geographical range westwards and northwards into Norwegian waters and the Fisheries Protection Zone around Svalbard.

Single observations have been made west and north of the Svalbard archipelago, as well as close to the Norwegian coast. Commercially viable densities of snow crab are expected to spread to larger parts of the Barents Sea, with major uncertainties tied to climate change.

The red king crab and snow crab have successfully established reproductive populations in the Norwegian Exclusive Economic Zone for more than a decade now.

1.2 Dilemmas in the snow crab fishery

In contrast to the red king crab fishery management's dual perspective of *a pest and a value*, the snow crab fishery is managed as a regular commercial stock, with management aims nevertheless still including minimizing risk of unwanted ecosystem effects. Although snow crab may provide lucrative fisheries, maintaining a productive stock is also likely to worsen the possible harmful effects on the ecosystem¹⁵.



Snow crab fishery (HighNorthNews, 2020)
Photo: The Norwegian Armed Forces.

The snow crab fisheries **management** has been determined by its reclassification in terms of origin.

From its initial establishment in Norwegian waters, snow crab was considered an alien invasive species, but this is no longer the case. This re-classification implies a cancelling related to obligations under the Convention on Biological Diversity (CBD) to contain the spread.

The stated aims for the management of the snow crab fishery went from *undecided* to the current aim: *Value creation for society by a balance of maximizing long term yield and minimizing risk of unwanted ecosystem effects*¹⁶.

Uncertainties persist on the origins of the Barents Sea stock of snow crab, and of its effects on the ecosystem.

The origins of the Barents Sea stock of snow crab remain contested: Initially thought to have been introduced by ballast water from eastern Canada or Greenland stocks, recent genetic analyses have now argued for the likelihood of a gradual natural migration, entering the Barents Sea from the north tip of Novaya Zemlya¹⁷.

After initially being classified with the highest *severe ecological risk* category on the Norwegian risk assessment of alien species in 2012 and 2018, the snow crab was downgraded to *potentially* high risk and lastly to *not evaluated* in 2023. Initial genetic evidence pertaining to its introduction pathway led to it being de-characterized as an alien species¹⁸.

¹⁵ Kaiser, Kourantidou & Fernandez, 2018

¹⁶ Hjelseth et al., 2023

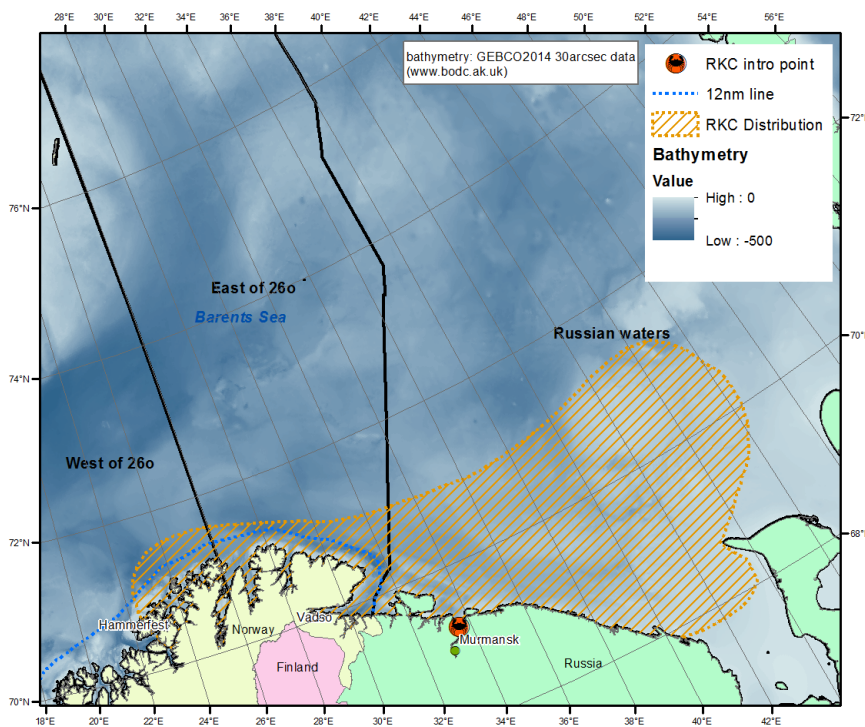
¹⁷ Dahle et al., 2022

¹⁸ Agnalt et al., 2023b; Sundet et al., 2018; Tandberg et al., 2021

1.3 Management of the red king crab and snow crab fisheries

Management of invasive species is challenging and costly. Unequal distribution of benefits and costs, and differences in stakeholder value systems are part of the difficulty.

Management of red king crab in Norway is spatially differentiated to both ensure maximum economic opportunities and to minimize the risks to ecosystems, the services they provide and the values they represent. The Norwegian management authorities involve local stakeholders in annual dialogue meetings where stakeholders can provide feedback on the proposed regulations and management of this species.¹⁹



The figure indicates the limits between management systems. Free harvesting of the red king crab is allowed to the west of 26°E, and it is regulated through quota system to the east of 26°E. The striped yellow area indicates the area of the red king crab's distribution. (Kourantidou and Kaiser, 2019).

Open-access fishery West of 26°E

Concerns regarding the potential negative impacts on the local ecosystem and on local fisheries resulted in Norwegian authorities implementing an open-access fishery in Western Finnmark in 2004 to limit the red king crab expansion²⁰. Vessels (also from the regulated area) can freely harvest the red king crab west of 26°E.

Quota regulated fishery East of 26°E

Since 2002 the red king crab quotas had been allocated to small-scale fishers in Eastern Finnmark to compensate for damages the crabs had caused as bycatch in the regular fishery. Registered vessels participate in a quota-regulated fishery east of 26°E. The commercial fishery is harvested at Maximum Sustainable Yield (MSY)²¹.

¹⁹ Falk-Andersson et al., 2024

²⁰ Kourantidou & Kaiser, 2021; Skonhoft & Kourantidou, 2021

²¹ Lovdata, 2023

Monitoring: To facilitate decisions on the **Total Allowable Catch (TAC)** and management regulations, the red king crab stock is assessed annually by the Norwegian Institute of Marine Research.

Monitoring in the west: A research cruise using pots to catch the crabs is the basis for evaluating if the open access fishery is limiting the spread of the crab and that the density of the crabs is at a low-level west of 26°E²².

Monitoring in the east: Stock estimates are based on information from annual research cruises using video transects, trawl, and pots. Crabs caught by the two latter are measured to get data on size and sex composition. An index for stock size is estimated based on this information and fed into a model that estimates the stock development, status, and prognosis. The continued crab fishery in the quota-regulated area implies that there is sufficient food resource for the red king crab stock at the present level²³.

West of 26° E: Open-access fishery, low red king crab population levels, and subsidies

The open-access fishery is regarded by management authorities as successful in keeping the red king crab population at a low level and limiting its establishment further west and south along the Norwegian coast²⁴, although there have been individual observations of red king crab in this area. Subsidies were introduced between 2010 and 2018 for under-market sized crabs (and females in some years) to incentivize further harvesting. Small crabs represent a cost to the fishers as handling them requires additional work and the market price is low. They were often discarded despite the discard ban²⁵.

The number of vessels involved both in the regulated and the open-access red king crab fishery has increased over the years²⁶

While the fishers initially were afraid of the impact of the red king crab on traditional fisheries and negative ecosystem impact, this attitude changed when the red king crab became an important source of income²⁷.

The number of vessels participating in the fishery has showed a sharp increase the past years with 400 vessels operating in the open-access area in 2021 and 2022.

Red king crab fishery: extending it further west?

The profitability of the red king crab fisheries to the east of 26°E has generated discussion for shifts in management. Some have suggested going from open-access to a regulated fishery in the west, and there have also been discussions of shifting the border westwards to create a foundation for a bigger regulated fisheries and economic opportunities²⁸. However, the economic and ecological consequences of such a shift are uncertain, and the PICO project has aimed to explore these.

²² Hvingel et al., 2022

²³ Hvingel et al., 2022

²⁴ Sundet et al., 2019

²⁵ DF, 2014

²⁶ Hvingel et al., 2020

²⁷ Eldorhagen, 2008

²⁸ Kourantidou and Kaiser, 2019

Management of snow crab by the Norwegian authorities was initiated in 2012. Since 2017, it has been organized as an “Olympic fishery”, with open-access fishing until the yearly TAC is reached, leading to catches increasingly concentrated in the first months of the year. There is no aim of stock reduction or limiting the crab’s further spread. Various options for access restriction and measures for improved sustainability are under discussion. Currently suggested revisions include a closure of access to the fishery from 2025 based on prior participation of fishing vessels, an extended period of seasonal closure, and a number of measures to improve catch selectivity and alleviate problems of ghost fishing, such as escape holes and dissolving thread in the crab pots²⁹.

Norwegian authorities have gradually put in place regulations to manage the snow crab as a regular fishery, rather than aiming for reduction of the stock and containment of its geographical expansion³⁰.

Two classificatory questions have been decisive in determining the framework of the snow crab fishery management by Norwegian and Russian authorities, as well as control and ownership in international waters. First, the classification in terms of its origin and introduction pathway as discussed above. Second, in 2015, Norway and Russia agreed to classify the snow crab as a sedentary species (see Box 1 for details), which gave Norway and Russia control within the continental shelves of the two nations.

Monitoring: The Institute of Marine Research conducts yearly population surveys of snow crab and submits recommendations to the Directorate of Fisheries. The latest survey in 2023 found a significant increase in stocks, and the 2024 quota was set to 10 300 tons, up from 7790 tons in 2023³¹.



The snow crab has been the subject of commercial fisheries since 2012. Unlike the red king crab, the snow crab fishery is not – and has not been – managed with an aim of reduction or containment of its geographical expansion. Photo: MostPhotos.

²⁹ DF, 2023; Standal & Hersoug, 2024

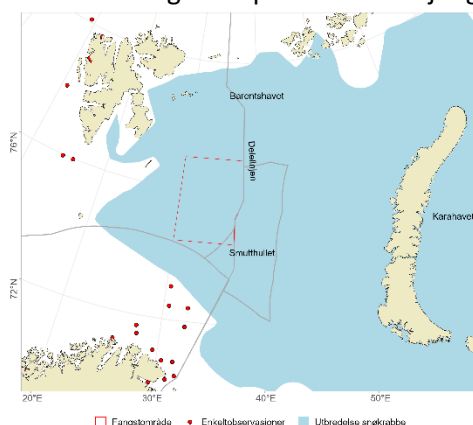
³⁰ Kvalvik, 2021

³¹ Hjelseth et al, 2023.

Box 1: The implications of classifying snow crab as a sedentary species

Classifying the snow crab as a sedentary species, making it a resource tied to the continental shelf rather than the water column, extended Norwegian and Russian control beyond their respective Exclusive Economic Zones (EEZs). It also split the area of active fishery according to the established dividing line (*Delelinjen*, see figure), and closed access to the international waters of the Loophole (*Smuthullet*, see figure) to vessels from other nations³².

As a resource tied to the continental shelf, the snow crab fisheries have become a focal point for an ongoing, wider dispute between Norway and the EU over the status of the Svalbard Fisheries Protection Zone (FPZ) and the continental shelf. Key to this complex issue is the applicability of the 1920 Svalbard treaty to the continental shelf, and the status of the FPZ established by Norway in 1977³³. Any precedent set in the case of snow crab could have implications for other seabed resources such as petroleum or minerals in the same areas, which helps explain the heightened stakes of the disagreement. In 2015, Norwegian authorities banned the catching of snow crab on the Norwegian continental shelf but granted exemptions exclusively to Norwegian vessels. A dispute with the EU Commission ensued, and in 2017 the Norwegian Coast Guard arrested vessels that had been granted EU licenses to fish the same waters. These events led to still ongoing legal disputes where the Norwegian Supreme Court's judgement stands in conflict with EU interpretation³⁴.



Snow crab continuous range (blue), observations (red dots) and main fisheries area on Norwegian side (Hjelseth et al., 2023).

The main part of the snow crab stock is located on the Russian continental shelf but supports valuable commercial fisheries also in the Norwegian area

Norwegian catches amount to around 1/3 of the total catches. Catches are concentrated in areas west of the international waters of the Loophole. The Norwegian snow crab fisheries are dominated by a small number of large, ocean-going vessels. In 2023, a total of 21 Norwegian vessels landed around 7500 tons of crab³⁵.

³² Hansen, 2016

³³ Tiller & Nyman, 2017

³⁴ Østhagen & Rapotnik, 2022

³⁵ Hjelseth et al, 2023

1.4 Uncertainty

Knowledge of environmental consequences is continuously evolving but remains uncertain. How to make decisions under persistent uncertainty while encompassing different stakeholder views therefore becomes crucial.

Red king crab: lack of agreement on potential ecosystem effects.

The studies of the impact the red king crab has on benthic communities are non-conclusive³⁶. Furthermore, funding for monitoring is limited which increases uncertainty³⁷.

In the case of the red king crab, consequences from the first "wave" of migration were different from those observed once a more stable situation was established over a longer period³⁸. Both aspects (evolving and uncertain) present fundamental challenges when developing management options.

Initially, large mussels and echinoderms (e.g. starfish) were reported to have disappeared from areas of high red king crab density. However, repeated studies have indicated that after the first invasion period, parts of the seabed fauna have recovered³⁹.

While benthic community composition and diversity have changed (abundance of most benthic species reduced, particularly non-moving burrowing and tube-dwelling polychaetes, bivalves and echinoderms), there has not been a complete loss of species and some species seem to have recovered⁴⁰.

The observed shifts in overall abundances depend on the timing and location sampled⁴¹. For example, while a 2019 cruise indicated no significant changes in benthic fauna composition in the surveyed fjords (across a seven-year long time series), overall, the red king crab is known to be putting pressure on large individuals of mussels, starfish and sea stars, which disappear over time in areas with high crab densities. These areas also typically experience reduced number of species and an overall reduction in benthic biomass.

Ongoing monitoring of larger bottom fauna is necessary to allow for longer time series that can reveal any significant variations⁴².

Snow crab: management of the fishery under substantial uncertainty

The risks of harmful effects on benthic ecosystems and commercial fisheries of an increased snow crab population have been evaluated by the Institute of Marine Research. Despite high uncertainty, and an expected significant role on the benthic communities of the Barents Sea, the risks of negative impact on other fisheries is currently evaluated as low. The impacts of climate change on the future distribution of snow crab are also highly uncertain⁴³.

³⁶ Falk-Andersson et al., 2024

³⁷ Kourantidou & Kaiser, 2019

³⁸ Falk-Andersson et al., 2024

³⁹ Uug et al., 2011; 2018

⁴⁰ Uug et al., 2018

⁴¹ Uug et al. 2011, 2018

⁴² Sundet et al., 2019

⁴³ Hjelseth et al., 2023; Mullaney et al., 2023

Communicating uncertainty.

In risk-based approaches uncertainty is often communicated to policy makers in terms of probability distributions.

For example, scientists may assess the threat to native species from the red king crab invasion as high with 30% probability, medium with 50% probability, and low with 20% probability.

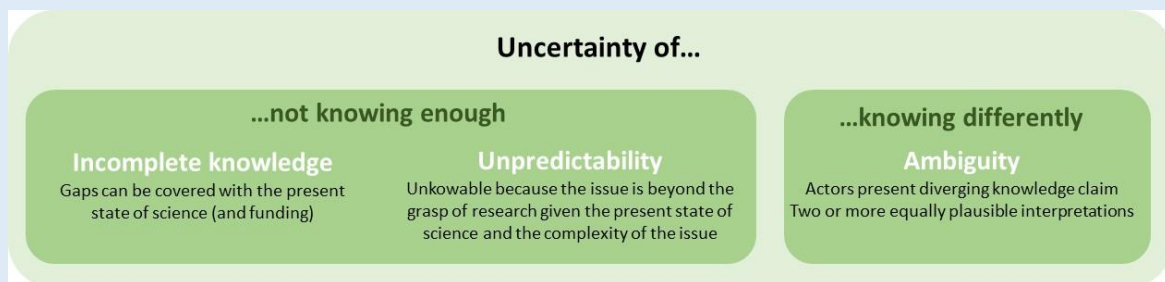
The literature points to common problems with this approach. For instance, experts may not actually be able to assign such probability values in a meaningful way: they may be biased and may even exclude factors that are uncomfortable to consider⁴⁴. When leaving evaluation of uncertainty to experts, they may be pushed towards meeting a consensus that does not exist, which effectively hides uncertainty from policymakers⁴⁵.

In such situations, it is advisable to take a step back and explore the background knowledge for a given set of probabilities and look at other approaches that can support decision making under uncertainty.

There are arguments, both from an empirical and theoretical point of view, for **eliciting different stakeholder groups' risk assessments of ecosystem impacts from the red king crab invasion.** This is what we have explored in the PICO project.

Uncertainties are not just connected to scientific knowledge⁴⁶

Three types of uncertainties can be distinguished: *incomplete knowledge*, *unpredictability*, or *ambiguity*. Perceptions of uncertainty are the result of interaction among different actors. These interactions influence which uncertainty will prevail. The way that these uncertainties play out in decisions is influenced by dominant discourses and storylines, as well as by socio-political contextual factors such as regulatory frameworks and funding opportunities.



Types of Uncertainty (Adapted from Floor et al., 2018)

⁴⁴ Fischhoff and Davis 2014; Pielke, 2007

⁴⁵ Stirling, 2010

⁴⁶ Floor et al., 2018.

2. Insights from PICO

2.1 Hopes and concerns manifested by key stakeholders associated with the red king crab fishery

Gaining a better understanding of the current challenges and dilemmas with respect to the management of the red king crab

PICO brought actors directly and indirectly involved with the red king crab fishery together with researchers for a workshop in Tromsø in October 2022. The aim was to gain a better understanding of the current opportunities, challenges and dilemmas with respect to the management of the red king crab.

Among the participants were stakeholders with commercial interest in the crab fisheries, management authorities at various levels, environmental NGOs, public organisations, and researchers from within and outside the PICO project⁴⁷.

Method

- Through a series of exercises, participants were encouraged to bring out their differing perspectives and to co-create a common ground for understanding the challenges in the complex management of the red king crab.
- In group work and plenary discussions, goals, pathways, and obstacles for desired outcomes from the management of the red king crab fishery were explored.

Results

Economic opportunities, food security, and ecosystem damages were some of the key issues brought forward by the participants during the plenary and group exercises. Participants also recognized the controversies and difficulties in managing a resource that is both valuable and at the same time damaging to the ecosystem.

Four sub-sections categorize the results that emerged from the exchange of thoughts:

- *Hopes and Concerns* (see Table 1 below);
- *Ecosystem-approach in the mindset* (e.g. comments brought up during the group work and discussions that encapsulated the three ecosystem-approach pillars: ecological, socio-cultural, and economic concerns)
- Viewpoints expressed on management mechanisms that could inform the design of models and scenarios explored in PICO; and
- *Dilemmas*: geographical expansion of the quota regulated area, and the composition of the fishing fleet.



PICO stakeholder workshop, Tromsø, October 2022. Photo: J. Falk-Andersson.

⁴⁷ Ramírez-Monsalve et al., forthcoming

Hopes	Concerns
<ul style="list-style-type: none"> • Gather more knowledge and tools to understand and manage the ecosystem impact; better understanding of social and economic aspects associated to the fishery. • Optimize the current system: in terms of access to and regulation of the fishery. • Optimize the current system: in terms of operations complementary to the fishery (e.g. feeding of wild-caught small crabs, utilization of crab's by-products, supply the market with live crabs). • Highlight the importance of the fishery (in terms of commercial operations) for Finnmark's local communities. • Recognize additional values for the local communities that go beyond commercial exploitation. 	<ul style="list-style-type: none"> • Persisting lack of understanding and knowledge on ecosystem impacts. • Managing all the stakeholders' interests. • Rushed political decisions. • Prioritization of the red king crab fisheries over other traditional fisheries. • Prioritization of the red king crab fisheries over other (known or unknown) uses of the benthic habitat (biodiversity as resilience).

Table 1: Hopes and concerns manifested by key stakeholders associated with the red king crab fishery in Finnmark and Troms.

Viewpoints expressed on management mechanisms

There was no intention to be prescriptive, but rather to collect the viewpoints of diverse stakeholders on management possibilities. Some of the suggestions concerned mechanisms already in place (i.e., quotas allocated to small-sized vessels and to active fishers based on documented landings of other species than the red king crab).

The issues/suggestions listed below would involve shifts away from existing practices:

- Different options for quota allocation: historical catch particularly of other traditionally caught species, equity considerations in quota distribution, quota trading (payments), quotas assigned via lottery.
- Regulations for the open-access fishery that allow for a more economically viable fishery west of 26°E.
- Introduce a market for quotas, so that access to the fishery can be sold/purchased.
- Opportunities to buy out the boat (wherein quotas can be sold and/or the quota can follow the boat if sold).
- Crab quotas allocated every 2nd year, while maintaining the requirement of actively participating in other fisheries.

Applicability of the findings

The discussions have informed the models currently developed by the researchers in the project.

Collected perspectives can feed a potential forthcoming process of finding ways forward that would reconcile different value systems and identify suitable compromises in managing the red king crab.

Interested in more information on these findings?

The report *Management of the Red King Crab in Norway. Perspectives offered at a stakeholder workshop. Tromsø. 19th October 2022* (Ramírez-Monsalve et al., forthcoming) contains further information of this event.

2.2 A stakeholder perspective on effects and risks of the red king crab

Collecting information on how various stakeholder groups assessed effects of and risks associated with the red king crab invasion in Norwegian waters



Map used for the question of establishment of red king crab in the next 15 years

An electronic survey was developed and shared among three stakeholder groups:

- The general public (local residents of Finnmark and northern Troms counties)
- Commercial coastal fishers in Finnmark and Troms
- Scientific experts on red king crab with various disciplines (biology, ecology, management and market)

The survey included a brief introduction about the red king crab and its current management system. Two main questions were asked:

- 1) How far beyond the present area (North cape) the red king crab would be established in the next 15 years under the current management regime, and
- 2) Which threats and opportunities this will pose on existing marine ecosystem services and human activities.

Method

- Responses were given on a 4-point Likert scale, going from small probability for establishment (1) to very large probability for establishment (4), and a 7-point Likert scale, going from very large threat/benefit (1) to no threat/benefit (6), and reverse effect (7). For threats and opportunities there was in addition an opt-out option "I don't know".
- We used the Pearson's chi-square test and Fisher's exact test to analyse potential differences in the distribution of responses across the three groups.

The data was collected in two waves.

- In May 2022 a professional survey company distributed the survey to their internet panel of households in Troms and Finnmark county.
- In December 2022, the same survey company implemented the survey to researchers and commercial fishers.
- The total survey sample was 100: 55 from the general public, 19 researchers and 26 fishers.

Results

When it comes to how likely it is that the red king crab will be **established in areas west of North cape** in the next 15 years, the local residents, compared to fishers and researchers, think it is more likely that the red king crab will establish beyond the current demarcation line.

The comparison of **ranking of threats** across stakeholder groups shows that, although the three groups differ in **how large** they assess the various threats to be, all **three** stakeholder groups **agree** with respect to the ranking of the **threats**. Local residents systematically and significantly assess the threats to cod, haddock, flounder and capelin from the red king crab to be larger than the researchers do. Local residents also assess the impacts on cod and haddock to be significantly larger compared to how fishers assessed this risk.

With regards to the **ranking of opportunities**, the local residents rank them differently from the fishers, while fishers and researchers rank the opportunities in a similar manner. The local residents assess opportunities for commercial fisheries to be significantly smaller compared to how fishers and researchers assessed these opportunities. Local residents also assessed the opportunities for tourism to be significantly smaller compared to how fishers assessed this.

Assessing the effects and risks associated to the snow crab

The survey reported above initially was planned to include both the red king crab and the snow crab. However, as the current knowledge on both threats and opportunities to society of the snow crab is even more scarce compared to the red king crab, the researchers found it difficult to formulate credible threats and opportunities that could be tested.

In addition, in all three stakeholder groups, the knowledge of and experience with the snow crab is significantly smaller compared to the red king crab, and thus results would have been more speculative.

Applicability of the findings

Our results and analysis speak to decision making and specifically the process through which policy making is designed to avoid conflicts and reconcile the different interests on the controversial crab.

Local residents provide a clear signal to management to pay more attention to the precautionary principle and ensure the public that necessary measures are taken to hinder further spread.

Interested in more information on these findings?

You could contact Margrethe Aanesen (SNF) or Michael Morreau (UiT) who were part of the Work Package 2 on **Participatory Risk Assessment**.

2.3 Understanding the willingness-to-pay (WTP) for controlling the spread of red king crab

Targeting a representative sample of the Norwegian population through a survey

An internet-based environmental valuation survey was conducted for eliciting Norwegians' willingness-to-pay (WTP) using a Discrete Choice Experiment (see below) for policies that would avoid the red king crab from spreading westward from the North Cape.

The goal was to assess the social benefits of policies that can reduce the spread of the red king crab and avoid the impact brought by this species on the benthic fauna and on other ecosystem processes.

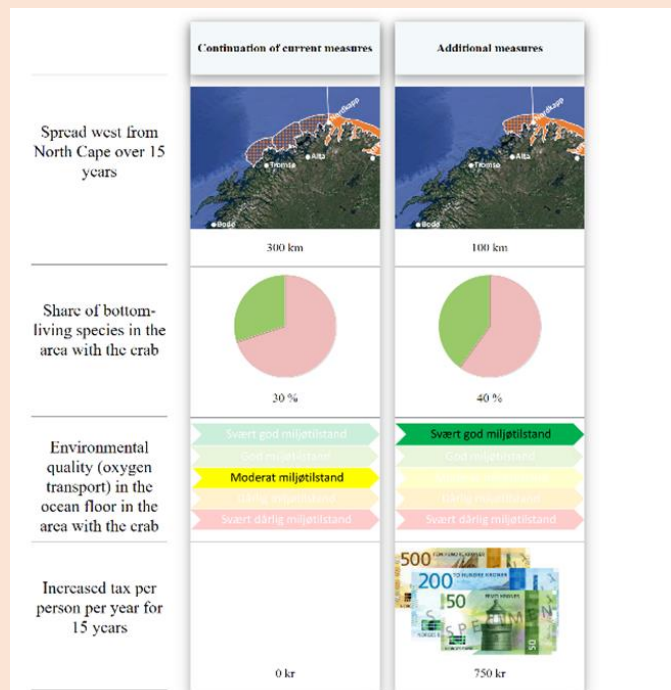
Using Discrete Choice Experiment (DCE)

In economics, a DCE aims to elicit people's preferences by asking them to choose between two or more distinct policy alternatives that differ in terms of effectiveness, impact and cost. By analysing these choices, we can learn about how they make trade-offs between effectiveness, impact and cost. In other words, the value they place on stopping or reducing the spread to safeguard the environment.

In the DCE, respondents were asked to choose between maintaining the current red king crab management for 15 years and implementing new policies.

Maintaining the current management plan represented the *status quo* alternative, which varied as part of the experimental design due to the unpredictability of future red king crab spread and impacts.

The *status quo* alternative implied further spread of the crab and came at no cost. The new management policies meant increased annual income tax, but it would effectively reduce the spread of the crab and reduce its environmental impacts through an effective set of policies that could include changes to gear, catch size restrictions, or even reintroduce subsidies for small and juvenile crabs in the open access fishery west of 26° E.



An example of a choice card used in the survey to elicit WTP for reduced spread, improvement in benthic species abundance and environmental quality of the ocean floor. *Miljøtilstand* referring to environmental condition.

The DCE was developed with substantial stakeholder input to ensure the validity of the survey instrument and the relevance of the results

A workshop was held in October of 2021 in Tromsø with experts, followed by a focus group in Fredrikstad. In November of the same year, focus groups were conducted in Vardø and Alta and personal interviews were carried out in Tromsø to test the survey instrument.

The workshop and focus groups helped identify and describe relevant attributes that characterized the impacts of the management policies. These include:

- Reductions in loss of bottom-living species like clams and worms (benthic species) in areas with red king crab,
- Deterioration in environmental quality of the seabed in the same areas, and
- Spreading of the crab westward from the North Cape.

Results

We find that, on average, people are willing to pay NOK 186 in additional income tax per year for 15 years to reduce future spread by 100km, increasing to NOK 872 for avoiding a 400km spread.

On average, people are willing-to-pay more than NOK 11 for one percentage point more benthic species remaining in the area with the red king crab. Even though people's preferences vary, 95% of people have a positive WTP for increased benthic species abundance.

WTP for improved environmental quality ranges from an average of NOK 334 to go from "Bad" to "Poor" quality, up to NOK 1162 to go from "Bad" to "High" quality. Interestingly, we see that the increase in WTP for going from "Good" to "High" is relatively small indicating a potential saturation effect.

We also explore how people's WTP is influenced by how the management policies are presented.

When respondents were reminded that they were being asked about managing a single invasive species and not all invasive species in general, their average WTP decreased from NOK 872 to 588 for a 400 km reduction in the spread of the crab, but their WTP was not significantly lower for impacts on benthic species abundance and environmental quality. This indicates that the well-known embedding effect was also present in this study and suggests that providing specific reminders about what is being valued can lead to improved estimates.

Applicability of the findings

This DCE can be used to inform policy makers that people value the preservation of benthic species diversity and marine environmental quality. Results can be used to calculate preliminary benefit estimates for use in Benefit-Cost Analyses (BCAs) of management plans to reduce environmental damages from the red king crab.

The results can also be used in bio-economic modelling to determine the optimal harvest of red king crab in the eastern region where it is managed to optimise the fishery when the external costs in terms of increased risk of spreading is taken into account in terms of people's WTP to avoid further spread westward.

Interested in more information on these findings?

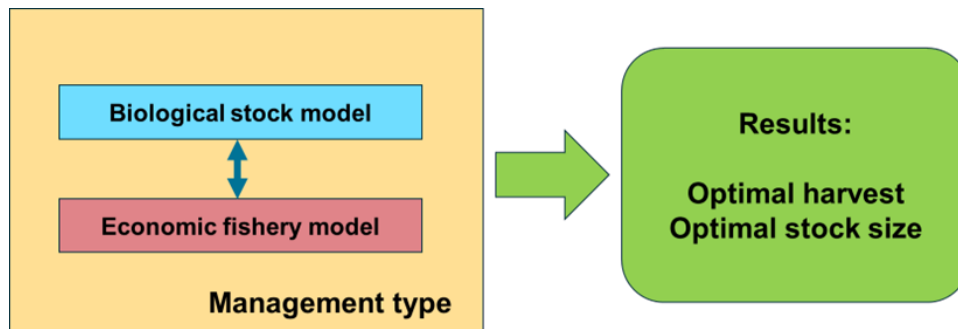
You could contact Erlend Dancke Sandorf (NMBU), Ståle Navrud (NMBU), or Kofi Godwin Vondolia (UCC) who were part of the Work Package 3 on **Valuation of trade-offs between red king crab/snow crab and marine ecosystem services**

2.4 Modelling the management of red king crab through bioeconomic analysis

In a model that combines biology and economics, the biological aspects of the red king crab are combined with human behavioural interaction.

When the bioeconomic model is set with a specific management goal (e.g. maximise economic yield) then we can find **what the optimal harvest and stock size of the red king crab should be** to reach that management goal.

We created a bioeconomic model based on the current management objective for the red king crab in Norway where the aim is maximising economic yield East of the 26°E line via a quota system and minimizing the risk to the ecosystem to the West of the 26°E line via an open access system.



A basic representation of a bioeconomic model

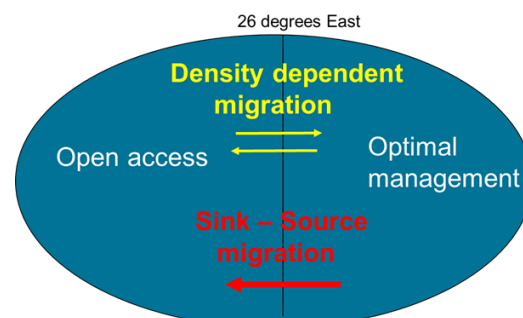
In our analysis, given the uncertainty regarding the potential migration of red king crab, we investigate the impact of two different migration types: density-dependent and sink-source migration (Box 2) and study how these differences may impact the optimal harvest and stock size.

Box 2: Modelling with spatial spread (East and West of 26°E)

Simple biomass models are applied; cohorts are not being included. The whole red king crab stock is combined, with its growth and natural mortality in one unit, but with spatial spread. The spatial spread aspect makes the model a form of sub-stock model.

The interaction between the two spaces we study (East and West of 26°E) is modelled using two different migration types, namely:

- density dependent movement, dependent on the relative density of the stock in the two areas, with continued movement towards the patch with lower density and
- unidirectional or sink-source migration where movement is in one direction, from East to West (see Figure above) independent of the relative density in the two areas



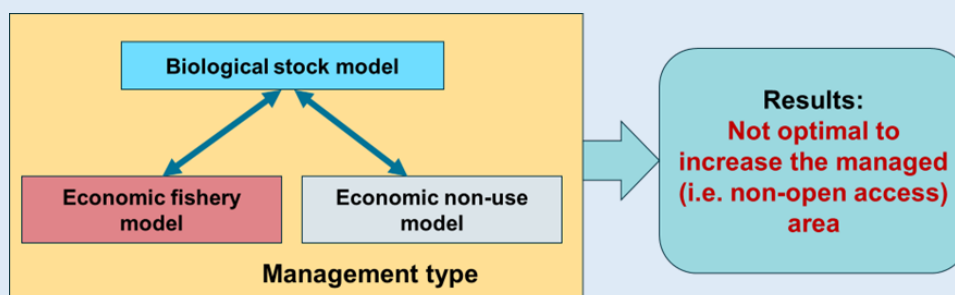
Movement mechanisms (Density dependent or Sink-Source) and management regimes (Open access; Optimal management) in the two-patch model describing the red king crab fishery

Expanding the management area to the West?

Another bioeconomic model is being developed to assess whether expanding the managed area to the West is recommendable.

This model includes results from the WTP study by assigning value to the ecosystem (benthic biodiversity and environmental quality of the seafloor). Preliminary results indicate that such an expansion cannot be defended, due to the non-use value of limiting spread far exceeding the net benefit of expanding the fishery aiming at maximising economic yield.

The developed model can be applied for both species the red king crab and the snow crab



The expanded model including non-use values connected to ecological impacts of the red king crab expansion

Results

Results show that a subsidy has the potential to increase the fishing in the West and thereby achieve the management goal of limiting further westward spread.

However, the subsidy also provides an increased incentive for loopholes in the system: based on the economic rationale of lower costs in the East, due to higher stock densities, incentives are created to fish beyond the allocated quota in the East and report harvest as being caught in the West where there are no quota limitations.

This leads to the need for increased control, thereby increasing the enforcement costs.

Applicability of the findings

The modelling results underline the need for careful use of subsidies.

Furthermore, subsidies in the case of density dependent migration leads to the greatest impact on the output of the regulated area in the East, as the effects are attenuated by the increased density difference due to the created loopholes in the system.

These results also underline the importance of understanding the biological mechanisms governing the crab population to identify the appropriate management actions.

People put a high value on a biodiversity values and healthy ecosystems. This value is higher than the value of expanding the management regime in the east, further south.

Interested in more information on these findings?

You could contact Claire Armstrong (UiT), Xuan Bui Bich (UiT), Brooks Kaiser (SDU), Melina Kourantidou (SDU) who were part of the Work Package 4 on **Integrated bioeconomic analyses of red king crab/snow crab and marine ecosystem provision.**

2.5 Validating preliminary project results through stakeholder interaction

Presenting and validating with stakeholders preliminary findings from the research, and discussing its contributions to the management of the red king crab

In the final period of the project, a set of dialogues was initiated with the actors who are directly and indirectly related to the red king crab fishery. It presented and validated the findings from the PICO research up to October 2023. Participants brought the voices from the fishery, management, local society, market organisation for Norwegian seafood processing industry, Sami interests, and natural science research.

Method

- Preliminary research results were discussed with stakeholders that directly and indirectly are related to the crab fishery in Northern Norway.
- Presentations and discussions with the stakeholders on the studies of perceptions of risks, values and opportunities, as well as the economic value of different management regimes.

Several events took place in October 2023.

- Workshops with stakeholders in Tromsø and Vadsø.
- Public event at the Vadsø library.



PICO outreach event, Vadsø, October 2023.
Photo: P. Ramírez-Monsalve.



PICO outreach event, Tromsø, October 2023.
Photo: P. Ramírez-Monsalve.

Topics discussed during the meetings:

- Specific problems with current management regimes
- Influence of climate change on commercial stocks
- Measuring the value of ecosystems

Topics of interest to the stakeholders:

- **Breaking the stereotype** that only scientific knowledge is the one to use for making management decisions, and exploring models that integrate experiential knowledge into the process, along with more stakeholder participation in research within the Norwegian management context.
- **Whose voices need to be heard** when making decisions on the fishery? Stakeholders who attended the event felt that the opinions of those with too little knowledge on the topic, or of those who live in more distant areas of the country and who would not be directly impacted by decisions made by management, were weighted too heavily.
- **Concerns by fisheries stakeholders on the situation with injured crabs** as they will not heal; damaging impacts of returning injured crabs to the sea; this points to a flaw in the current management system. In addition, the low value of small crabs was highlighted as a key problem by some, in need of mechanisms such as compensations or new ways of making use of small crabs.
- **Problems with the current snow crab fishery system** were raised as a concern (e.g. overcapacity, low profitability, management unpredictability, freezing versus live export), and that other and better ways of exploiting the snow crab are precluded in the current system. Among the issues that some of the fisheries' stakeholders would like to see explored in the future is the possibility of two systems: one for live crab landing in Finnmark, another one for vessels which process at sea into frozen product.
- The need for a wider, **more encompassing process to evaluate the current red king crab management system**. Maybe it is time for a new policy re-evaluation? A call for having differentiated management according to vessel sizes with different requirements. Also, a call to consider the possibility of differentiated rules for zones, within the regulated area, for instance for individual fjords: area-specific challenges such as higher fishing pressure and prevalence of injured crabs, or presence of sensitive species can be difficult to address with a one-size-fits-all management approach.

Applicability of the findings

The meetings served two purposes: as spaces to validate findings from our PICO research, and at the same time to collect insights considered of interest to stakeholders of the red king crab fishery during the second half of 2023, e.g. the call for higher diversity in providers of knowledge; the call for better inclusion of local stakeholders' views; the call to explore incentives to land non-commercial crabs.

Interested in more information on these findings?

You could contact Jannike Falk-Andersson (NIVA), Bård Hobæk (NIVA), or Paulina Ramirez-Monsalve (NIVA) who were part of the Work Package 1 on **Knowledge co-creation and dissemination**.

Concluding remarks

The management of commercially valuable invasive species requires the identification of suitable compromises and solutions that can reconcile the diversity of risks, human preferences, perspectives among various interest groups, and international obligations. Among the insights we provide through PICO and that could assist the management of the red king crab and snow crab are:

- There have been discussions of extending the regulated area of red king crab westwards, but our results may indicate that this is not advisable. The measured value of limiting further spread to secure values related to the native ecosystem far surpasses the added value of a potential fishery similar to that east of 26°E.
- Subsidies for red king crab catches in the open access area may be helpful in hindering spread, but care must be taken to avoid incentivizing cheating and increased need for control.
- The high value people put on limiting negative ecological impact of the red king crab invasion, suggests that this should be studied further to guide management of the snow crab too.
- Local residents in the Troms and Finnmark counties provided a clear signal to management to pay attention to the precautionary principle. They were more concerned than researchers and commercial fishers regarding how far beyond the current demarcation line the red king crab will establish in the next 15 years, and which threats this will pose on species like haddock, flounder, capelin and cod. The public also assessed the opportunities for fisheries and tourism from crab establishment beyond the current demarcation line to be lower compared to commercial fishers and researchers.
- People who hold strong preferences for the marine environment are willing to pay a substantial amount per person per year to reduce the spread of invasive crabs, preserve benthic species abundance and safeguard environmental quality (oxygen transport) in the ocean floor.
- A number of specific concerns over flaws and shortcomings in the current management regime of the red king crab were raised by stakeholders, such as the prevalence of injured crab, lack of incentives for higher value products, differentiation of requirements for participation in fisheries, and area-specific challenges within the regulated zone. An inclusive process should bring experience-based knowledge, stakeholder and the public's preferences into the evaluation of the current management of invasive crabs, to suggest means of addressing such problems.

Interested to know more?

Below is the list of articles and reports we published as part of PICO thus far.

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Red king crab Photo credit: MostPhotos



Snow crab Photo credit: MostPhotos

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