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Report from the workshop:

Workshop on king- and snow crabs in the Barents Sea

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Report from the workshop:
Workshop on king- and snow crabs in the Barents Sea
Tromsø, 11 – 12 March 2014

Edited by Ann Merete Hjelset

HAVFORSKNINGSINSTITUTTET
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Background

Institute of Marine Research (IMR) and PINRO was asked by the Joint Russian-Norwegian Fisheries Commission to organize a workshop on red king crab and snow crab. The workshop was arranged in Tromsø March 11th to March 12th 2014.

In total 27 participants attended during the two days and a total of 15 oral contributions were given. The workshop had two sessions where oral presentations gave current knowledge status related to four thematic issues and at the end of the workshop, there was an open discussion aiming to highlight and recommend new issues for further studies.

The red king crab was introduced to the Barents Sea by Russian scientists more than 40 years ago and has now become a common species in coastal areas in northeastern Norway and coastal and also covers more offshore areas in Russian waters. Along the Norwegian coast the red king crab is common west to the border between Troms and Finnmark, and eastwards to the entrance to the White Sea in Russian waters. It is a commercial fishery for red king crab the Barents Sea, and the quotas in the two countries are decided upon separately.

The first specimens of snow crab were recorded in 1996 at the Goose Bank in the eastern part of the Barents Sea. Since then it has spread throughout most of the Russian zone and are now found in most in most parts of the eastern Barents Sea. Roughly estimates carried out by Russian scientist show that the snow crab biomass is approximately ten times higher than the red king crab biomass, and about half the shrimp biomass. This tells us that the snow crab is now a major part of the Barents Sea ecosystem, but our knowledge on this new inhabitant is scarce. Russian authorities plan to start a small fishery for snow crab in 2014.

With the aims to bring forth a knowledge status quo in the biology and fishery for the two crab species, an invitation was sent out to scientific institutions, industry and management bodies in Norway and Russia to participate and to provide new knowledge on either red king crab or snow crab. The scope was to reveal new knowledge and to highlight knowledge gaps regarding the two species.

During the workshop several good presentations were given and we had very good discussions after each thematic session. At the end of the workshop we summed up and the following subjects were highlighted to be followed upon in the future:

For both species;

- Investigate predators and their consumptions on the red king crab and the snow crab in the Barents Sea
- Habitat preference of early life stages of crabs to reveal potential spread;
- Benthic production and carrying capacity for the snow and king crab;
- Improve survey design and data collection for both crabs;
- Establish estimates on by-catch mortality of the king- and snow crabs;
- Carry out red king crab and snow crab stomach analysis to reveal diet;

For the red king crab;

- Impact of the red king crab on the benthic community in open sea areas
- Impact of the fishery on the red king crab stock structure;
- Status of growth and moulting frequency of the red king crab;

For the snow crab;

- Baseline studies regarding snow crab impact in the Barents Sea;
- Monitoring the dispersal front of the snow crab in the Barents Sea and the Kara Sea;
- Diseases and parasites in the snow crab;
- Modeling snow crab larvae dispersal;
- Investigate the reproductive biology of the snow crab;
- Develop new and adequate scientific sampling gear for the snow crabs

In this report you can find the abstracts from each lecture given in addition to an overview of the power points presentations given.

Program

	Program Tuesday March 11th, 2014
13:00-14:00	**All participants are welcome to enjoy lunch before we starts the workshop.**
14:00	Welcome to workshop
14.05-14:15	**Jan H. Sundet, Institute of Marine Research, Tromsø** Presentation of workshop and introduction to agenda
14:15	Ecological role of the king- and snow crab in the Barents Sea
14:20	**Mona Fuhrmann, UiT** Role of the invasive red king crab (*Paralithodes camtschaticus*) in the benthic food web
14:50	**Eivind Oug, NIVA** Changes of soft bottom fauna (1994-2012) in Varangerfjorden, northern Norway, following the invasion of the red king crab (*Paralithodes camtschaticus*)
15:20-15:40	Coffee and tea break
15:45	**Helena Kling Michelsen, UiT** The timing, abundance and distribution of red king crab larvae within a north-Norwegian fjord
16:15	**Konstantin Sokolov, PINRO** Megalopa of snow crab in the Kara Sea
16:45	**Gro I. van der Mereen, Institute of Marine Research, Austevoll** Effects of early benthic phase predation, competition and habitat on the life history of red king crab in Norwegian waters
17:15-17:45	**We end the session with a discussion and sum up the theme**

	Program Wednesday March 12th, 2014
8:45	Coffee and tea
9:00	Life history parameters of the king- and snow crab
9:05	**Ann Merete Hjelset, Institute of Marine Research, Tromsø** Review of life history parameters of the red king crab in Norwegian waters
9:35	**Sten Ivar Siikavuopio, NOFIMA** Temperature effects on feed intake, growth, metabolism and survival of red king crab (*Paralithodes camtschaticus*)
10:05	**Nina Mikkelsen, UiT/Torstein Pedersen, UiT** Invasive red king crabs feed on both capelin and their eggs
10:35	**Jan H. Sundet, Institute of Marine Research, Tromsø** Status snow crab in the Barents Sea
11:05-11:20	Coffee and tea break
11:25	**Geir Dahle, Institute of Marine Research, Bergen** Population genetics – snow crab. Genetic differentiation around the Arctic Ocean?
11:55	**Ann Lisbeth Agnalt, Institute of Marine Research, Bergen** Presenting potential spreading of snow crab larvae in the Barents Sea
12:25	**We end the session with a discussion and sum up the theme**
13:00-14:00	Lunch
14:00	Assessment methods applied of the king and snow crab stocks in the Barents Sea
14:05	**Carsten Hvingel, Institute of Marine Research, Tromsø** Designing assessment processes for fishery resources that includes ecosystem considerations – a case study of King crab off northern Norway
14:35	**Konstantin Sokolov, PINRO** Modeling of population dynamics of commercial crabs in the Barents Sea
15:05	**Kristin Windsland, Institute of Marine Research, Tromsø** Total and natural mortality of red king crab (Paralithodes camtschaticus) in Norwegian waters: Catch curve analysis and indirect estimation methods
15:35-15:50	Coffee and tea break

15:50	Management options for the king- and snow crab stocks in the Barents Sea
15:55	**Guro Gjelsvik, Directorate of Fisheries** Evaluation of the red king crab management
16:30-18:00	Closing session: Knowledge gaps in the biology of the king- and snow crab in the Barents Sea – elucidating new scientific challenges
	Here we are aiming to highlight knowledge gaps for the two crab species in the Barents Sea and we encourage all of the participants to take part of the discussion.

After every presentation there will be time for some questions.

All of the participants are encouraged to take part of the discussion and ask small or large questions. This is a workshop where we can discuss various aspects around red king and snow crab.

Participants at the workshop

Delegate name/e-mail address	**Organisation**
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Presentations given under the theme;

Ecological role of the king- and snow crab in the Barents Sea

Mona Fuhrmann, UiT

Role of the invasive red king crab (*Paralithodes camtschaticus*) in the benthic food web

Eivind Oug, NIVA

Changes of soft bottom fauna (1994-2012) in Varangerfjorden, northern Norway, following the invasion of the red king crab (*Paralithodes camtschaticus*)

Helena Kling Michelsen, UiT

The timing, abundance and distribution of red king crab larvae within a north-Norwegian fjord

Konstantin Sokolov, PINRO

Megalopa of snow crab in the Kara Sea

Gro I. van der Mereen, Institute of Marine Research, Austevoll

Effects of early benthic phase predation, competition and habitat on the life history of red king crab in Norwegian waters

Role of the invasive red king crab in the benthic food web: Results from stomach analysis and stable isotopes

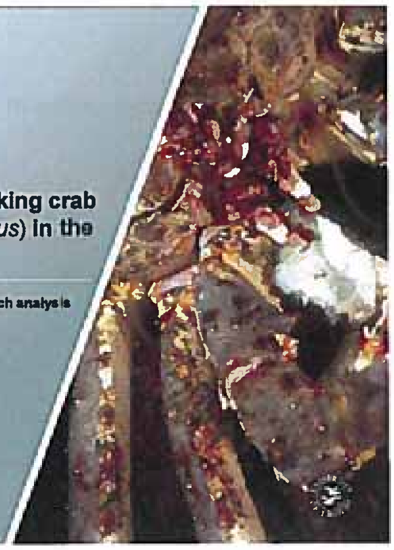
Mona Fuhrmann, Torstein Pedersen, Einar Magnus Nilssen

The introduced red king crab (*Paralithodes camtschaticus*) has become an abundant predator of the benthic community along the north Norwegian coast, potentially altering the community and competing with other native predators. Previous diet studies based on stomach analysis (SA) found soft bottom communities to be the main foraging areas of the crab. The crab exhibits a large range of prey taxa and has therefore been regarded as a generalist. Stomach analysis, however, provides only snap shots of the diet and does not allow estimates of long term variation or the importance of easy digestible prey items. Stable isotope analysis (SIA) is an alternative and complementary approach to SA and was used in the present study to investigate the trophic position of this new invader. We analyzed stable isotope signatures of carbon and nitrogen from the red king crab and benthic community, including potential prey taxa. We tested for spatial, temporal and body size variation in obtained signatures. To gain more detailed information on local feeding behavior and prey preferences, the results were compared to data obtained by SA from the same area. Our results from SIA indicate a different signature in the autumn season, towards a more pelagic carbon source and a higher trophic position. This was likely due to the crabs feeding at deeper localities instead of an active choice of different prey. A difference in king crab size groups was not detected by SI signatures, but stomachs indicated slight differences and need further analysis. The crabs diet found in the stomachs was reflected in the SI signatures and differences in diet were mostly related to different feeding areas, where crabs, as expected from opportunists, probably feed on available prey. We calculated a trophic level (TL) of 3, which was comparable with the TL estimated for red king crabs in the western Bering Sea (see Aydin et al. 2002). Possible competitors with similar isotopic signatures were other native crabs, predatory asteroids and molluscs, the deep water shrimp and the bottom feeding plaice. Main diet items were bivalves and polychaetes, SI signatures also indicated sea urchins and brittle stars. Small infauna was the most frequent occurring prey in stomachs. This study provides insight into the trophic structure of an invaded fjord, as well as the variation in foraging behavior of crabs. The red king crab is a cold water species and with increased shipping in the north, the risk for a future spread towards the north is real. The area of study, Porsangerfjord, has year around cold-bottom temperatures in its inner part and might serve as a reference area for future impact studies on high latitude systems.

UIT THE ARCTIC UNIVERSITY OF NORWAY

Role of the invasive red king crab (*Paralithodes camtschaticus*) in the benthic food web

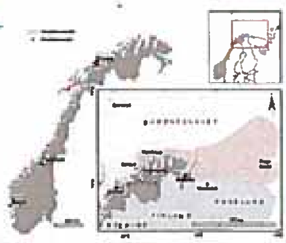
Results from stable isotopes and stomach analysis



Mona M. Fuhrmann

Background

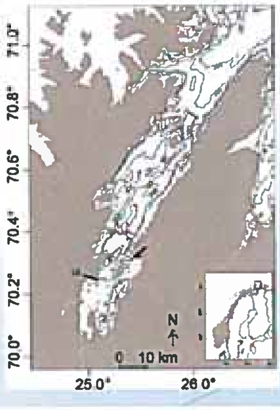
- Diet
  - Generalist, opportunistic[1,2,3,4]
- Impact on benthos:
  - Effects on benthic animals and fish through direct and egg predation[1,5]
  - Altering benthic communities and sediments[6]



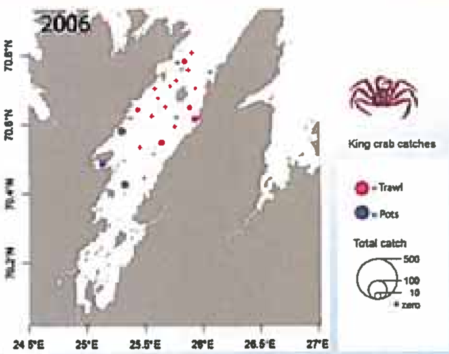
Study aims

- Trophic position in the benthic food web
- Competition with other predators
- Trophic niche
  - Resource use
  - Variability in feeding habits
  - Comparison between stable isotope and stomach analysis

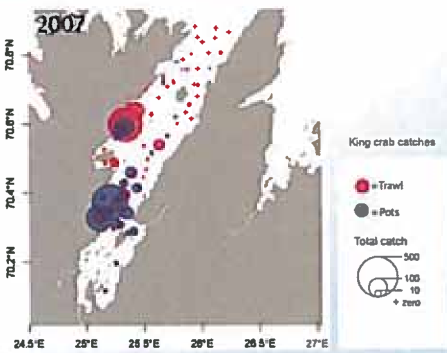
Study area: Porsangerfjord



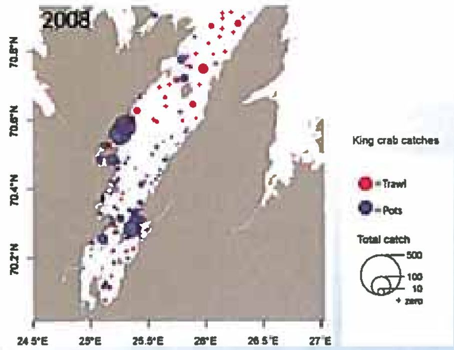
Study area: Porsangerfjord



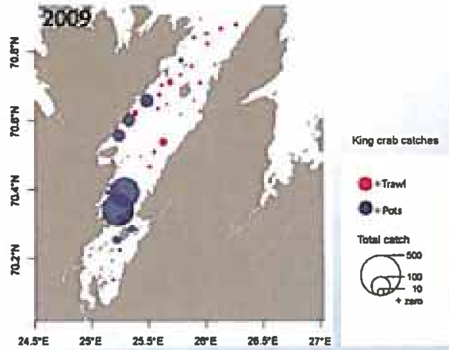
Study area: Porsangerfjord



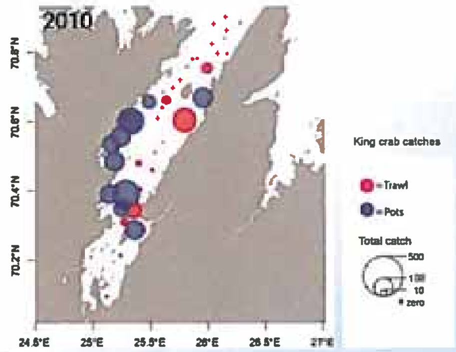
Study area: Porsangerfjord



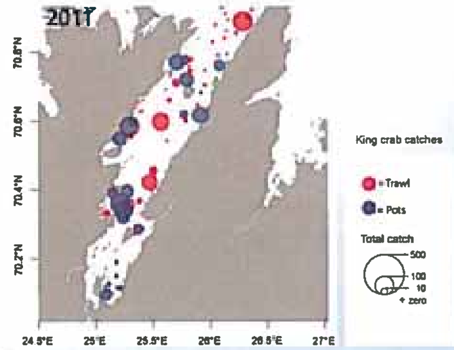
Study area: Porsangerfjord



Study area: Porsangerfjord



Study area: Porsangerfjord



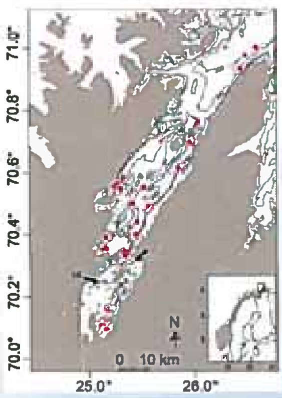
Study area: Porsangerfjord

Courtesy of Einar Nilssen

Sampling

King crabs
- Stable isotopes
- Stomachs

Benthos
- Stable isotopes



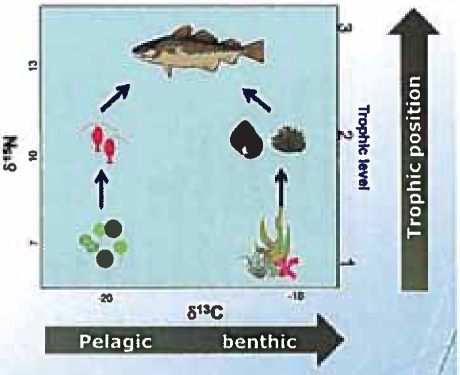
Methods – Stable isotopes

$^{15}N/^{14}N_{sample}$ / $^{15}N/^{14}N_{standard}$

$\delta^{15}N$

$^{13}C/^{12}C_{sample}$/$^{13}C/^{12}C_{standard}$

$\delta^{13}C$



Methods

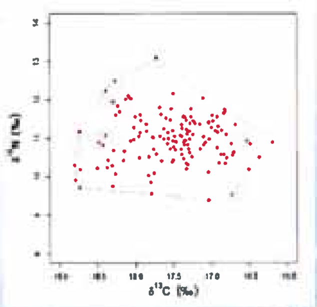
Stable isotope analysis (SIA)	Stomach analyses (SA)
+ Long term integration	- Snapshot of diet
+ Less invasive	- Invasive
+ Less taxonomic expertise	- Taxonomic expertise
	- Bias towards slow digestable prey
- No detailed prey information	
- Prey sampling	+ Detailed diet information
- Different fractionation	+ Proportion estimates

The "isotopic niche"

- Tool to investigate the ecological niche
- Area with isotopic values (Newsome et al. 2007)
- Different niche width metrics

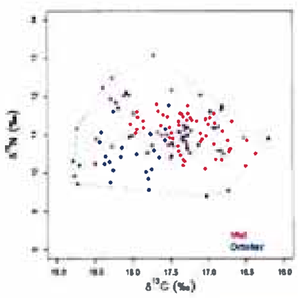
- Niche width
  - Wide prey range
  - Habitat use
  - Niche shifts
  - Specialisation of individuals

- Isotopic composition of prey
- Outliers

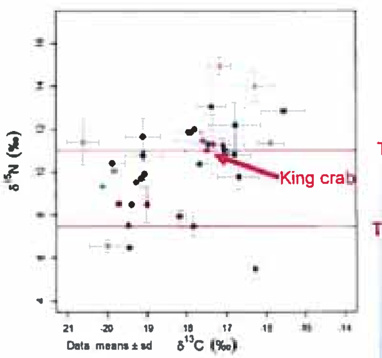


"Isotopic niche" of the red king crab in Porsangerfjord

Results – Seasonal differences



Results – Trophic position



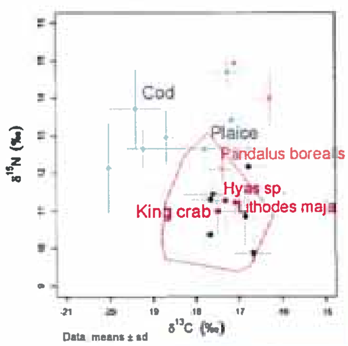
Trophic level

TL = (δ15Ncons − δ15Nbase)/Δδ15N + TLbase

Δδ15N = 3.4‰ (Post 2002)

- Bivalvia
- Cnidaria
- Crabs
- Echinodermata
- Gastropoda
- Zooplankton
- Polychaeta
- Shrimps
- Other

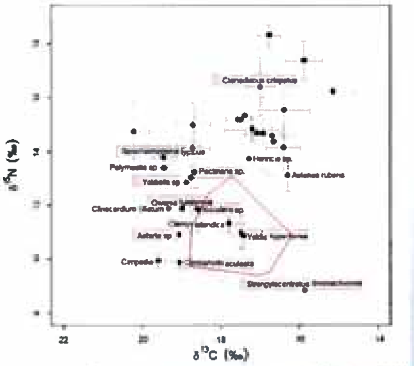
Results – Trophic position Competition



«isotopic niche» of King crab

- Crabs
- Echinodermata
- Gastropoda
- Shrimps
- Fish

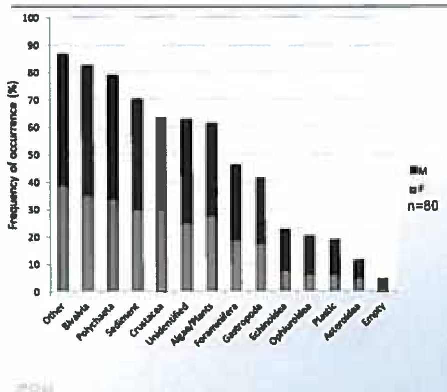
Results – Diet Stable isotopes

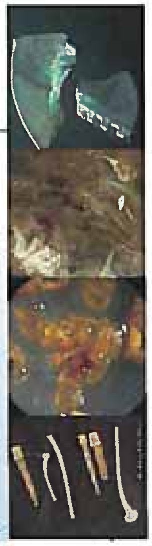


Data: means ± sd

Prey: $\delta^{15}N$ + 3.4‰, $\delta^{13}C$ + 0.4‰

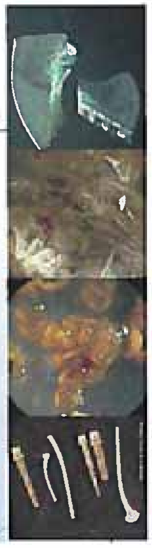
Results – Diet Stomach analysis



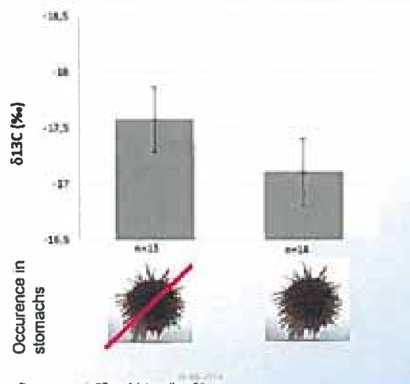


Results – Diet Stomach analysis

- Soft bottom species in Porsanger most important
- Frequency of occurence in stomachs
  - Infauna: 93%
  - Epifauna: 84%
- Generalistic feeding
- Importance for impact on the benthic community



Results – Diet combining SIA and SA



Data: means ± 95 conf interval n=31

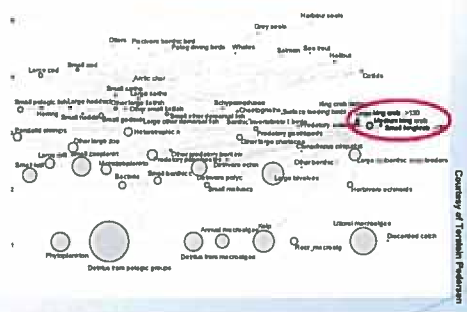
- Example: Predation on sea urchins
- 23% preyed on on sea urchins in Porsanger
- → reflects in isotopic signature
- → Availability of sea urchins

Conclusions

- The king crab feeds at trophic level 3
- Possible competition with other crabs, benthic fish and predatory echinoderms
- Probably large trophic niche
  - Opportunistic, generalistic
  - Soft bottom species are the main type of prey
  - Variation in feeding habits: seasonal
- Combined SI and SIA can be a powerful tool to investigate the trophic niche of a species

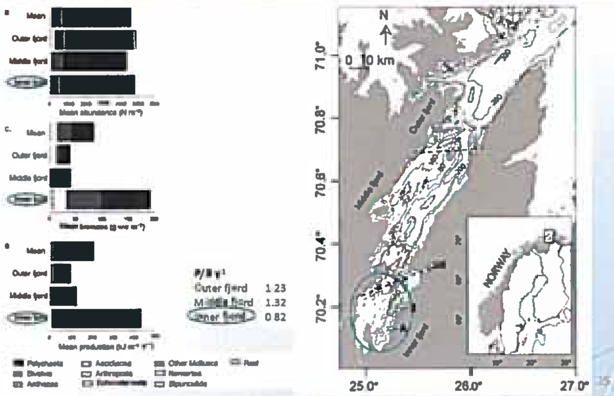
How does predation affect energy flow in the ecosystem?

Diet data → Ecopath with Ecosim ← B, P/B, catches, EE



Courtesy of Torstein Pedersen

Macrofaunal production in Porsangerfjord



Data from 2010

Thank you !!!

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Knowledge gaps

- How does the kk affect higher trophic levels and energy flow in the system?
- Ecopath modelling
- Biomass and production estimates in benthic surveys
- Consumption, energetic values

Changes of soft bottom fauna (1994-2012) in Varangerfjorden, northern Norway, following the invasion of the red king crab (*Paralithodes camtschaticus*)

Eivind Oug[1)], Sabine K.J. Cochrane[2)], Jan H. Sundet[3)]

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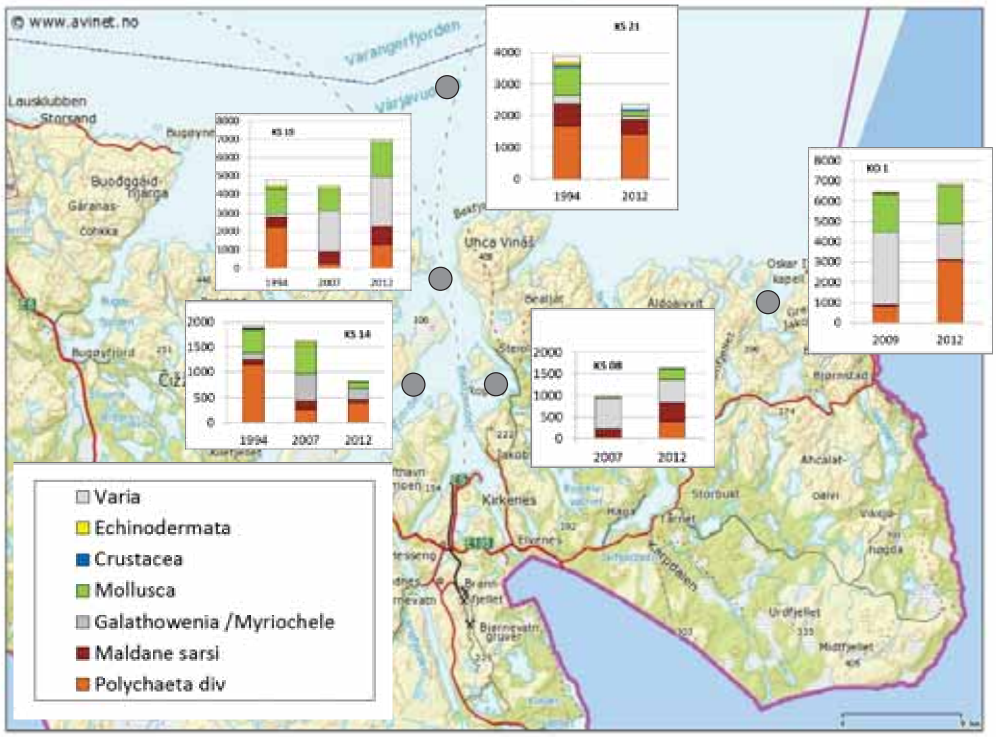
2) Akvaplan-niva, FRAM – High North Research Centre for Climate and the Environment, Tromsø, Norway
3) Institute of Marine Research, Tromsø, Norway

The red king crab (*Paralithodes camtschaticus*) was introduced from the northern Pacific to the Russian Murman coast during the 1960s and 1970s. The crab invaded NE Norwegian coastal waters in the early 1990s. The stock expanded rapidly in the latter half of the 1990s and the crab has now become well established in northern fjords. Since 2002 there has been a quota-regulated commercial fishery within a management area covering fjords and coastal waters in eastern and central parts of Finnmark county. The crab is an active predator on benthic fauna especially feeding in soft-bottom environments. It is hypothesised that the predation may lead to reduced abundances of prey species which in turn may have implications for the ecosystem functioning and natural nutrient regeneration processes in the sediments. The present studies were carried out in 2007-2009 and 2012 in the Varanger fjord area close to the Russian border. For infauna, quantitative data from 1994 were used as a basis to compare faunal composition before and after the crab became abundant in the area. In 2007-2009 both epifauna (animals living on the sediment surface) and infauna (animals living in the sediments) had become markedly reduced in crab-invaded areas (190-260 m). It appeared that echinoderms, non-moving burrowing and tube-dwelling bristle worms (polychaetes), and most bivalves were reduced, whereas some small-sized polychaetes and small bivalves had increased. The increasing polychaetes were small thread-thin tube-building species (*Galathowenia / Myriochele*) which are assumed to be of low nutritional value for the king crab. *In situ* sediment profile imagery (SPI) was used to examine sediment structure and biogenic activity. At several locations, the sediment habitat quality was degraded due to hypoxic conditions and low biological activity below surface layers. It is suggested that the crab had removed organisms performing important functions such as bio-irrigation and sediment reworking. Five localities were revisited in 2012. The composition of the fauna was largely as in 2007-2009, but in several localities a few species of small polychaetes had increased, possibly indicating a moderate improvement of the ecosystem status (see figure). At a locality in the main fjord (380 m) the small tube-building species was far less abundant. At this locality the fauna was reduced both in species numbers, abundances and diversity compared to 1994 (figure). In more shallow water (10-90 m) in the inner part of the Varanger fjord, the fauna was less changed from 1994 to 2008. Several echinoderms and larger specimens of various other species had been reduced, but the general species composition was largely as in 1994. The species changes have been compared with data from a simultaneously established (1994) and revisited (2008) station transect (10-90 m) in another north Norwegian fjord which has not yet been invaded by the crab. It is assumed that less crab predation in the inner Varanger fjord may be due to lower crab densities and coarse sediments in shallow areas with stones and calcareous algae that offer hiding places for prey organisms. In the deep fjords, the crab most likely overexploited the food resources in the first phase of the invasion. It may be speculated whether the moderate improvement of the fauna is sign of a gradual adjustment between the king crab and the populations of prey species in the fjords.



Abundances (ind m^{-2}) of soft bottom fauna at five stations in the Varanger area in 1994 (before main crab invasion) and in 2007-2009 and 2012.

Workshop king and snow crabs in the Barents Sea
Tromsø 11-12 March 2014

Changes of soft bottom fauna (1994-2012) in Varangerfjorden, northern Norway, following the invasion of the red king crab (*Paralithodes camtschaticus*)

Eivind Oug[1], Sabine K J Cochrane[2], Jan H Sundet[3]

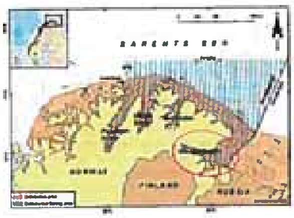
1) [illegible] Water Research, Oslo/Grimstad, Norway
2) [illegible] Centre for Climate and the Environment, Tromsø, Norway
3) [illegible] Tromsø, Norway

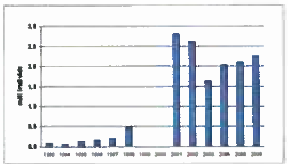
Background

- First observed in Norwegian waters 1977
- Invaded Varangerfjord area during 1990s
- Basis for important local commercial fishery
- Active predator on benthic fauna
  - Adult crabs stay and feed in deep soft-bottom areas (100-300 m) during most of the year
  - Moves actively for tracking epifauna
  - Digs into the sediment for catching infauna
- Insufficient knowledge on ecosystem effects
  - studies from Russian waters show reductions of species abundances and biomass

Norwegian management policy with two contrasting goals

- As a resource:
  - East of North Cape: quota-regulated commercial fishery aimed at sustainable yield
- As an alien species:
  - West of North Cape: measures to keep the crab stock at a minimum level and prevent further spreading



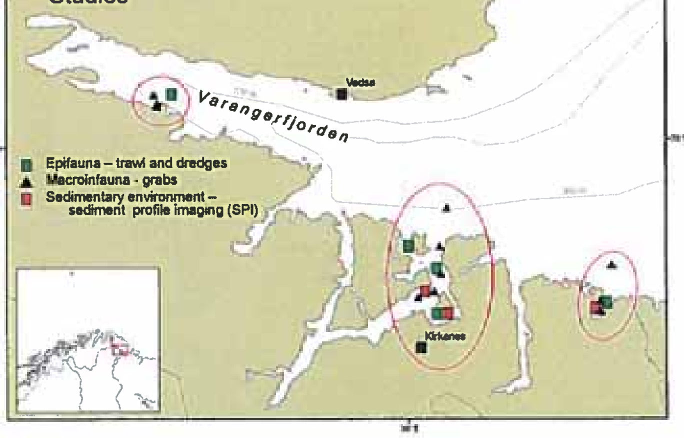


Stock estimates Varanger 1993-2006

Hypotheses: impacts of king crab on soft sediments

- Direct effects on benthic fauna:
  - Reduction in abundances and biomass
  - Altered faunal composition and structure
- Implications for:
  - Community functioning
    - Trophic relationships
    - Burrowing and sediment activity
  - Sediment conditions and biogeochemical processes
- Present studies:
  - Epifauna
  - Macroinfauna – pre- and post crab invasion
  - Sedimentary structure

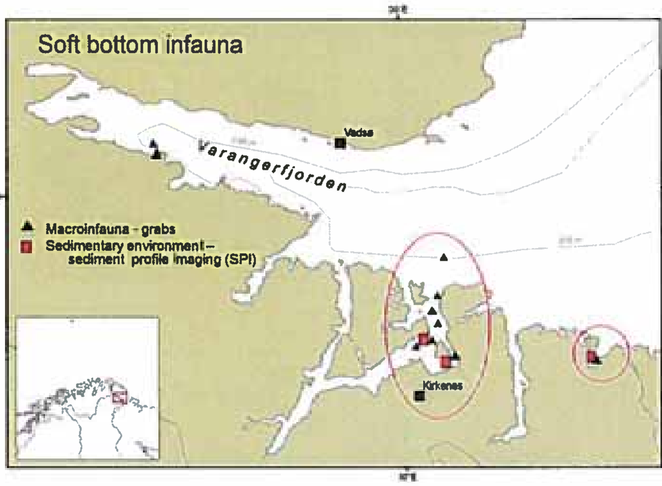
Studies



Epifauna

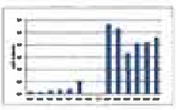
Catch in crab trawl

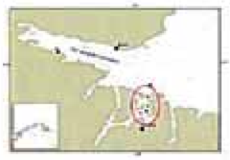
	70 m	200 m	260 m
Porifera	++	++	++
Polychaeta	11	[illegible]	9
Mollusca	8	2	7
Crustacea	2	-	-
Echinodermata	4	3	4
Varia	6	2	4
Sum species	29	16	24
Specimens	58	60	57



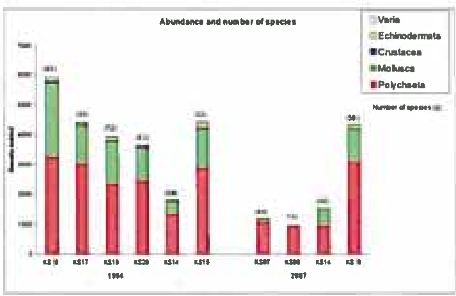
Infauna Bøkfjorden

Before and after crab invasion


Estimated crab stock



- 1994 6 stations (0.4 m²)
- 2007 4 stations (0.4 m²)
- 1 mm screens
- Depth 55 - 268 m



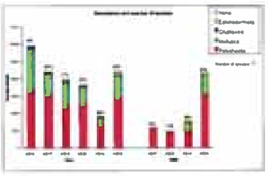
Infauna Bøkfjorden

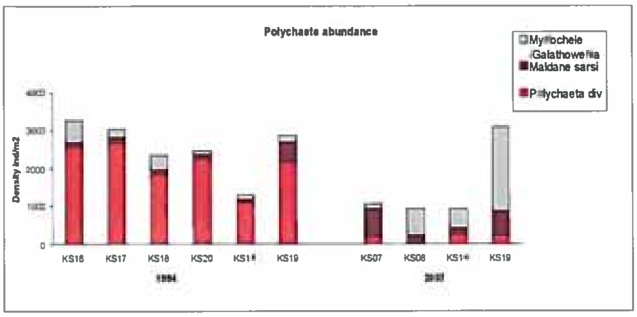
Per cent change for dominant species 1994 -2007, deep stations (198-264 m)

	Mean density ind. m^{2} 1994	Mean density ind. m^{2} 2007	Change (%) 1994-2007
Polychaeta			
Lumbrineris mixochaeta	390	73	-81
Scoloplos Leitoscoloplos	138	4	-97
Prionospio cirrifera	51	-	-100
Spiophanes kroeyeri	73	4	-95
Chaetozone setosa	232	-	-100
Euclymenidae (incl. *Praxillella*)	332	25	-92
Maldane sarsi	198	416	110
Galathowenia oculata	223	915	319
Myriochele olgae	28	418	1396
Laphania boecki	431	1	-100
Proclea malmgreni	82	1	-98
Bivalvia			
Yoldiella frigida fraternal	263	168	-36
Yoldiella lenticula	277	19	-93
Dacrydium vitreum	73	33	-56
Thyasira equalis	155	325	109
Thyasira pygmaea	434	224	-48
Sipunculida			
Golfingia cf minuta	75	21	-72
Echinodermata			
Ctenodiscus crispatus	13	-	-100

Infauna Bøkfjorden

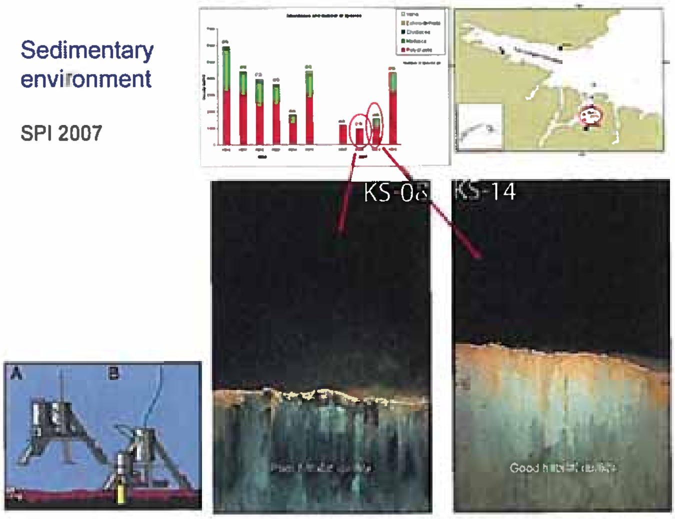
Abundance of Polychaeta: "oweniids" and *Maldane sarsi*

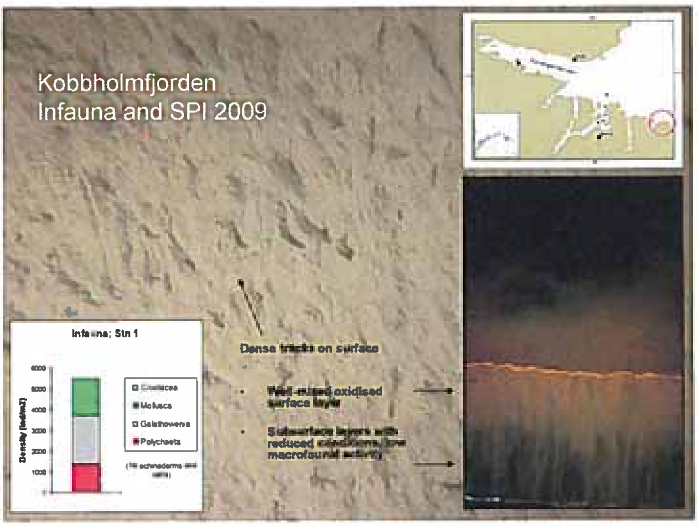




Sedimentary environment

SPI 2007

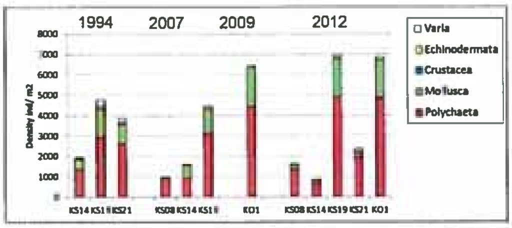




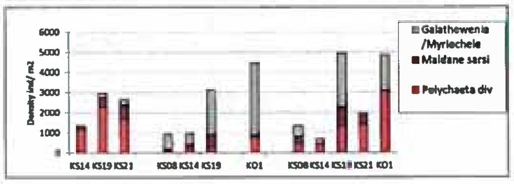
Infauna: faunal changes on five stations 1994-2012

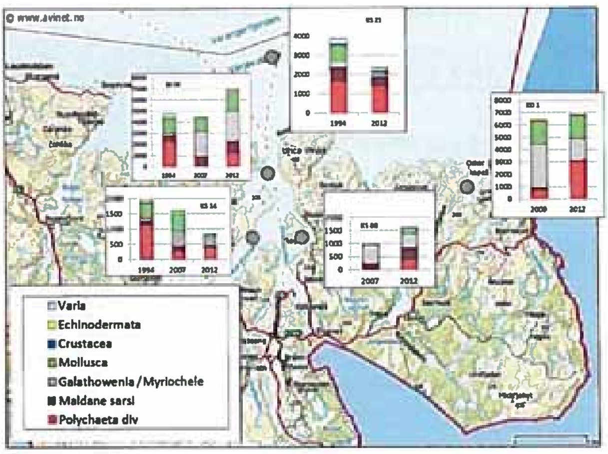
Infauna – revisited stations 1994 - 2012

All species

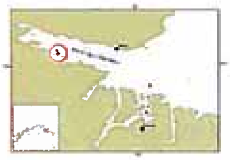


Polychaeta



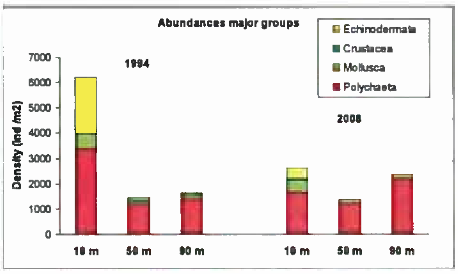


Infauna shallow and moderate depths

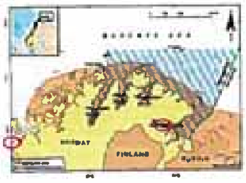


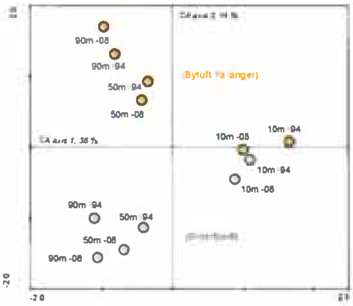
Before and after crab invasion

- 3 stations (0.4 m²) sampled 1994 and 2008
- Depth gradient 10 - 90 m



Faunal changes 1994 -2008





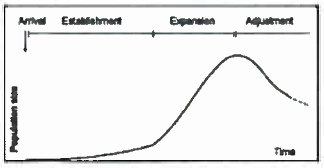
- Correspondence analysis,
  50 most abundant species

Summary

- Markedly reduced fauna in deep soft bottom areas after crab invasion
  - Epifauna (sea stars, brittle stars, cnidarians)
  - Infauna (polychaetes, bivalves)
- Strong dominance of a few species of tube-building polychaetes (bristle worms) in deep fjords
- Moderate faunal recovery in 2012
  - Reduced crab density
- Less changes in shallow areas
  - Less crab predation (?)
    - Low crab densities
  - Coarser sediments with stones and calcareous algae – more hiding places for prey organisms (?)

Crab population and recovery of soft bottom fauna

General development pattern of alien species:



From Reise et al. (2006)

'adjustment' phase

Probable causes

-Overexploitation of resources
-Predators, competitors, parasites increase
-Evolutionary responses

Speculation:

Do we now see a gradual adjustment between the king crab and the populations of prey species in the fjords?

Conclusions – impacts on soft bottom systems

- Markedly reduced fauna
  - Epifauna (sea stars, brittle stars, cnidarians)
  - Infauna (polychaetes, bivalves)

⇩

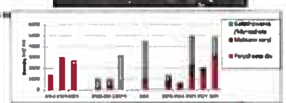
- Loss of structural and functional diversity
  - Reduced number of species
  - Increased community "dominance"
    - Some few thin tube-building polychaetes and small bivalves increase

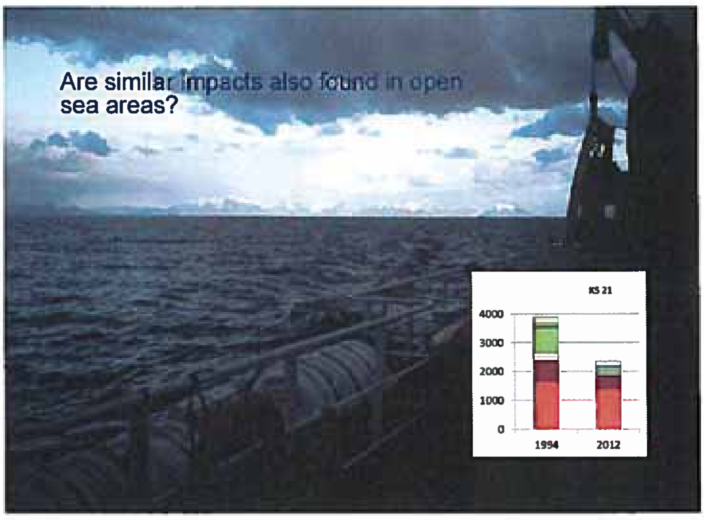
⇩

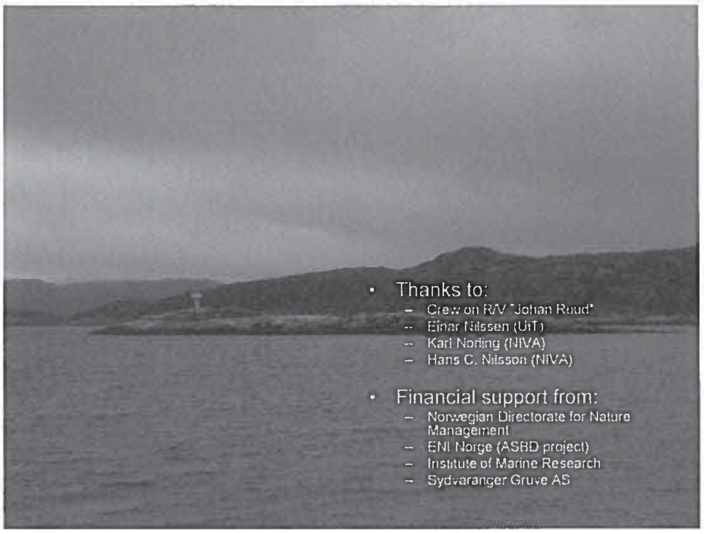
- Fundamental changes in sediment integrity
  - Stronger layering
  - Progress towards anoxia in deeper layers
    - Depressed bioturbation (sediment mixing, irrigation etc.)
    - Affecting biogeochemical processes decomposition, nutrient renewal

⇩

- Essential knowledge
  - Soft bottom ecosystem functioning and production






Thanks to:
– Crew on R/V "Johan Ruud"
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– Hans C. Nilsson (NIVA)
Financial support from:
– Norwegian Directorate for Nature Management
– ENI Norge (ASBD project)
– Institute of Marine Research
– Sydvaranger Gruve AS

The timing, abundance and distribution of red king crab larvae within a north Norwegian fjord

Helena Kling Michelsen

One commercially and ecologically important species in Norwegian waters is the red king crab (*Paralithodes camtschaticus*). This is an alien species and is under extensive investigation. To obtain the best management strategies of the species there is a need to understand all aspects of their life history. Research has so far focused on the adult population and their potential effects on benthic communities and spread along the coast. Limited research has been done on the larval and juvenile stages, which are important for recruitment and could have considerable potential to spread with ocean currents. Therefore, to help elucidate some of the questions surrounding the larval stages, timing, abundance and distribution of king crab larvae is being investigated in the Porsanger Fjord, Norway. Larvae were sampled at six stations ranging from the outer to the inner part of the fjord in February, March, April and June 2013 by pulling a WP2 net from the sea floor to the surface. Preliminary results indicate that larval release starts in February (average 5 zoea/50 m^3) with a peak in April (average 13 zoea/50 m^3) and larvae settling on the sea floor around June. Larval density was highest within the shallow and enclosed station in Veinesbukta. Other crab larvae were also identified and results indicate that the king crab is the earliest spawner with larvae dominating in February and March, while *Pagurus* sp. dominate in April and *Hyas* sp. dominate in June. Future work will concentrate on the vertical distribution of king crab larvae through a 24 hour period, gut fluorescence of field caught crab larvae to see if they display diel variation in feeding and deployment of artificial substrates for collection of newly settled crabs.

UiT THE ARCTIC UNIVERSITY OF NORWAY

The timing, abundance and distribution of red king crab larvae within a north-Norwegian fjord

PhD project by Helena Kling Michelsen

Supervisors: Camilla Svensen, Marit Reigstad, Einar Nilssen and Torstein Pedersen

Overview

- Background
- Objectives
- Current work
- Preliminary results
- Further work

Background - meroplankton

- Meroplankton – pelagic larvae of benthic organisms
- Released at different times during the year
- Display different feeding modes
- Drift freely in the pelagic
- The life stage is important for recruitment success

Background – red king crab

- Zoea released in the pelagic during early spring
- Four zoeal stages, one glaucothoe and one megalopae (juvenile)
- Duration in the pelagic is temperature and food dependent
- Positively phototactic
- Limited research on the larval stages within Norwegian waters
  - Models on larval drift

Objectives

i. The timing and distribution (vertical and spatial) of red king crab larvae within the Porsanger Fjord, Norway

- Based on literature, zoea are released in the pelagic during early spring and stay in the pelagic 2-3 months (release in March or April and settling in May or June)
- Attempt to capture newly settled crabs
- We expect there to be areas with higher larval concentration within the fjord (spawning areas)
- We expect to find the larvae vertically distributed in the upper water layers (positively phototactic)

Objectives

ii. Grazing and nutrition of red king crab larvae

- Gutfluorecence on zoea caught in the field (diel variation)
- Feacal pellet production experiments
- Predation experiments

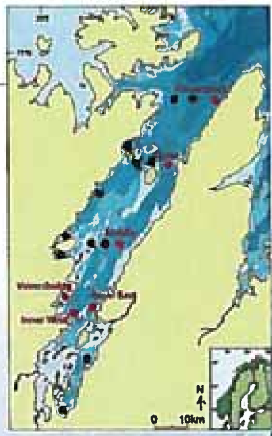
iii. Evaluate methods for capturing king crab zoea (WP2, WP3 and different mesh sizes)

Porsanger Fjord, Norway

- Open fjord with a deep sill
- Inner part is ice covered during winter and contains two deep-water basins with arctic species
- One of the most investigated fjords in northern Norway
  - Fjord ecology (EPIGRAPH)
  - Effects climate change on benthic communities
  - Marine maps (NGU)
  - marine environmental data/Havmiljø data (UIT)

Current work

- Sampled six stations through one year: Feb, March, April, June, Aug, Oct, Jan (marked red)
- More extensive survey in April (marked black)
- WP2 net with 180 µm mesh from seafloor to surface
- Total of 61 samples collected
- CTD taken at each station



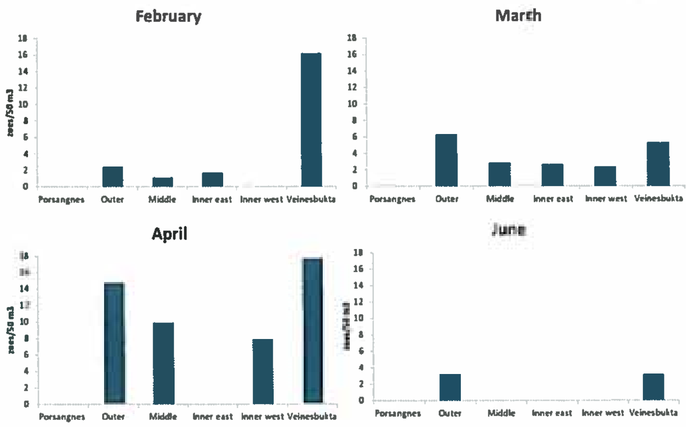
Red = fixed year stations
Black = April stations

Lab analysis

- Zooplankton are identified and enumerated:
  - Holoplankton are identified to order
  - Meroplankton are identified to the lowest level
  - Crab zoea are identified to genus or species
  - Red king crab zoea are identified to zoeal stage
- Zoea are photographed and carapace length is measured (eye notch to back of carapace)

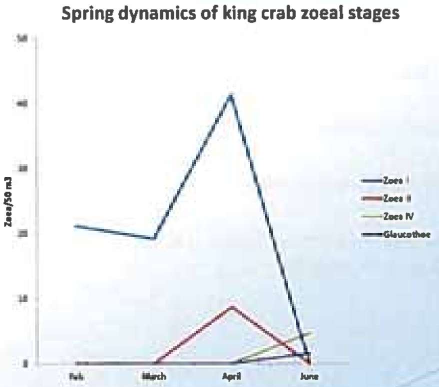
Preliminary results

Abundance of king crab zoea at each station during spring 2013



Preliminary results

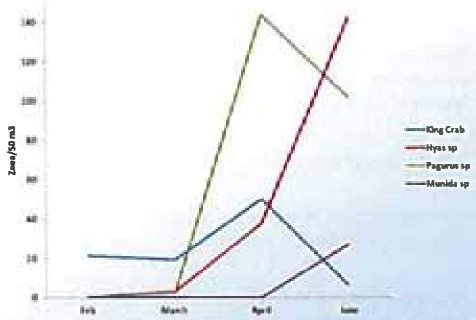
Spring dynamics of king crab zoeal stages



Zoea from all stations pooled

Preliminary results

Spring dynamics of crab zoea



Zoea from all stations pooled

Plans for this spring

- Vertical distribution through a 24 hour period
- Gutfluorecence and some experiments
- Test a WP2 net with a 180µm mesh and a WP3 net with a 300µm
- Deploy artificial substrates for collection of early benthic stages

Artificial substrate (Blau and Byersdorfer 1994)

WP3 (300 µm)

Thank you for listening!

Megalop of snow crab in the Kara Sea

Konstantin Sokolov

The presentation of Konstantin Sokolov was dedicated to the spatial distribution of larvaes (megalopa) as well as adult specimens of the snow crab *Chionoecetes opilio* caught in the Kara Sea in October 2013. Authors of presentation are A. Orlova, A. Dolgov and K. Sokolov.

All data were collected in October 2013 in the Kara Sea during the Russian survey for demersal fish. A standard Russian trawl net (diameter 50 cm, mesh size 564 µm) was used for sampling larvae's of the snow crab. Samples were taken in the near bottom layer. Gear was attached to the upper panel of the bottom trawl.

At total 22 samples were collected, larvae (megalopa) of *Chionoecetes opilio* occurred in 10 samples (totally - 41 individuals).

It was shown that abundance of snow crab larvae varied from 2 to 40 individuals in 1000 m^3. Most dense concentrations were found in the west-southern and west-northern parts of the Kara Sea.

All larvae's of *Chionoecetes opilio* were observed at near bottom temperature about 0° and minus 1° C.

There were also matured as well as immature specimens sampled in the SE part of the Kara Sea. Catches constituted between 100 and 3000 specimens per 30' bottom trawling.

There were some peculiarities of the spatial distribution of the red king crab and snow crab in the Barents Sea shown and some information concerning future fishery regulation system was presented.

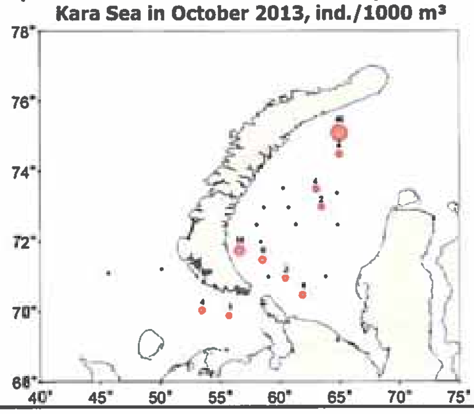
Also it was shown that indexes of the biomass of commercial males of the snow crab in the Barents Sea in 2005-2013 show continuous rapid increasing of the commercial stock in numbers.

Chionoecetes opilio в in the Kara Sea in October 2013

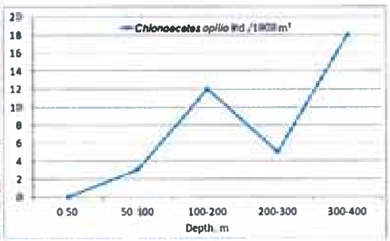
(Anna Orlova, Andrey Dolgov, Konstantin Sokolov)

- Data were collected in October 2013 in the Kara Sea.
- The sampling gear – standard Russian trawl net (diameter 50 cm, mesh size 564 µm) in near bottom layer.
- 22 samples were collected, larvae (megalopa) of *Chionoecetes opilio* occurred in 10 samples (totally - 41 individuals).
- Abundance of snow crab larvae calculated as individuals in 1000 m³.

Spatial distribution of *Chionoecetes opilio* в in the Kara Sea in October 2013, ind./1000 m³

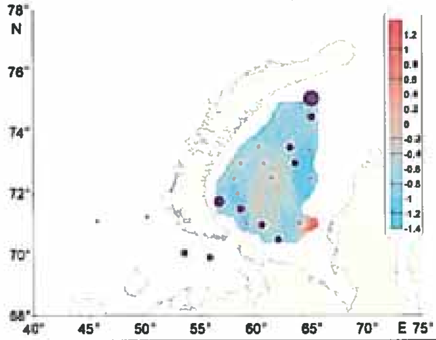


Occurrence of *Chionoecetes opilio* a on various depth range in the Kara Sea in October 2013

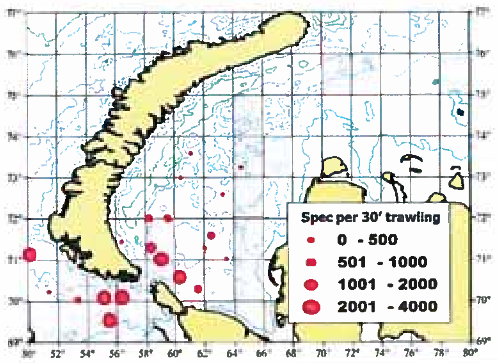


Note – only 1 sample with Ch.opilio was collected on depth 300-400 m

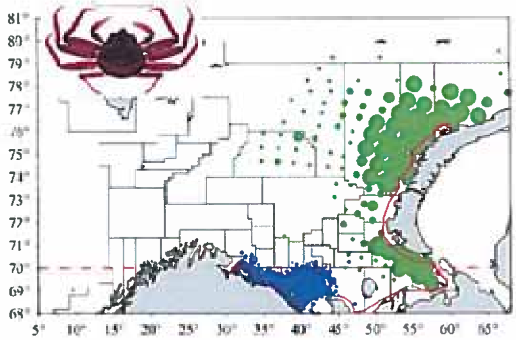
Distribution of snow crab larvae in relation to near bottom temperature in the Kara Sea in October 2013, t°



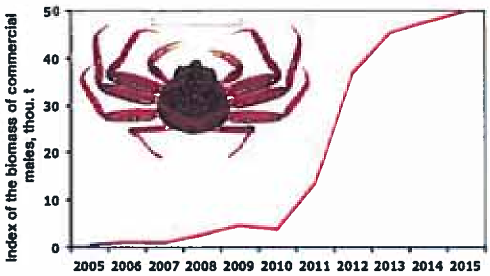
Catches of snow crab in the SE part of the Barents Sea and in the Kara Sea in October 2013



Spatial distribution of the red king crab (blue) and snow crab (green) in the Barents Sea

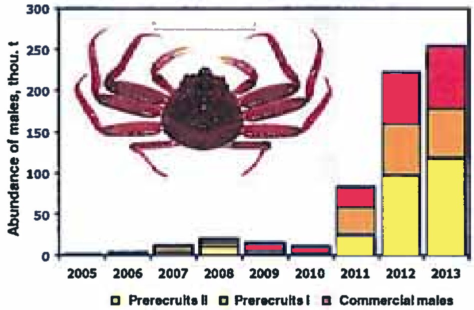


Indexes of the biomass of commercial males of the snow crab in the Barents Sea in 2005-2013



2014 – Year of commercial fishery opening!

Abundance dynamics of the snow crab in the Barents Sea in 2005-2013



Effects of EBP predation, competition & habitat on the life history of red king crabs (*Paralithodes camtschaticus*)

Felicia Keulder & Gro I. van der Meeren, Institute of Marine Research

Previous studies of the red king crabs (RKC) in the Barents Sea have studied the larval phase, the distribution of the young crabs as well as recruitment, dispersal and stock dynamics in the mature RKCs. Prediction for ecosystem impact as well as dispersal potential is based on physical tolerance, ecology and environmental factors. However, one life stage, the life changing events during settlement has mostly been omitted. What impacts do predation, competition and habitat during the early benthic (postlarval) phase have on life history parameters such as survival, mortality and recruitment of the RKC population in the Barents Sea? Equally, what impacts will invasions of settling and newly settled postlarvae RKC have on the locations where this happens?

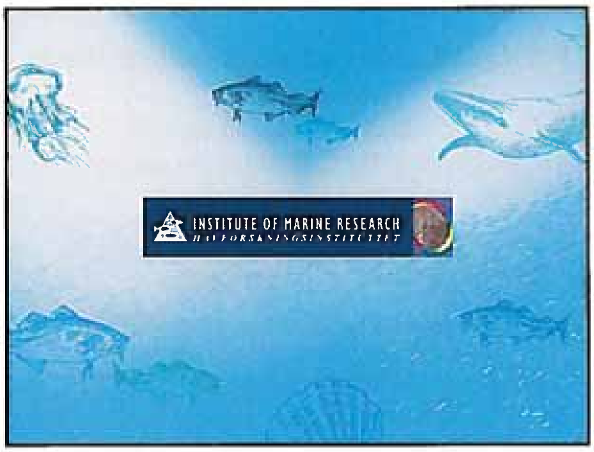
It is argued that RKC postlarvae (glaucothoe) are very cryptic during the early benthic stages since they find refuge in highly complex habitat. However success in finding suitable habitat can be disturbed by the presence of predators, which could reduce survival. Mapping of potential habitat outside the present range of the RKC could provide a map for surveillance of further dispersal as well as function as data for modelling of potential dispersal.

Testing the survival success of these early settling postlarvae may be done in controlled mesocosms experiments, by introducing predation pressure and competition with species most likely to interact with settling postlarvae in Finnmark, Troms and even further west and south of the previous range of RKC in Norway. Control experiments should be done in areas already invaded by RKC and where settlement takes place.

What is the impact of predation on early recruitment of RKC populations in long-term invaded (well established) vs recently invaded and predicted invasion areas in Norwegian waters? Will the introduction of the postlarval RKC result in cascade effects on their role as a new and plentiful prey source for native predators? Prey selection experiment are suggested by introducing each predator species in to a mesocosm (simulating the natural habitat) with its current preferred prey (choose a mollusc, echinoderm and a crustacean prey species) and RKC present in equal densities.

What species may experience reduced predation by the identified predators due to the presence or availability of early stage RKC which resulted in predators alternating feeding preference to RKC (and possibly exerting high predation on EBP RKC)?

Ultimately, we question what impact does predation, competition and limited habitat during the early benthic phase have on life history parameters such as survival, mortality and recruitment of the RKC population in the Barents Sea and how does this translate into estimates/assumptions used in stock assessment models? What implications do these altered species interactions have for important coastal fisheries resources and ecosystem species? Are there biological barriers along the coast of mainland Norway that may block RKC dispersal? These are questions in need of answers and therefore in need of research.



Effects of early benthic phase predation and competition and habitat on the life history of red king crab in Norwegian waters

Felicia Keulder & Gro I. van der Meeren

The Workshop on king-and snow crabs in the Barents Sea
Quality Hotel Saga, Tromso, March 11th 2014

INSTITUTE OF MARINE RESEARCH
HAVFORSKNINGSINSTITUTTET

Background

Previous studies focused on:

- Impacts and threats on native fauna
- Fisheries and stock assessment
- Recruitment modelling
- Dispersal and dispersal potential for larvae and mature crabs
- Tolerance to physical factors
- Genetics

Background, cont.

No studies has focused on the post-larvae phase

- Habitat requirements
- Settling behaviour
- Early benthic life:
  - Predators and predation pressure
  - Prey
  - Competition

Key research question

Can early phase predation limit RKC recruitment and dispersal success?

- *What impact will predation of post-larvae have on success of RKC-recruitment?*
- *What species interactions or cascade effects are expected to result as effects of predation on early stage RKC recruitments?*

Availability of settling substrate And nursery grounds for settling RKC

Mapping the potential settling areas outside the present dispersal area

Mapping the native species living in the potential settling areas outside the present dispersal area

What is the impact of predation on early recruitment of RKC populations in

well established vs **recently invaded**
and
predicted invasion areas?

What are the natural predators of early benthic phase RKC in Norwegian waters?

What is the level of predation exerted by each predator on early benthic phase RKC under controlled conditions?

What species interactions or cascade effects are expected
due to predation on
early phase RKC recruitment success
in future invasion areas?

What species may experience reduced predation due to the presence of early stage RKC ?

What species may experience increased competition (how much of an increase) due to the occurrence of ecologically compatible or similar sized EBP RKC?

Research, Field

Mapping habitat and biodiversity

Monitoring seasonal changes

Monitoring RKC settling and post-larvae distribution

Long-time monitoring for change in biodiversity

Testing reliability of experimental results

Research, Controlled experiments

Post-larval RKC conditioning

Learning abilities and innate behaviours

Post-larval RKC prey selection

Potential predators affinity for post-larval RKC vs native prey

Testing reliability of experimental results

Benefits of post-larvae studies

Ecosystem effects,
modelling

Better predictions on future dispersal potential

Better predictions on vulnerability of native competitors, predators and prey

Better management advice

Thank you

Presentations given under the theme;

Life history parameters of the king- and snow crab

Ann Merete Hjelset, Institute of Marine Research, Tromsø

Review of life history parameters of the red king crab in Norwegian waters

Sten Ivar Siikavuopio, NOFIMA

Temperature effects on feed intake, growth, metabolism and survival of red king crab (*Paralithodes camtschaticus*)

Nina Mikkelsen, UiT/Torstein Pedersen, UiT

Invasive red king crabs feed on both capelin and their eggs

Jan H. Sundet, Institute of Marine Research, Tromsø

Status snow crab in the Barents Sea

Geir Dahle, Institute of Marine Research, Bergen

Population genetics – snow crab. Genetic differentiation around the Arctic Ocean?

Ann-Lisbeth Agnalt, Institute of Marine Research, Bergen

Presenting potential spreading of snow crab larvae in the Barents Sea

A review of life history parameters in the red king crab in Norwegian waters

Ann Merete Hjelset, Jan H. Sundet and Einar M. Nilssen

The life-history theory explains the broad feature of a life-cycle, how fast the organism will grow in size and numbers, when it will mature, how long it will live, how many times it will give birth and how many offspring's it will have through a life span. Here we give a review on the knowledge we have on life history parameters in the red king crab in Norwegian waters.

Size at sexual maturity is a key life history parameter, since it describes when individuals start contributing to the reproduction in the population. It is important to have knowledge about this size in newly exploited populations, because some individuals should be protected from the fishery, and have the opportunity to reproduce before they reach legal size, set for the fishery. For female red king crabs in our waters, this is especially relevant after introduction of a female quota in 2008. Three time periods was defined; a period with a restricted research fishery initiated in 1994 and ended in 2001.Then a commercial fishery was established in 2002. From 2008, Norway established its own management regime and that also included that small quotas on female crabs was added to the male quota. Minimum legal size is set for both sexes. Our study shows that females mature around 107-113 mm carapace length in the period 1994 to 2013, and there is a geographical difference in size at maturity, with increasing size of maturity westwards. Females in our waters mature at larger size compared to females in native areas. Fishing pressure on large males does not yet seem to affect female size at sexual maturity in the total stock, but new analysis shows indications on a decrease in Varangerfjorden, but not further west.

For the male red king crab there are three levels of size at maturity. The first is the physiological size at maturity, which represents the internal gonadal development. The second is the morphological size at maturity, linked to allometric growth, and at last, the most important size of maturity is the functional size at maturity or behavioral size at maturity which is the actual size where the individual starts to reproduce. Other studies show that, in the wild the average size of mating males was 32 – 42 mm larger than their female partner. This has not been examined in Norwegian waters, but according to the literature, the minimum legal size is now equivalent to the functional maturity size for male red king crab.

To examine the size span and the maximum size in the males and females, a 95th percentile value of carapace length was estimated. All data pooled for the four main fjords, showed an increase in maximum size in the first period for both males and females, then it started to decrease and the two last year's shows a slight increase. In the beginning there was a low harvest rate, and males could continue to grow large. So the harvest rate increased and targeting the large males increased, and caused a decrease in large males. The decrease is seen in female's maximum size as well and can be due to loss of large males.

There has been shown that there has been a reduction in individual fecundity in an average female in the period 200 to 2007. It has also been seen a reduction in spawning events for an average female, decreasing from five to two events.

It is two factors affecting growth in crabs. The first is temperature and the second is food availability. We do not believe there has been change in temperature, but the availability of food has been reduced. Some analysis done on male red king crab in Varangerfjorden indicates that there is a reduction in growth rate and this should be studied further.

It is important to continue to monitor life history parameters in the red king crab and to get more knowledge about the relationship between males and females.

A review of life history parameters in the red king crab in Norwegian waters

Ann Merete Hjelset and Jan H. Sundet, Institute of Marine Research
&
Einar M. Nilssen, University of Tromsø

Workshop on king and snow crab
Tromsø 11-12 of March

INSTITUTE OF MARINE RESEARCH

Background, why monitor life history parameters

- Reproduction and survival in a species are described by life-history parameters
- Important life-history parameters are
  - Size at birth
  - Size at maturity
  - Reproductive investment
  - Length of lifespan

Why study size at maturity

- Size at maturity is a key life-history parameter
- Especially important in new fisheries
- Have opportunity to reproduce before they reach legal size set for the fishery
- Could be affected by fishery

Size at maturity female crabs

- The size where 50% of the females were carrying eggs
- This size were found by fitting the proportion of mature females to a logistic curve

- Data was pooled according to geographical area (fjord) and time periods

Time periods

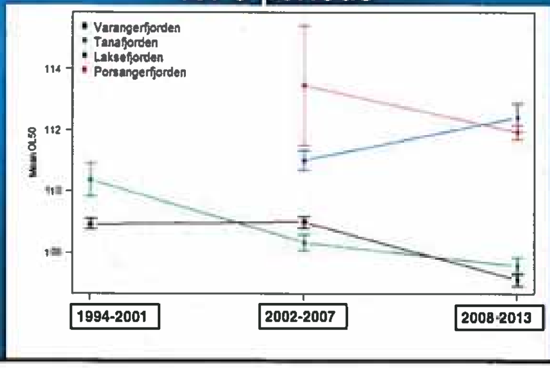
- During the study period of 20 years, the stock has increased significantly
- 1994 to 2001; research fishery
- From 2002; a commercial fishery
- From 2008; quota on females

Geographical areas

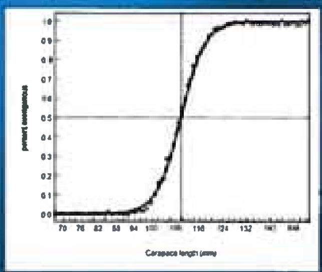
Size at maturity for female crabs

	1994-2001 (8 years)	2002-2007 (6 years)	2008-2013 (6 years)
	Research fishery	Commercial fishery	Commercial fishery & female quota
Varangerfjorden	108,9 ± 0,2 (n=7794)	109,0 ± 0,2 (n=6492)	107,0 ± 0,2 (n=3977)
Tanafjorden	110,3 ± 0,5 (n=1090)	108,3 ± 0,3 (n=2915)	107,5 ± 0,3 (n=2249)
Laksefjorden	-	111,0 ± 0,3 (n=2411)	112,4 ± 0,5 (n=1697)
Porsangerfjorden	-	113,4 ± 2,0 (n=117)	111,9 ± 0,2 (n=3650)

Mean size at maturity values for 3 periods



OL_{50} for whole population



Females are carrying eggs around 107-113 mm carapace length in the period 1994-2013

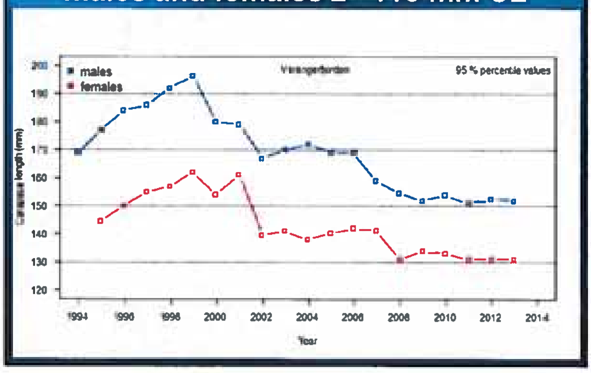
Summary OL_{50} values for whole population

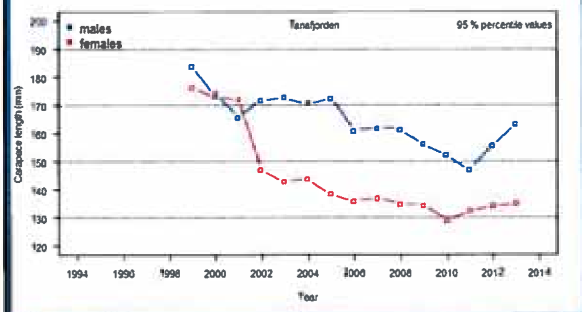
- Females are carrying eggs around 107-113 mm carapace length in the period 1994-2013
- Geographical difference in size at maturity, increasing values westwards
- Females mature at larger size compared to native areas (20 mm larger)
- Fishing pressure on large males does not yet seem to affect female size at sexual maturity significantly

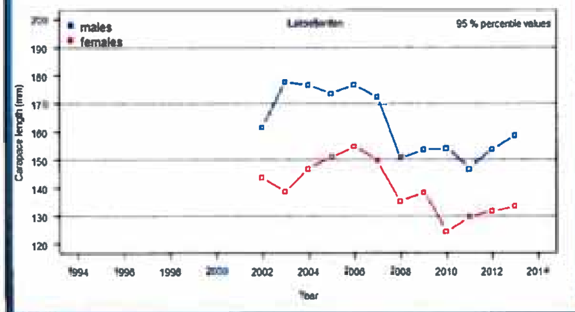
Size at maturity for males

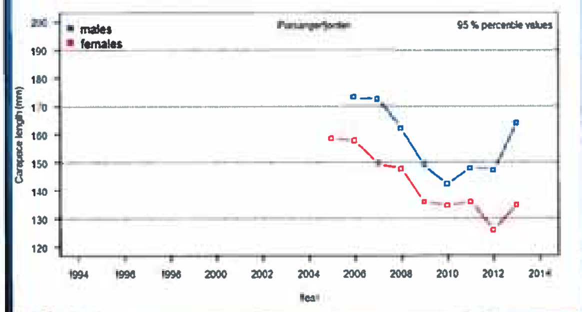
- Three levels of size at maturity
  - Physiological mature size – gonad development
  - Morphological mature size
    - Is shown to be 20 – 15 mm smaller than
  - Functional maturity size – start reproducing
- In the wild average size of mating males was 32 – 42 mm larger than their female partner
  - Unknown relationship for our waters

Size span males and females ≥ ~110 mm CL

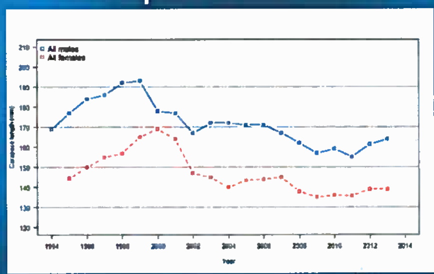








Size span in the stock



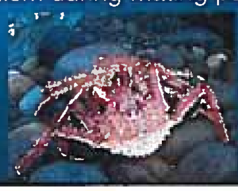
* 95 percent of the stock size lies below this value in each year

Development in 95th percentile

- Low harvest rate (1995 – 1998)
- Targeting the largest specimens
- Reduction in size due to fishery

Development in 95th percentile

- Reduction in females due to lack of large males
- Females dependent on a larger male to guard them, avoid predation or cannibalism during mating period



Spawning events in a mean sized female

Major reduction in number of spawning events for an average female

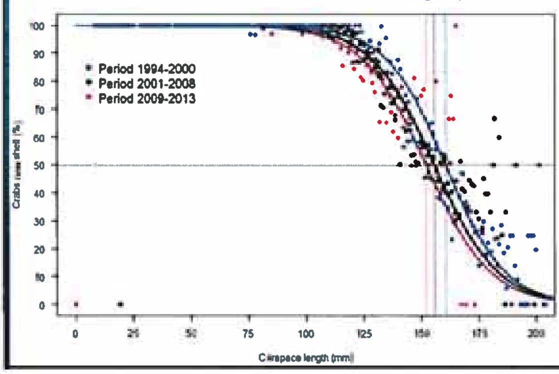
Growth in red king crab

- Females moult before each spawning
- Male crabs undergo irregular moults
- The probability that a male moult is a function of both size and moulting history
- Decreased probability of annual moulting with increasing size

What influence on growth

- Temperature
- Food
  - Low inter-specific competition for food due to low population density
  - There have been a surplus of available food
- These factors varies spatially and temporally in the field.

Moulting frequency in male crabs in Varangerfjorden



- We know;
  - Size at maturity for female red king crab
  - Reduced size span for both males and females
  - Reduced reproductive events from 5 to 2 for an average female
  - Moulting frequency is reduced in males

- We do not know;
  - Status on the fecundity – decrease in individual fecundity has been seen
  - Functional size at maturity for male red king crab – important for determining legal minimum size
  - Relationship between males and females in the stock
  - Further studies on growth rate – reduced food availability?

Effects of temperature on feed intake, growth, oxygen consumption and temperature preference in red king crab

Sten I. Siikavuopio* and Philip James

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Abstract

The current study investigates the effects of temperature on male red king crab (*Paralithodes camtschaticus*) (average = 2.2 kg) at different temperatures (4, 8 and 12 °C). A 110 days trial was undertaken with groups of male king crabs held in 12 land-based holding tanks (4 replicates per temperature treatment). There was 100% survival throughout the experimental period in the lowest temperature treatment (4 °C). One animal died in the medium temperature group (8 °C) and four animals in the highest temperature treatment (12 °C). Feed intake increased with increasing temperature from an average of 1.0 g kg^{-1} (dw) day^{-1} at 4 ºC to 2.8 g kg^{-1} day^{-1} crab at 12 ºC. The percentage meat content in the leg was significantly higher at the final census (60.0%) compared with the initial census (37.5%) in all temperature groups but there were no significant differences in the percentage meat content of the king crabs held in the different temperature treatments at the conclusion of the experiment. Oxygen consumption was also significantly affected by temperature and increased with increasing temperature. The results of the experiment show that the optimal temperature to maintain, and enhance, the meat content of king crab is close to 4 ^{o}C. At this temperature the metabolism and feed intake of the king crabs remains relatively low and yet the percentage meat content is the same as crabs held at 12 ^{o}C which consume significantly more feed and have significantly higher mortality.

Effects of temperature on feed intake, growth, oxygen consumption and temperature preference in red king crab

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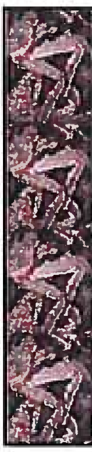

The objective of the present study was to investigate the effects of different temperature conditions on:

1. Survival
2. Growth performance
3. Feed intake
4. Oxygen consumption

- There has been limited systematic work on the effects of water temperature on the king crab in respect to growth, feed intake, oxygen consumption and survival

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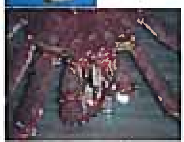
Materials and methods

- Animals: Adult male red king crab
- Size of animal: 2.2 kg
- Feed: Nofima dry feed developed for red king crab (protein 53.8%, lipid 14.9%, carbohydrate 12.3%, ash 11.9% and water 8.2%)
- Feeding strategy: Fed to excess
- Temperatures/salinity: 4, 8 and 12°C / 34 ‰
- Experimental setup: 4 replicates, with 16 animal pr. temperature regimes
- Experiment period: 120 days (May-Sept)



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Analysed variables :

- Calculation of meat content (MC %)
- Feed intake (FI), expressed as grams of dry feed eaten per kg animal per day
- Swim tunnel respiratory chamber (Loligo System) was used to measure the oxygen consumption (mg/kg/h⁻¹)

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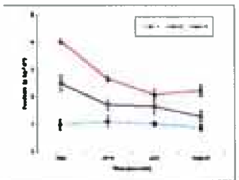
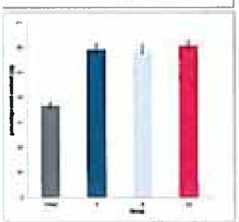
Results

- 100% survival at 4°C
- 94% survival at 8°C.
- 75% survival highest temperature treatment (12°C)
- Feed intake (dw) increases with increasing temperature from 1 g kg^{-1} d^{-1} at 4 °C to 2.8 g kg^{-1} d^{-1} at 12 °C
- The meat content increased in all temperature groups
- No significant differences between treatments at the end of the experiment





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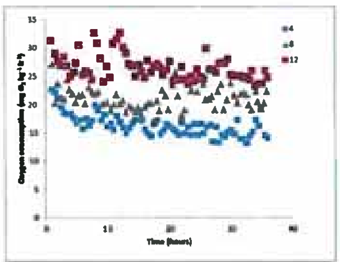
Results

- Oxygen consumption was significantly affected by temperature
- 15 mg O_2/kg⁻ʰ 4°C
- 25 mg O_2/kg⁻ʰ 12°C



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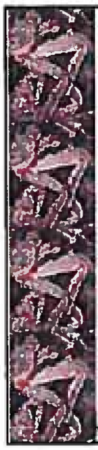


Conclusions

- Temperature has significant effects on feed intake, oxygen consumption and survival of king crab
- Meat content increased in all temperature groups, but there were no differences between the temperature groups
- Temperature of 12°C appears suboptimal for adult red king crab when taking into account, growth, feed intake, oxygen consumption and survival
- The results of the experiment show that the optimal temperature for king crab is at a temperature of 4°C or lower

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Thermal preference

Background

- Temperature is the most important physical factor that influences and restricts marine organisms' geographical distribution
- The selected temperature (after 24 hour) is considered to be species-specific and is called the final thermal preferendum (FTP)
- FTP reflect the optimum temperature required for biological processes such as metabolism, movement, reproduction, FCR and growth
- The FTP seems to be influenced by size or age, and juveniles tend to select higher temperatures than adults

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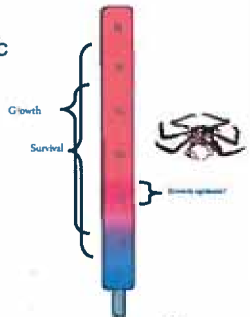
Temperature

- Red king crab can be found at wide temperature ranges of -0.8°C to +8.5°C
- The temperature variation in the Norwegian king crab area 1°C to 14°C
- Temperature preference study under laboratory conditions is missing



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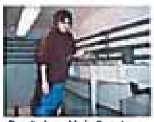
Temperature preference study

- Time: February – May
- Animals: 26 animal ; 12 adult males, 7 immature and 7 roe-bearing females
- Feed: dry feed and fish
- Feeding strategy: in excess
- Temperatures/salinity: 6°C / 32-33 ‰
- Light regimes: simulated natural photoperiod (~70 N)
- Experimental setup: thermal gradient tank (2 and 14°C), 48 hours



Results from: Maria Saprobe

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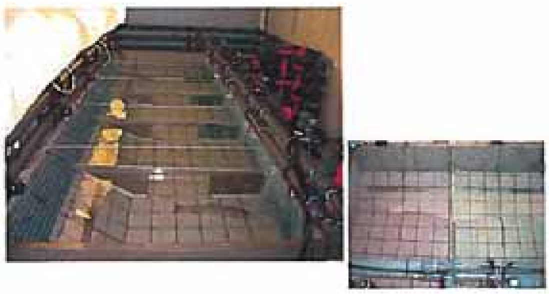
Thermal gradient tank



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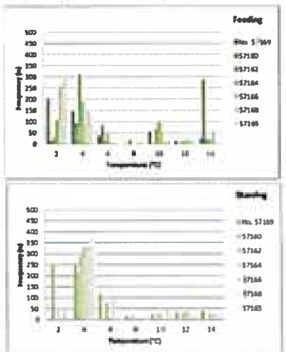
Immature females of red king crab



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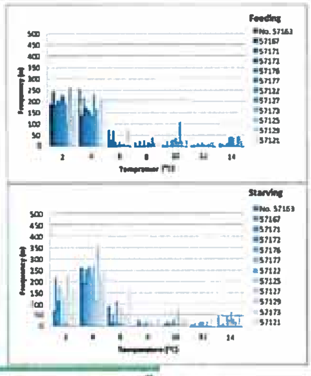
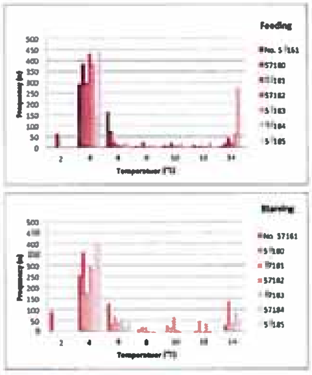
Males of red king crab

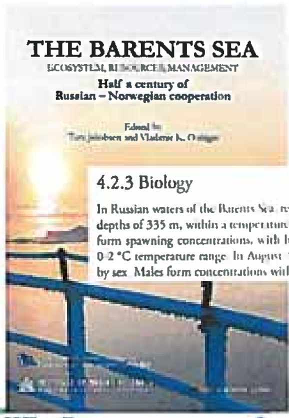


Roe bearing females



Conclusions

- No significant difference in preferred temperature between fed and non-fed animals in any of the groups
- The average final temperature preference ranged between 2.8°C and 3.2 °C.
- Mature spawning female had the highest average temperature preference (3.2°C)
- But no significant differences in preferred temperature between the male, mature and immature female red king crab



4.2.3 Biology

In Russian waters of the Barents Sea, red king crabs occur from the coastal shallow to depths of 335 m, within a temperature range of −0.8 to +8.5 °C. In April–May, they form spawning concentrations, with both males and females remaining within the 0–2 °C temperature range. In August–September, aggregations are usually separated by sex. Males form concentrations within a range of 4–6 °C, females of 5–7 °C.

Invasive red king crabs feed on both capelin and their eggs

Nina Mikkelsen and Torstein Pedersen,

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Institute for Arctic and Marine Biology

ABSTRACT

The aim of the present study was to test the hypothesis that the invasive red king crab, *Paralithodes camtschaticus*, may hamper capelin recruitment through egg consumption, by conducting fieldwork studies (2005, 2006), laboratory experiments (2011), and applying models of consumption. To explore response to capelin egg density by the predator, crab abundances and capelin egg density were estimated in stratified study areas. An exponential decay model was used to estimate stomach evacuation rates of capelin eggs in red king crab stomachs, and the average evacuation time estimated was 5.38 h at 2.9°C. The average evacuation time was applied to a consumption model where uncertainty in input values was assessed by Monte Carlo simulation. Estimated egg consumption values were 0.04% and 2.23% of the total number of eggs in studied spawning areas, in 2005 and 2006, respectively. High variability in number of eggs in stomachs was observed and was responsible for most of the uncertainty in consumption estimates. Crabs displayed no responses to egg density, although logistic regression models showed that the occurrence of eggs in stomachs increased with increasing egg density, and concurrent results were found for the occurrence of capelin. Our findings imply that semelparity in Barents Sea capelin may lead to predator swamping, thereby reducing capelin egg consumption by the invasive red king crab.

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Invasive red king crabs feed on both capelin and their eggs

Nina Mikkelsen & [illegible]
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Institute [illegible]

Background

- Demersal fish eggs may experience high mortality due to predation and this predation may have a significant impact on recruitment of fish
- Recruitment variability is considered to be a major driving force in stock fluctuations in fish
- Is the red king crab an important predator on capelin eggs?

Main objective

Examine the magnitude of predation on capelin eggs and post-spawned capelin as alternative prey by the red king crab

Hypotheses

1. RKC feed on both capelin eggs and capelin
2. Consumption of capelin eggs by RKC increase with increasing capelin egg density
3. RKC aggregate at sites with high capelin egg density
4. Stomach evacuation rates of capelin eggs in RKC can be estimated experimentally
5. Consumption of capelin eggs by the RKC hampers the recruitment of the Barents Sea capelin

Methods overview

- Predation in field
  - Occurrence of capelin eggs and capelin in red king crab stomach
  - Red king crab response to capelin egg density
  - Obtain crab stomach data for use in consumption model
- Experimental work
  - Stomach evacuation rate of capelin eggs in RKC
- Estimate consumption
  - Consumption model using Monte Carlo simulation approach taking into account the uncertainty in input data

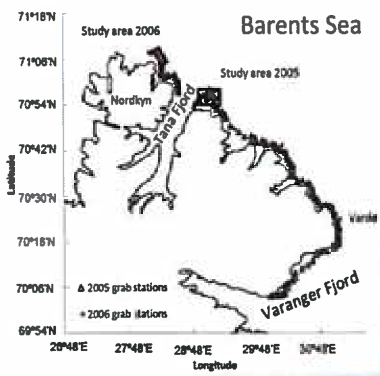


Fig. 1. Survey areas at the coast of Finnmark, northern Norway. Grab stations in 2005 (black triangles) and 2006 (red circles) are shown. Located spawning sites of the Barents Sea capelin (*Mallotus villosus*) chosen as study areas in 2005 and 2006 are shown as rectangles

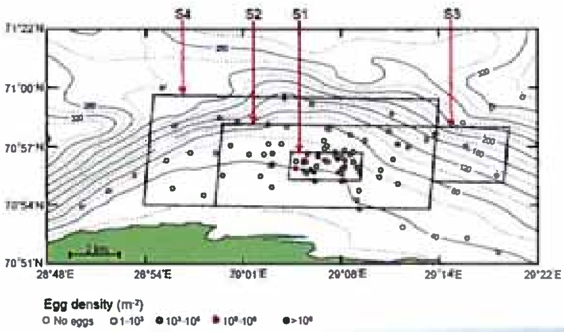


Fig. 2. Study area in 2005 with depth contours (m). Egg densities (m^{-2}) estimated from grab samples in strata S1, S2, S3 and S4. Egg densities (ED) (m^{-2}) in grab samples are classified as No eggs (empty circle), ED < 1-10³ (yellow circle), 10^3 < ED < 10^5 (blue circle), 10^5 < ED < 10^6 (red circle) and ED > 10^6 (black circle). Grab samples from both survey I and II are shown

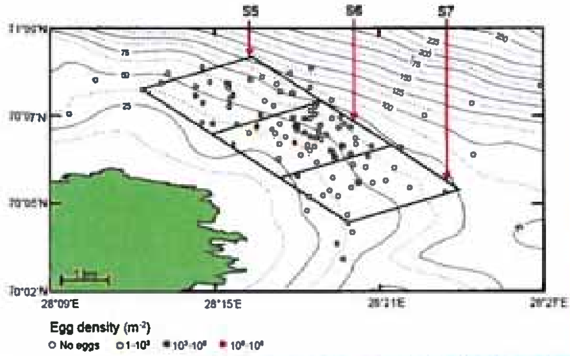


Fig. 3. Study area in 2006 and depth contours (m). Egg density m^{-2} estimated from grab samples in strata S5, S6 and S7. Egg density m^{-2} in grab samples are classified as No eggs (empty circle), ED < 1-10³ (yellow circle), 10^3 < ED < 10^5 (blue circle), 10^5 < ED < 10^6 (red circle). Grab samples from both survey I and II are shown

Stomach analysis

- Stomachs analyzed
  - 2005: n=125
  - 2006: n=60
- Occurrence of fish eggs and capelin in stomachs (Presence/Absence)
- Eggs in stomachs were counted and identified

Stomach evacuation of capelin eggs in RKC

To estimate daily ration and consumption of capelin eggs by the red king crab, it was necessary to estimate the gastric evacuation rate of such eggs in red king crab.

Experimental animals

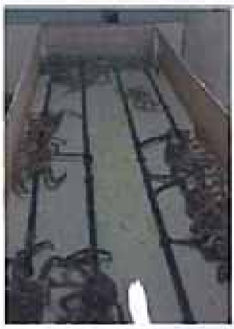


Fig. 2A. Stocking tanks for red king crab used in stomach evacuation experiment

Fig. 1A. Plastic boxes (50 l) with letter files made of rigid perforated PVC and fertilized capelin eggs-clumps in natural seawater. Boxes were used for transportation of eggs to experimental facilities

Experiment (2011)

- 18 mature male king crabs (mean weight: 1422 g)
- Meals of capelin egg clumps 0.27% of crab weight
- Crabs killed hourly at predetermined time
- Eggs found in stomachs were counted and weighted

Fig. A3. Red king crab in experimental tank feeding on capelin eggs

Stomach evacuation model

- Experimental data were fitted using nonlinear regression in SYSTAT
  - Proportions of eggs left in stomach at a given time were fitted to model.
- Model
  - Exponential decay model

Egg consumption model

$$C = \left(\frac{W}{A}\right) \cdot 24 \cdot T \cdot P$$

W = average number of eggs in stomach

A = average time to evacuate eggs

T = time eggs are available for predators

P = total number of crabs

Uncertainy in input data to Consumption model

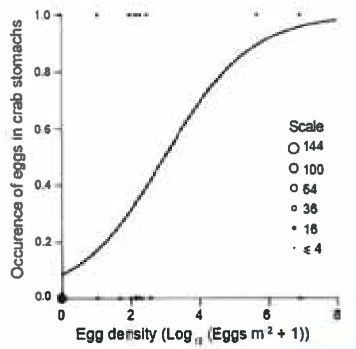
- Monte Carlo simulations were used to estimate consumption with 95% confidence intervals
- Values for input data were randomly selected from distributions assumed to describe the uncertainty in the data

Results

- Predation in field:
  - Occurence of capelin
  - Occurence of capelin eggs
  - RKC response to capelin egg density
- Stomach evacuation rate of capelin eggs in RKC
- Consumption of capelin eggs by RKC

Predation in field

- RKC feed on capelin eggs 23% (2005), 10 % (2006), but more frequently on capelin 82%(2005) and 22% (2006)
- The number of eggs found in stomachs was highly variable
- Maximum number of eggs in one crab stomach was 4090 capelin eggs
- Some crabs were able to find and eat capelin eggs at far distance from Centre of spawning area



$$P(X) = \frac{1}{(1 + e^{-(-2.39 + 0.80 \times ED)})}$$

Fig. 4. Occurrence of capelin (*Mallotus villosus*) eggs in red king crab (*Parlithodes camtschaticus*) with increasing egg density as independent variable. Observed data are illustrated by markers and the fitted logistic model (P(X) is illustrated by the line

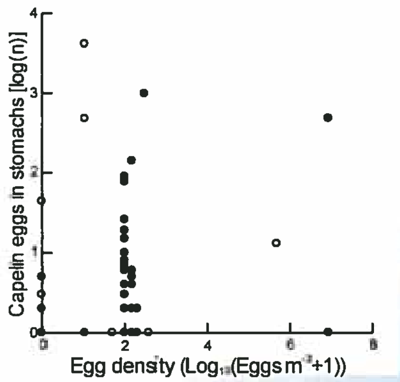


Fig. 5. Number of capelin eggs in red king crab stomachs (n_{2005}=125, n_{2006}=60) plotted against capelin egg density [Log_{10} (Eggs m^{-2}+1)]

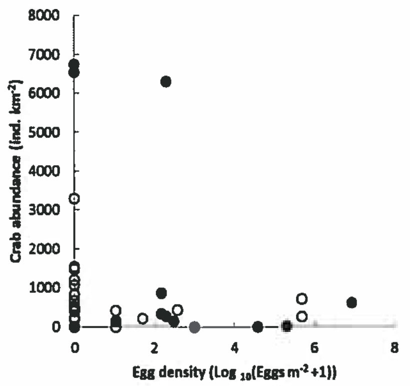


Fig. 6. *Paralithodes camtschaticus*. Abundance of red king crab (Ind. km^{-2}) related to the density of capelin eggs [Log_{10} (Eggs m^{-2}+1)]

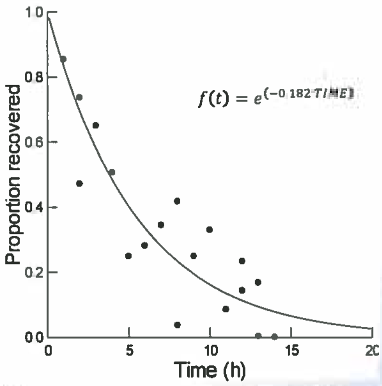


Fig. 7. *Paralithodes camtschaticus*. Stomach evacuation rate of red king crabs fed capelin eggs at 3°C. ● Observed proportion of eggs left in stomach at given time is illustrated by points. The line represents the exponential decay function fitted to observed proportion of stomach contents f(t)

Results

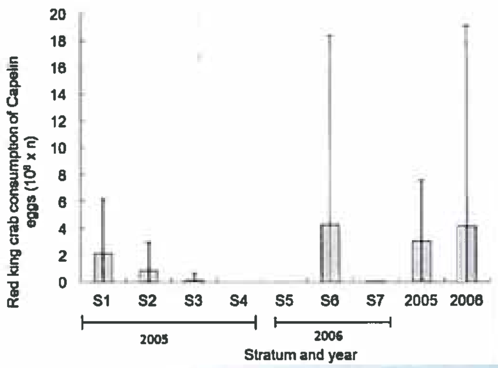


Fig. 8. *Paralithodes camtschaticus* and *Mallotus villosus*. Monte Carlo estimated consumption of capelin eggs by red king crab. Total consumption (n) with 95 % confidence intervals per stratum (S1-S7) and totally in the stratified area by year is shown

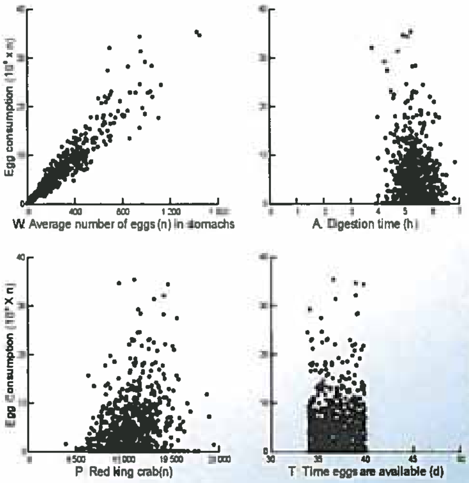


Fig. 10. Results of 1000 Monte Carlo simulations of consumption of capelin eggs by red king crab plotted versus; average number of eggs (W), digestion time (A), number of crabs (P) and time eggs are available (T), plotted against consumption estimates of capelin eggs by red king crabs in study area in 2006, taking into account uncertainty in input data by sampling from probability distributions assumed to represent the input data. Spearman rank correlation coefficient is shown

Conclusions

Capelin egg consumption by the red king crab accounted for approximately 0.03% and 2.23% of the total egg mass in the study areas in 2005 and 2006

The total egg loss due to RKC feeding activity is higher than the estimated consumption because crabs damage eggs and may cause uneaten eggs to drift away from spawning sites

Red king crab feed more frequently on post spawn capelin than their eggs

Conclusions continued

1. RKC feed on both capelin eggs and capelin
2. Egg consumption by RKC does not increase with increasing egg density, but the occurrence of eggs in stomachs does
3. RKC does not aggregate significantly at sites with high egg density
4. Stomach evacuation rates of capelin eggs in red king crab was estimated to xx hour at 3°C
5. Egg consumption by RKC does not hamper capelin recruitment directly.

...however

Ecological value of post spawn capelin to native species should be considered when implementing ecosystem approach in management of the Barents Sea capelin

Haddock may experience competition for post spawn capelin as prey from the invasive red king crab.

Acknowledgements

- Crew at R/V Johan Ruud
- Technicians Trond Ivarjord, Berit Bendiksen, Fredrikke Musæus and Helge Meissner
- North Capelin fish plant in Honningsvåg
- Hans Christian Strand, IMR

The snow crab (*Chionoecetes opilio*) in the Barents Sea

Jan H. Sundet, IMR.

Extended abstract from the lecture held at the workshop on red king- and snow crab, Tromsø, March 11 – 12. 2014.

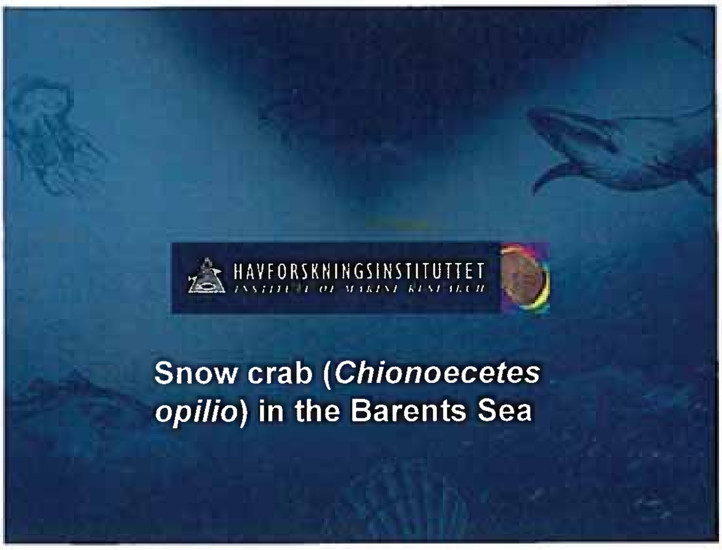
The native distribution areas of the snow crab are in the Bering Sea, along the east coast of Canada and on the west coast of Greenland. In all these areas there is a significant fishery taking place on this crab, with the largest fishery in eastern Canada (landings 2013 > 100 ktons).
In the Barents Sea, the first recordings of the snow crab was done in trawl catches at the Goose Bank in the Russian zone, where five crabs were caught in 1996. Immediately, a discussion started on where these crab originates from, and how they have been transferred.
Some years after the first recordings, Norwegian scientist made some genetic studies comparing snow crabs from eastern Canada and Greenland, with crabs from the Barents Sea. There were however, minor similarities between these groups of crabs indicating that the snow crab in the Barents Sea unlikely originate from these western areas.
A new hypothesis then evolved questioning whether the crab has migrated westwards from a native population in the Chukchi Sea, north of the Bering Strait. Findings of the snow crab both in the East Siberian Sea and in the Laptev Sea could strengthen such a hypothesis. There are however, two major facts weakening this hypothesis. The snow crab have until last year not been found in the Kara Sea, the area closest to the Barents Sea and secondly; the development pattern of the snow crab stock in the Barents Sea. Looking at how the snow crab stock has evolved since the first recording, this reveal the typical development of an introduced, non-native species becoming invasive. With a relative long lag-phase (1996 – 2011) followed by an almost exponential growth (2011-2013). The origin of the snow crab introduced to the Barents Sea is therefore still a mistery.

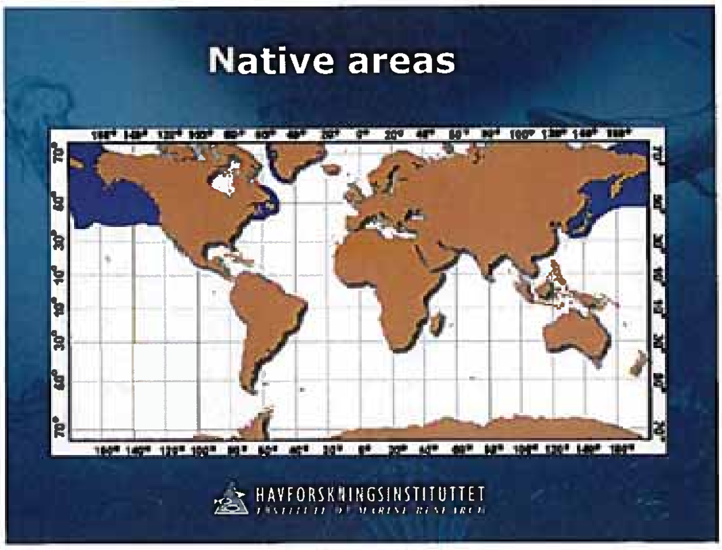
The data we have on the snow crab from the Barents Sea is relatively sparse and the best data set is from the joint annual Norwegian – Russian Ecosystem survey covering almost the entire Barents Sea from 2004 – 2013. However, the sampling gear used on these cruises, the Campelen trawl, is not optimal for catching snow crabs. Therefore, the data can only be used to reveal distribution and probably provide density indexes.
Based on these data, the distribution of the crab in the Barents Sea has increased rapidly since 2004, and in 2013 it was found in almost the entire northern Russian economical zone (REZ).
Sex and size distribution of crabs caught by Norwegian vessels show a dominance of male crabs in the catches. Findings of abundant juvenile size classes also indicate good recruitment to the stock.
Catches in the REZ show that snow crab larvae probably is transported by prevailing surface currents from hatching areas in south (Goose Bank) to settling and nursery areas in coastal waters of northern Novaja Zemlja. An up to three month pelagic larval phase open up for a long distance transport in these areas.

The snow crab has a potential to become a major fishery in the Barents Sea. The crab stock has increased rapidly and developed to be a major player in the Barents Sea ecosystem. Our major concern is therefore what consequences it will have on the recipient ecosystem.

Preliminary results from stomach content analysis show that the snow crab feed on many different prey groups, where bivalves, polychaetes, crustaceans and echinoderms dominate. This reveals that the crab most likely is an opportunistic omnivore predator.

An alarming recording is that we found that almost 20 percent of the stomachs to contain plastic.


HAVFORSKNINGSINSTITUTTET
Snow crab (*Chionoecetes opilio*) in the Barents Sea


Native areas
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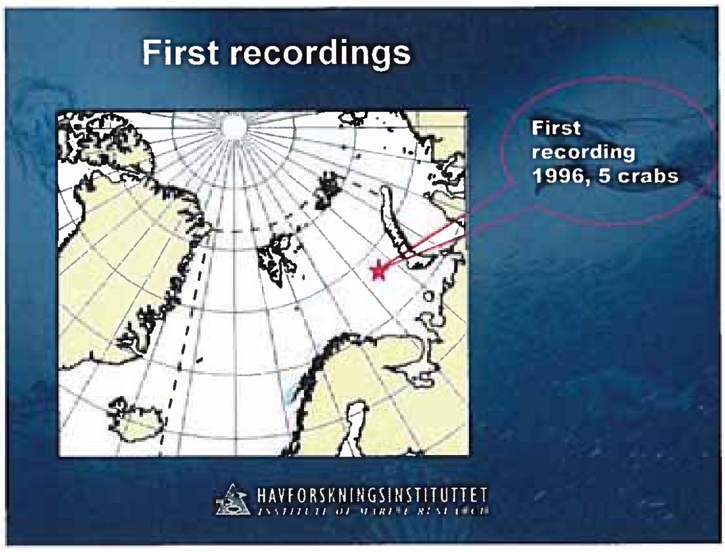
First recordings
First recording 1996, 5 crabs
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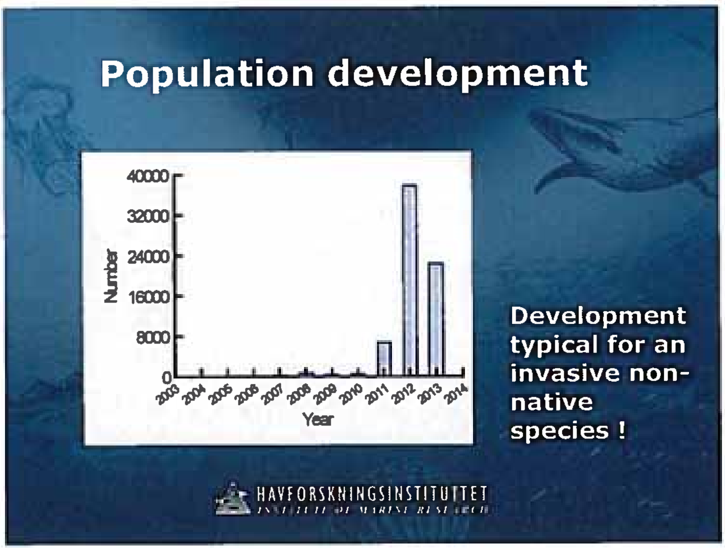
Origin ?
Chukchi Sea
East Siberian Sea
Laptev Sea
?
Kara Sea


Population development
40000
32000
24000
16000
8000
0
Number
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
Year
Development typical for an invasive non-native species !
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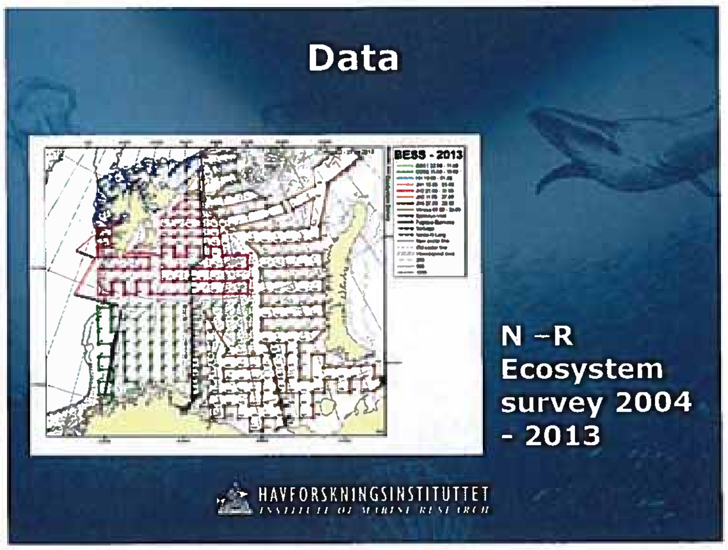
Data
BESS - 2013
N – R Ecosystem survey 2004 - 2013
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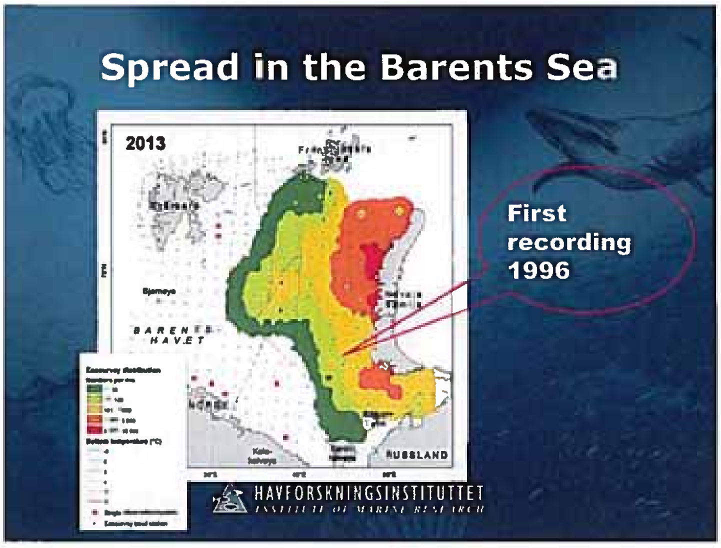
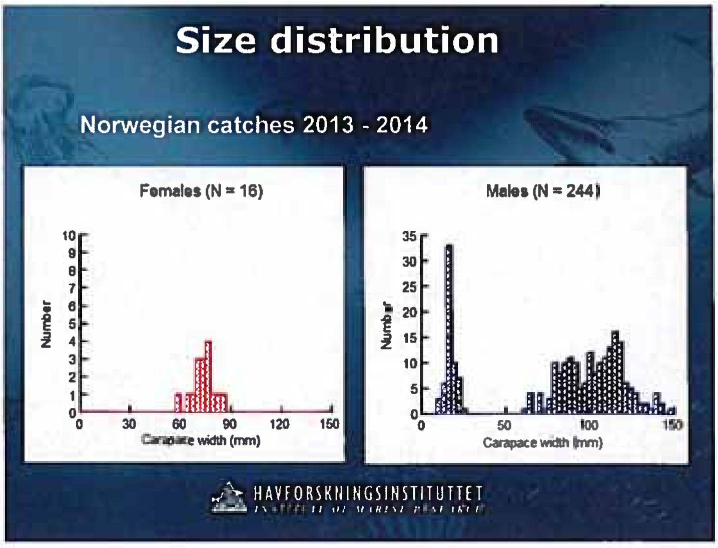


Spread in the Barents Sea
2013
First recording 1996
BARENTS HAVET
RUSSLAND
HAVFORSKNINGSINSTITUTTET



Size distribution
Norwegian catches 2013 - 2014
Females (N = 16)
Males (N = 244)
Number
Carapace width (mm)
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Size groups
•Juvenile crabs < 50 mm CW (?)
•Sublegal males 50 – 100 mm CW
•Legal males > 100 mm CW
•Mature females > 50 mm CW
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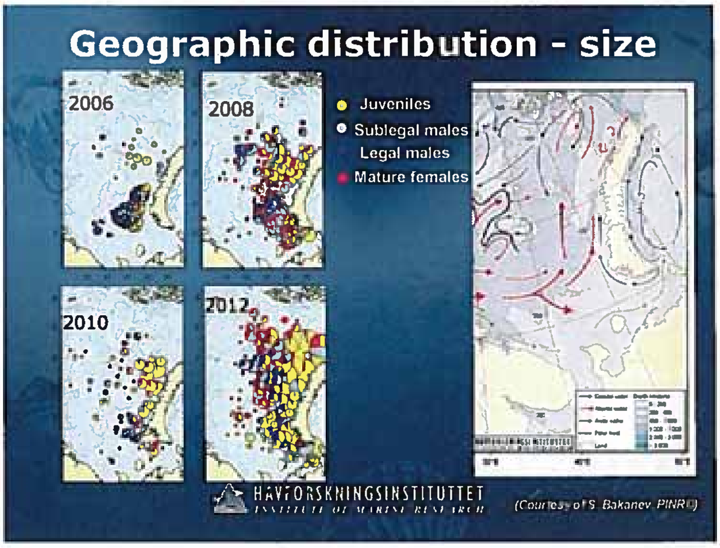

Geographic distribution - size
2006
2008
2010
2012
Juveniles
Sublegal males
Legal males
Mature females
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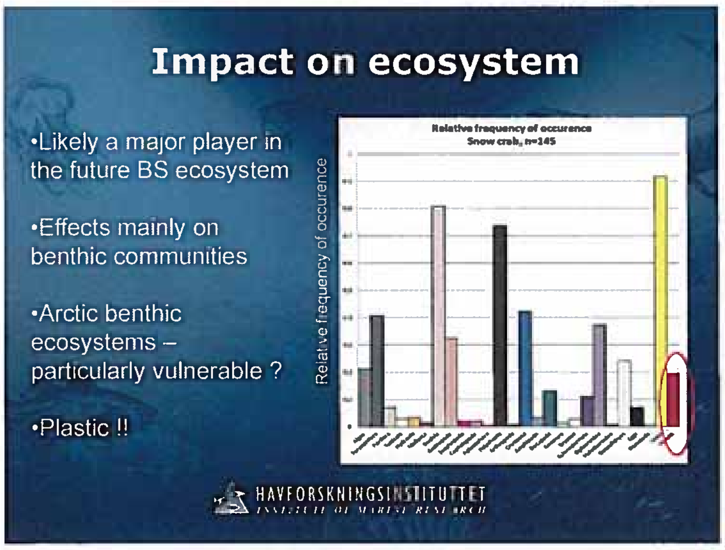
(Courtesy of S. Bakanev PINRO)



Impact on ecosystem
•Likely a major player in the future BS ecosystem
•Effects mainly on benthic communities
•Arctic benthic ecosystems – particularly vulnerable ?
•Plastic !!
Relative frequency of occurence
Snow crab, n=145
Relative frequency of occurence
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Thank you !

Population genetics – snow crab.
Genetic Differentiation around the Arctic Ocean?

Geir Dahle, Ann-Lisbeth Agnalt, and Eva Farestveit, Institute of Marine Research, Bergen.
Jean-Marie Sevigny and Eric Parent, Institute Maurice Lamontagne, Mont-Joli, Canada

Samples from the Barents Sea and samples collected at locations around the Arctic Ocean; Bering Sea, Labrador Coast, Gulf of St Lawrence and west coast of Greenland, were genotyped utilizing 14 different microsatellite. Pairwise Fst was calculated between all samples, and showed a clear population structure in the total material consisting of 684 individuals. The thirteen samples grouped into three clusters, each significantly different from each other. The first cluster includes all samples from the Barents Sea (2004 – 2012), the second cluster samples from the Bering Sea and the Canadian east coast (New Foundland, Gulf of St Lawrence and Labrador coast) while the third cluster included the two samples from the west coast of Greenland (Disko Bay and Equlait). The three clusters were significantly different, with the largest genetic distance between the Barents Sea and Greenland. The cluster with the Bering Sea and Canadian samples seemed to be closer connected to the Barents Sea. This clustering might be a result of the patterns of currents around the Arctic Ocean and Greenland, but more studies needs to be conducted

Population genetics – snow crab (Chionoecetes opilio).

Genetic differentiation around the Arctic Ocean?

Geir Dahle

Eva Farestveit, Jean-Marie Sevigny, Eric Parent, Ann-Lisbeth Agnalt

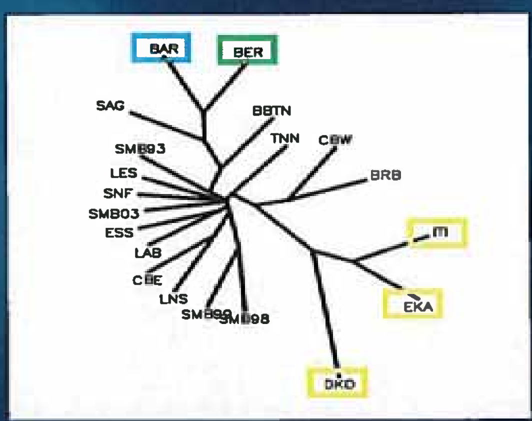
INSTITUTE OF MARINE RESEARCH
HAVFORSKNINGSINSTITUTTET

Why genetics?

- Information about differentiation between groups of individuals
- information about possible links between areas
- might reveal information about how the Barents Sea has been invaded

- ✓ Ballast water:
  - ✓ few incidents
  - ✓ few individuals
  - ✓ founder effect (?)
- ✓ "Invasions":
  - ✓ more individuals
  - ✓ different cohorts (?)
  - ✓ no founder effect (?)

- ✓ Founder effect
- ✓ Selection
- ✓ Genetic drift

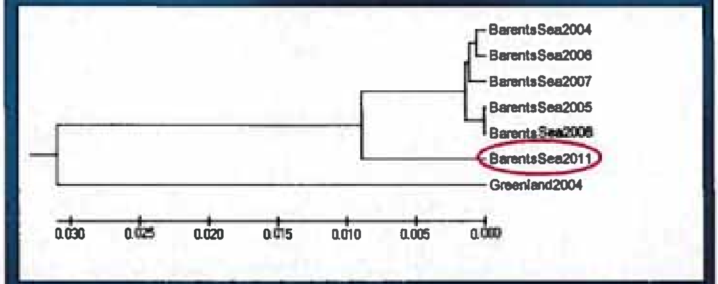


Sevigny J.-M

Population genetic studies in 2012

Microsatellites:

Cop2, Cop3, Cop3-4II, Cop4, Cop4-1, Cop113



2014

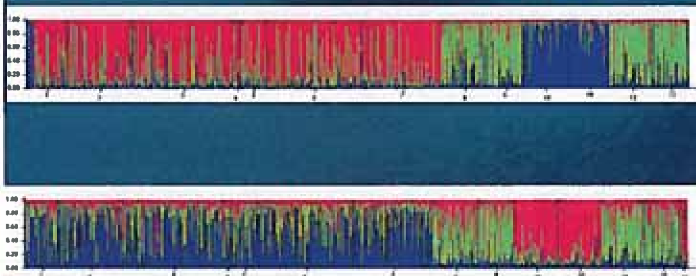
Analyse groups of individuals around the Arctic Ocean with
9 new microsatellites

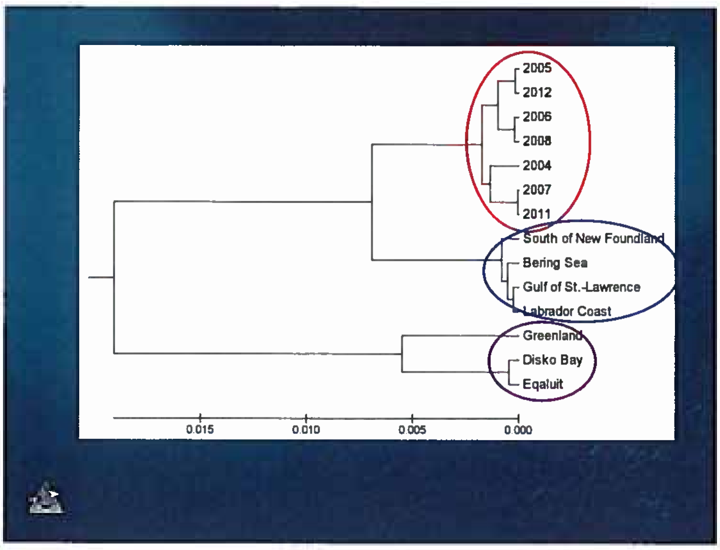
Temporal stability in the Barents Sea -
Barents Sea 2011?

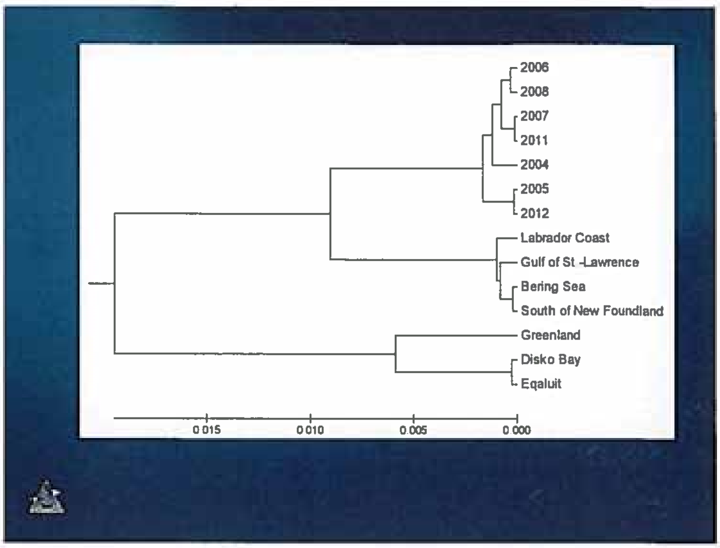
2014

Microsatellites:

CF15, CF17, CF27, CF34, CF36, CF37, CF39, CF60, CF63




2005
2012
2006
2008
2004
2007
2011
South of New Foundland
Bering Sea
Gulf of St.-Lawrence
Labrador Coast
Greenland
Disko Bay
Eqaluit
0.015
0.010
0.005
0.000


2006
2008
2007
2011
2004
2005
2012
Labrador Coast
Gulf of St -Lawrence
Bering Sea
South of New Foundland
Greenland
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0.015
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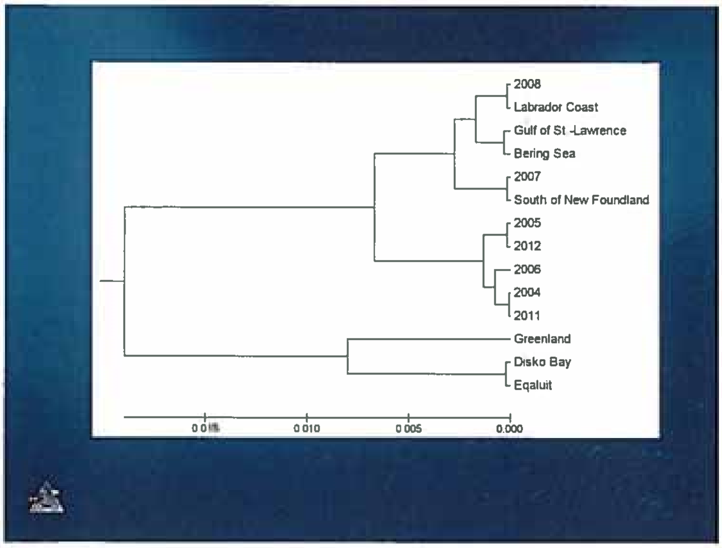
2008
Labrador Coast
Gulf of St -Lawrence
Bering Sea
2007
South of New Foundland
2005
2012
2006
2004
2011
Greenland
Disko Bay
Eqaluit
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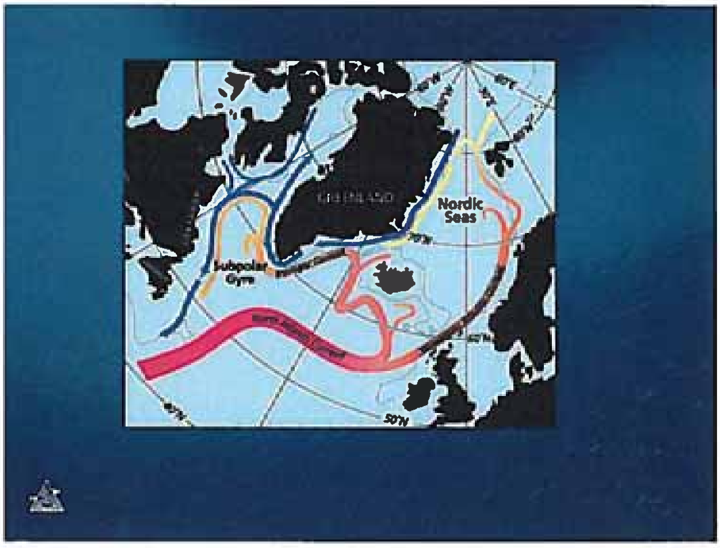
0.005
0.000


GREENLAND
Nordic Seas
Subpolar Gyre


Thank you

Life-history of snow crab (*Chionocetes opilio*), and potential spreading of larvae in the Barents Sea.

Ann-Lisbeth Agnalt, Ann Merete Hjelset, Geir Dahle and Mari Myksvoll
Institute of Marine Research, (IMR) Norway

Abstract

Snow crab (*Chionocetes oipilio*) is considered a non-native species in the Barents Sea. It was first discovered in 1996 by Kuzmin et al. (1999). The snow crab population has since increased in number as well as distribution range. In overall, the largest female found by the Norwegian vessels was 93 mm carapace width (CW) while males can be found up to 140 mm CW. This also reflects the size difference in grasping pairs as observed in other areas. Maturity is reached after terminal moult for both sex, occurring over a wide range of sizes and age. Little is known of mating and life history of the snow crab in the Barents Sea, but key parameters from other know areas and populations will be presented.

The Goose Bank has previously been identified as the main recruitment area based on presence of ovigerous females and small-sized crabs. It is also known from other areas that the larvae are hatched from April to June. The pelagic larvae goes from zoea I to zoea II and will eventually reach megalope before settling after about three to five months. The larvae are found throughout the water column. All this is vital information when applying simulation models to answer key questions as “How far can the larva hatched at the Goose Bank disperse in the Barents Sea over a period of three to five months?” and Is it possible that snow crab larvae hatched in the Pacific can enter the Polar region and the Barents Sea? The latter is related to risk of new and continues invasions, and thus genetic analysis.

Life-history of snow crab

potential spreading of larvae in the Barents Sea

Ann-Lisbeth Agnalt, Ann Merete Hjelset, Knut Jorstad, Geir Dahle & Mari Myksvoll

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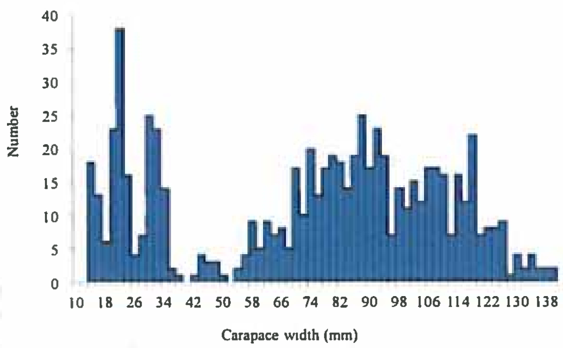
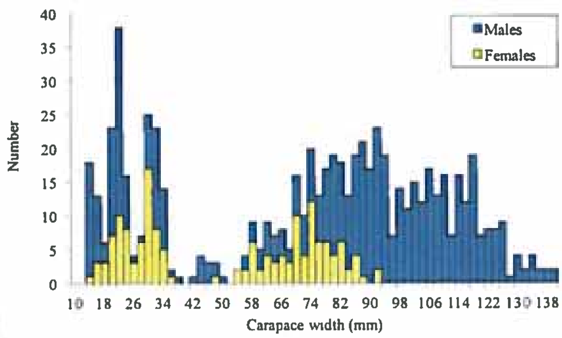
Chionoecetes opilio

Sizes (carapace width) 2004-2013



Sizes (carapace width) 2004-2013



- Largest female 93 mm CW

Mating

A bit on mating from populations in other areas

- Maturity reached after terminal moult for both sex, across a wide range of sizes and age
- Snow crabs prefer a narrow temperature range of cold water < 3 to 4°C.

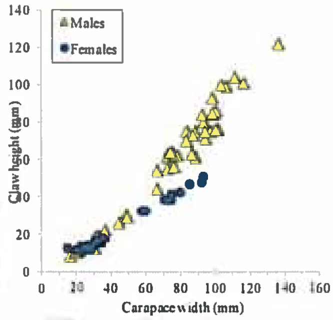
- 2-3 weeks prior to mating, the male snow crab will hold onto the female (grasping pairs)
- Will move to shallow waters
- This migration usually occurs February to March

http://bioweb.uwlax.edu/bio203/s2012/cropp_cass/reproduction.htm

Claw size – matters!

http://www.dfo-mpo.gc.ca/science/publications/uww-msm/articles/snowcrab-crabedesneiges-eng.html

Male maturity



Presence of sperm

33–38 mm CW eastern Canada

20–30 mm CW higher latitudes e.g. in the Chukchi Sea

43-45 mm Barents Sea

Grasping pairs

50-60 mm CW eastern Canada

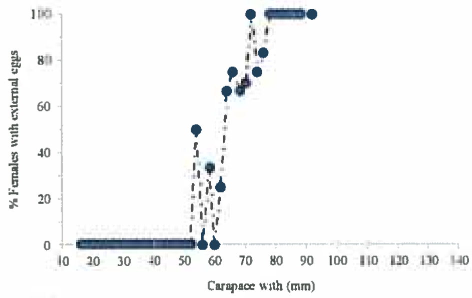
Comeau et al 1999, Hinckley et al 2010
Filina 2009, Filina & Pavlov 2009

Females can mate with several males

- Sperm accumulates in the female during mating (spermatheca) ⟶
- Females can mate with different males during their first breeding season (up to 6 is found)

Sainte-Marie et al. 1999. Multiple choice criteria … mating
http://snowcrablove.blogspot.no/2010/09/csi-for-crabs.html

Females w/eggs in the Barents Sea



- Smallest female with eggs was 54 mm CW
- All females above 78 mm CW are ovigerous

Snow crab in the Barents Sea

Captured February 2004 – 71 mmCW

Captured February 2004 – 71 mmCW

Reproductive strategy

- Temperature dependent
  - 1-year cycle in laboratory 4.5 to 5.5C
  - 2-year cycle in the field at -1 to 1C

Comeau et al 1999
Kon 1974

Snow crab in the Barents Sea

Captured February 2006 – 75 and 83mm CW

Egg production
(other areas)

- A female of approximately 67 mm CW produce up to 54,000 eggs
- Can produce from 12,000 to 160,000 eggs depending on size
- Extruded between February and April
- After the larvae are hatched the female may mate again or use the stored sperm to fertilize future clutches of eggs

Comeau et al 1999
Sainte-Marie 1993

Larval stages

- Hatche from April to June
- Found throughout the water column, between the surface and the sea bottom
- Pelagic, feeding upon the plankton for 3 to 5 months,
- Go through various stages before settling on the sea bottom (zoea I, zoea II, Megalope)

Scherbakova &Korn 2011
http://www dfo-mpo.gc.ca science publications sww mum articles snowcrab-crabedesneiges eng html

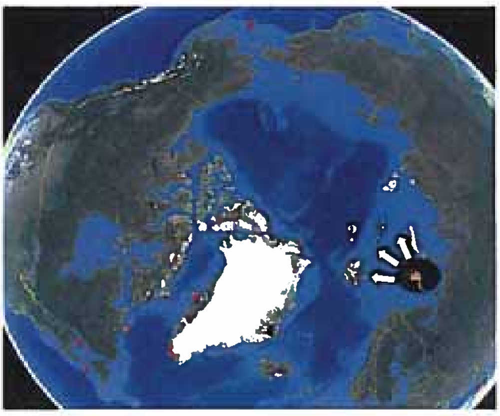
Larval dispersal in the Barents Sea

- Main spawning ground Goose Bank (< 100 m)
- We find females with eggs

- Do we look for the larvae?

Kuzmin 2000, Alsvåg et al. 2009)

How far can the larva that are hatched at the Goose Bank disperse in the Barents Sea over a period of 3 to 5 months?

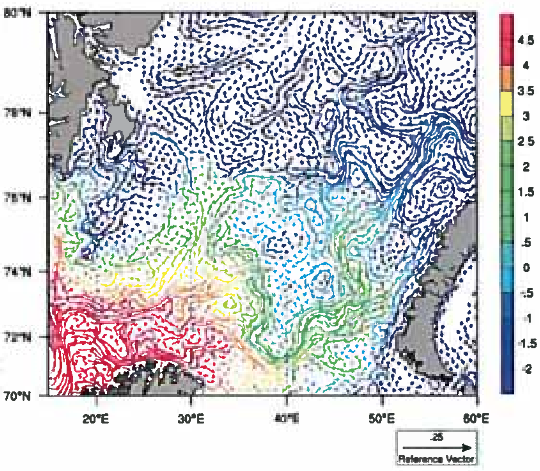


We do have the tools to simulate this

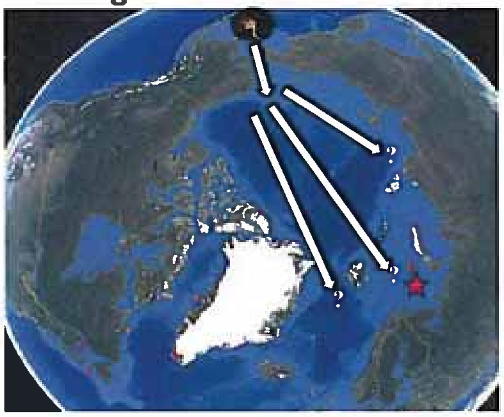
- Model available at IMR for the Barents Sea region
- Should run the model between April and October, for each year
- Virtual larvae releases near the bottom
- Move upward in the water column to the mixed layer, and retained there until time of settlement

- Currently we don't have finances to do this

Current



Is it possible that snow crab larvae hatched in the Pacific can enter the Polar region and the Barents Sea?

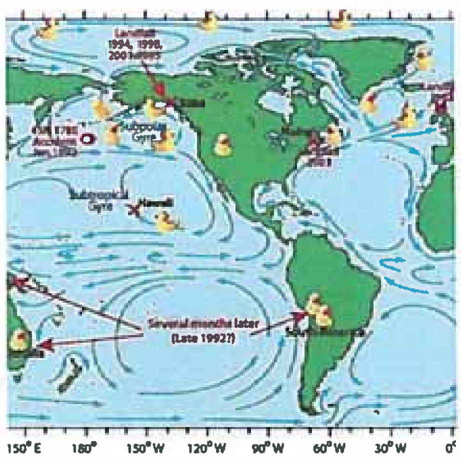


Ducks on the move

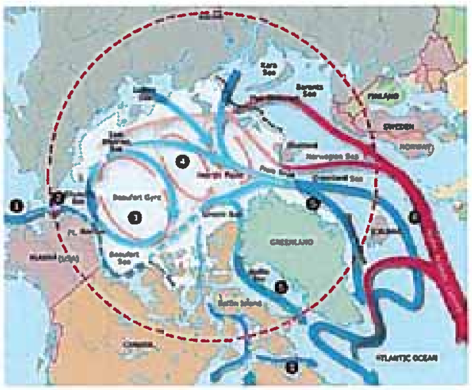
- During a Pacific storm on 10 January 1992, 29 000 plastic bath toys were washed off a ship.

- Two-thirds of the ducks floated south and landed three months later on the shores of Indonesia, Australia, and South America.

Ducks on the move



Ocean circulation in the Arctic



http://www.divediscover.whoi.edu/arctic/circulation.html

Ocean circulation in the Arctic

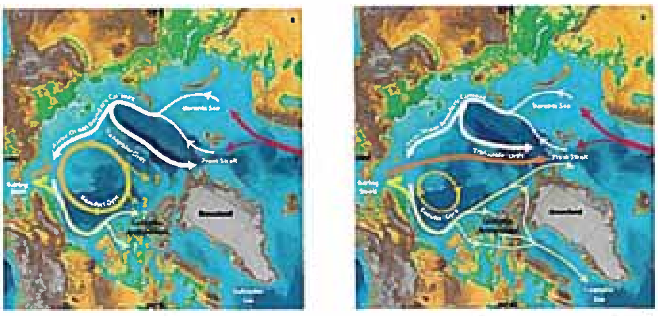


FIG. 2. Upper ocean circulation patterns in the Arctic Ocean (a) before and (b) after the shift to a strongly cyclonic atmospheric circulation regime. Red arrows indicate inflow of Atlantic water into the Arctic Ocean through the Barents Sea and Fram Strait. White arrows indicate surface flows of polar water. Yellow and orange arrows indicate inflow of Pacific water into the Arctic Ocean through the Bering Strait. Pale yellow and orange arrows indicate mixtures of polar- and Pacific-derived waters.

Greene et al. 2008. Arctic climate change and its impacts on the ecology

La Recherche Expedition of 1838-1840
North Atlantic-Scandinavian islands including Faroelsland, Spitsbergen and Iceland

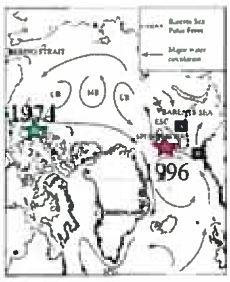
"La Recherche" close to Bear Island, Svalbard, August 7 1838 (painter: Auguste Mayer)

Snow crab at Spitsbergen 1838-1840

... or was this actually captured at Greenland? ....

Examples of Trans-Arctic interactions

- Pacific diatom *Neodenticula seminae* in the Atlantics in 1999, Labrador Sea.
- Coincided with modifications in Arctic hydrography and circulation. Increased flow of Pacific water in the northwest Atlantic along with some ice-free years.
- The pacific copepod *Calanus marshalla* at Spitsbergen in 1996 (possibly also in 1974
- ..... Other fish examples



Reid et al. 2007. A biological consequence of reducing Arctic ice cover
Sundt & Melle. 1998. Atlantic observations of Calanus marshallae

Can this happen?

The New King of the Barents Sea

www.sustainablesushi.net Snow Crab Love

Presentations given under the theme;

Assessment methods applied of the king and snow crab stocks in the Barents Sea

Carsten Hvingel, Institute of Marine Research, Tromsø

Designing assessment processes for fishery resources that includes ecosystem considerations – a case study of King crab off northern Norway

Konstantin Sokolov, PINRO

Modeling of population dynamics of commercial crabs in the Barents Sea

Kristin Windsland, Institute of Marine Research, Tromsø

Total and natural mortality of red king crab (Paralithodes camtschaticus) in Norwegian waters: Catch curve analysis and indirect estimation methods

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Presentation given under the theme;

Management options for the king- and snow crab stocks in the Barents Sea

Guro Gjelsvik, Directorate of Fisheries

Evaluation of the red king crab management

Towards a new advisory process
– The king crab off northern Norway

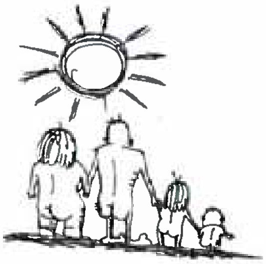
Carsten Hvingel

The advisory process for King crab off Northern Norway is being redesigned to allow to a greater extent for ecosystem considerations. The aim is to do so without increasing the total activity (ship time, analyses, meetings) and without compromising the current “single stock” assessment.

In a first step a specification of the deliverables from the single stock assessments was made based on the fishery manager’s formal requests for advice and stated management objectives. Models of stock dynamics and of the survey data was then constructed to deliver according to these specifications. In addition, these models were designed to be flexible in the way they accommodate various data situations. The amount of data collection needed to provide the necessary precision of model estimates could thereby be analyzed.

Surveys were previously conducted every year. Analyses showed that surveying just every second year had minor affect on estimated trends in stock dynamics and on the precision of the yearly stock estimated. Future investigations will also look into opportunities for reducing within year reduction in survey efforts as well.

Conclusions so far indicate that survey efforts to provide data for the single stock assessment could be reduced by up to 50%. This would make “room” within the same budget for increasing the ecosystem effect studies.

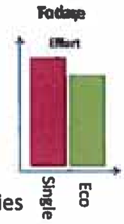


Towards a new advisory process
– the king crab off northern Norway

Carsten Hvingel
Institute of Marine Research Norway

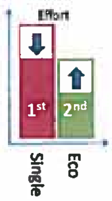
Fisheries management

- Precautionary Approach
  - Focus: Single stock impact
  - Aim: Manage stock productivity
  - Tool: Control *removals* of the target stock
- Ecosystem Approach
  - Focus: Ecosystem impact
  - Aim: Manage biodiversity, habitat integrity, species interaction
  - Tool: Control the *fishing activity*



The 1st task: reduce "single stock effort"

- Precondition:
  - total allocation of effort in the assessment process shall remain unchanged,
- Consequence:
  - increasing the focus on ecosystem impacts means reducing effort allocated to single stock perspectives.



Can we optimize the single stock assessments and still be OK?

Optimizing the advisory process

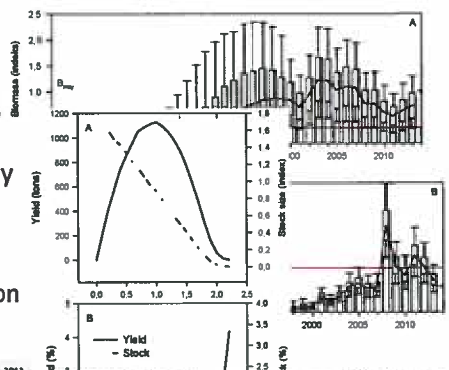
- Data collection
- Assessment model
- Advice
- Management decisions

Optimizing the advisory process

- Data collection ...determines what data to collect
- Assessment model ...determines model design
- Advice ...determines what the advice should contain
- Management decisions What to decide?

Managers wish list

- Stock size
- Fishing mortality
- Production
- Stability
- Status/Prediction
- Risk



[illegible]	2012	2013
Risk stock < B_{lim} (0.3B_{msy})	11 %	7 %
Risk stock < B_{msy}	89 %	78 %
Risk fishing mortality > F_{msy}	98 %	78 %
Risk fishing mortality > 1.7F_{msy}	56 %	9 %
Stock size (B/B_{msy}), median	0.62	0.72
Fishing mortality (F/F_{msy}), median	[illegible]	[illegible]
Productivity (% av MSY)	86 %	92 %

[illegible]	0	500	1000	[illegible]	[illegible]	[illegible]
Risk stock < B_{lim} (0.3B_{msy})	4 %	7 %	11 %	13 %	22 %	43 %
Risk stock < B_{msy}	66 %	73 %	85 %	90 %	96 %	99 %
Risk fishing mortality > F_{msy}	0 %	14 %	85 %	98 %	100 %	100 %
Risk fishing mortality> 1.7F_{msy}	0 %	1 %	41 %	81 %	96 %	100 %
[illegible]	31 %	44 %	66 %	72 %	86 %	[illegible]
Stock size(B/B_{msy}), median	0.82	0.73	0.60	0.55	0.44	0.34
Fishing mortality (F/F_{msy}), median	[illegible]	0.64	[illegible]	[illegible]	4.14	7.13
Productivity (% av MSY)	97 %	93 %	84 %	80 %	[illegible]	[illegible]

The assessment model

- Hierarchical state-space model using Bayesian inference
  - It handles
    - data sparse/unbalanced situations
    - observation and process errors
    - estimation of probability distributions
    - missing data ➡ Cope with unforeseen circumstances in statistical coherent manner.
  - Bonus ➡ Planned "missing data"

➡ "Borrow strength", Include uncertainty, Risk based advise.

Hvingel, C. and M.C.S. Kingsley. 2006. A framework to model shrimp (*Pandalus borealis*) stock dynamics and quantify risk associated with alternative management options, using Bayesian methods. *ICES J. Mar. Sci. 63:68–82.*

The survey index

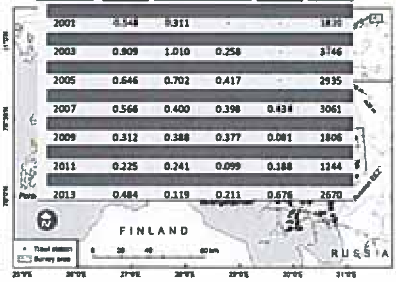
- Data is modeled
  - It handles
    - excess zeroes
    - non-normal distributed positive data ➡ reduce bias from inappropriate modeling.
    - missing data ➡ Cope with unforeseen circumstances in statistical coherent manner.
  - Bonus ➡ Planned "missing data"

Hvingel, C., Kingsley, M.C., Sundet, J.H. 2012. Survey estimates of king crab (*Paralithodes camtschaticus*) abundance off Northern Norway using GLMs within a mixed generalized gamma-binomial model and Bayesian inference. *ICES Journal of Marine Science 2012 Vol 69.(8): 1416-1426.*

Options for optimizing

- We want to reduce "single stock efforts"
  - Survey every second year ➡ Implications for the assessment model

➡ Implications for the survey model and then for the assessment model

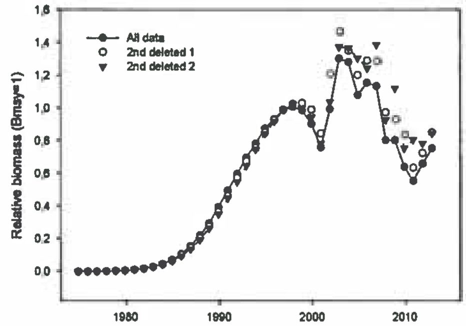


Year	Area: Varanger	Tana	Lakse	Porsang	Total
[redacted]					
2001	0.548	0.311	-	-	1830
[redacted]					
2003	0.909	1.010	0.258	-	3146
[redacted]					
2005	0.646	0.702	0.417	-	2935
[redacted]					
2007	0.566	0.400	0.398	0.434	3061
[redacted]					
2009	0.312	0.388	0.377	0.081	1806
[redacted]					
2011	0.225	0.241	0.099	0.188	1244
[redacted]					
2013	0.484	0.119	0.211	0.676	2670

The Analyses

Option 1: Count every second year

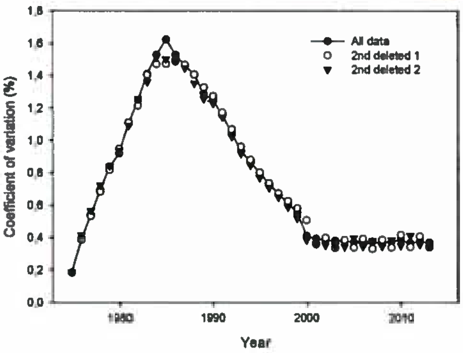
- Stock dynamics



The Analyses

Option 1: Count every second year

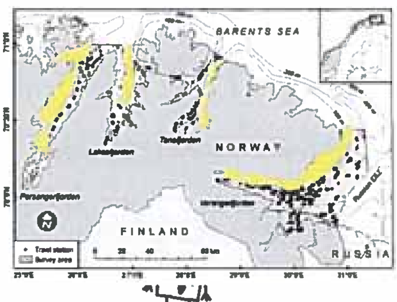
- Precision



The Analyses

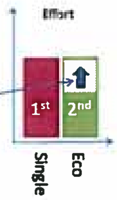
Option 2: Reduce counting within year

- Ongoing



The tasks

- Regarding the 1st task:
  - We can reduce "single stock efforts" up to 50% and still deliver!
  - Outstanding: finding the optimal approach
- The 2nd task:
  - Filling the Ecosystem box:
    - Process studies
    - Ecosystem Interaction
  - Determined by:
    - Management requests
    - Scientific questions



Goals

Before	After
• Advice – 90% counting – 10% ecosystem • Funding – 98% internal – 2% external • Science – 85% grey literature – 15% primary publ.	• Advice – 50% counting – 50% ecosystem • Funding – 80% internal – 20% external • Science – 70% grey literature – 30% primary publ.

Thanks for your attention!

Modeling of the population dynamics of commercial crabs in the Barents Sea

Konstantin Sokolov

The presentation was dedicated to some aspects and principals of stock assessments and modeling of commercial crab's population in the Barents Sea.
Both crabs (red king crab and the snow crab) are non-indigenous animals for the Barents Sea, playing quite important role in ecosystem and fishery.
Brief history of crab invasions shows rather good results of introduction.
The origin of the snow crab is still unclear and may be associated either with an accidental transport of larvae in the ballast water or with the natural migration. First capture of the snow crab was recorded in 1996.
In those days, the red king crab became very common in South of the Barents Sea. After 20 years there is completely different picture of distribution of crabs. There is almost no overlapping of these areas.
Now in the Barents Sea are two fishable stocks. One of them has been exploited over 15 years. The second stock of snow crab is just opened and has great potential.

These two stocks have some specific points which should be take into account for stock assessment. They are crustacean what means problem with age determination. In this case a possible solution can be to use size-structure models incorporated with stochastic growth and moulting processes. For advanced modelling we should take into account a spatial distribution of population. There are some concerns caused by problem of spatial structure modelling.
The second major problem with crab stocks in the Barents Sea is their invasive nature. Initial biomass in modelling cannot be equal of carrying capacity or virgin stock as for production models. Moreover there are not any assumptions concerning equilibrium state of the stock. Population dynamics are very unstable. The initial stage of invasive dynamic characterised by huge jump of abundance. During this stage one can obtain large observation errors in abundance idiocies.
And last problem is lack of information because crabs are new species for the Barents Sea having short exploitation history. Fishery performance is quite changeable from year to year. Scientific observation has short history. In the beginning there is a data-poor situation supposed that it is possible to reach a data-rich situation and use complex and powerful models.

Data collecting is initial stage for modeling. Red king crab fishery and scientific survey started at the same time. Initially there was good catch data because there were only 2 vessels and each vessel had observer onboard. Then situation with catch data was changed. Quality of catch statistic was dropped by some reasons. But since 2008 catch data is quite reliable and we can use it in models.
Considerable low catches in the beginning gave us quite large observation errors and outliers in obtaining of the survey index. Then stock was increased and survey catches were high and stable. Survey catch composition was good for complex model. Data quality was dropped from 2006. Survey was stopped in 2011 but from 2008 trap survey is carried out. During last 6 years design of survey was changed twice and quality of data is questionable.
Snow crab assessment is based on by-catch information from observers. Data was good in the beginning of observations. But since 2003 number of observers was decreased considerably and quality of data was dawn. Now the main assessment tool is Russian-Norwegian ecosystem survey. From year to year data quality is increasing. In 2013 we performed trap survey which can be based for new time series. Catch data for last year is poor because Russian vessel didn't participate in the fishery right now.

So according to data availability there are some periods what allow implementing different models. For red king crab there is a period when data can support: Catch-Survey analysis model. Length-based analysis; Last period we have a good fishery data and possible to use depletion models.

For snow crab the production model could be used. When survey data became representative the Length-Based Analysis also could be used.

Data poor approach can use simple production and depletion models. Surplus production model requires abundance index. In case of snow crab assessment we use number of by-catch observations for each year and indices from ecosystem survey. It is possible to use model with or without catch data. Bayesian approach can be used for prior assumption for carrying capacity and growth rate. Also we use Robin Hood approach in which assessments from data-rich species or population are used to inform assessments of data-poor species. For red king crab stock assessment last 3 years we use depletion model based on CPUE and catch data.

In case of medium approach the catch-survey analysis model can be used for the red king crab. This model can demand from two to four age groups of males. Stochastic growth parameters, catchability and natural mortality are evaluated using Bayesian approach.

In case of comprehensive catch data from survey and good catch statistic we should use length-based analysis. It's more complex model which use from 10 to 20 size classes of males and females. It requires catch composition by length classes. It also should include stochastic growth matrix and handling mortality options.

Data poor models have own advantages and disadvantages. For stochastic production model pros are:

1) Low data requirement;
2) Simple and understandable conception for fishery management;
3) Stochastic version with risk analysis and reference points.

But there are also some contras:

1) Mostly based on our assumptions than data (no virgin stock before fishery)
2) No recruitment assessment and prediction potential is very low.
3) Confidence interval is very wide and accuracy is low.

For depletion model pros are:

1) Quite reliable assessment for fishable stock;
2) Simple implementation;

And contras:

1) Do not reflect total stock dynamic and recruitment
2) No prediction.

Some principles of Catch-Survey Analysis were discussed.

Results of modeling using Length-Based analysis were shown. This is male abundance dynamic by year and classes from 1993 to 2013. Through the bulk of length classes there are high-abundance of year classes diagnosed very badly. Russian scientists rejected to use this model for the red king crab stock assessment. But we hope to use it in nearest future for snow crab assessment.

Assessment of crab stocks in the Barents Sea has a short history but is big challenge. Among them are usage of standard finfish assessment methods is limited by specific biological aspects of animal (growth, moulting, etc.); simple surplus-production approach is limited by invasive nature of populations and huge uncertainty of carrying capacity.; more complex size –structured analyses is limited by input data quality; but modeling work is in progress and many problems have been already solved by using; traditional and up-to-date methods; powerful software and stochastic calculations; international experience and data-rich populations.

Modelling of population dynamics of commercial crabs in the Barents Sea

Meeting of Russian and Norwegian scientists, March 2014
Assessments for management of living marine resources in the Barents Sea and adjacent waters – a focus on methodology

Sergey Bakanev, PINRO, Murmansk, Russia

Two commercial species of crabs

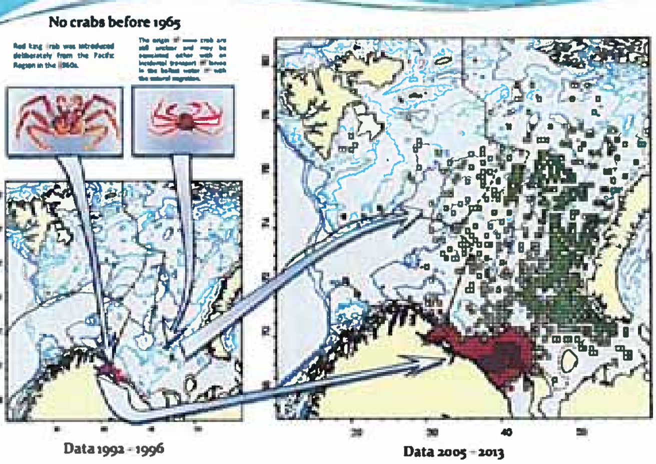
Red king crab

Scientific classification	
Kingdom	Animalia
Phylum	Arthropoda
Subphylum	Crustacea
Class	Malacostraca
Order	Decapoda
Infraorder	Anomura
Family	Lithodidae
Genus	*Paralithodes*
Species	*P. camtschaticus*
Binomial name	
Paralithodes camtschaticus (Tilesius, 1815)	

Snow crab

Scientific classification	
Kingdom	Animalia
Phylum	Arthropoda
Subphylum	Crustacea
Class	Malacostraca
Order	Decapoda
Infraorder	Brachyura
Family	Oregoniidae
Genus	Chionoecetes
Species	*C. opilio*
Binomial name	
Chionoecetes opilio (O. Fabricius, 1788)	

Occurrence of commercial crabs in the Barents Sea



Peculiarities of modelling

Three major points:

- Crustacean
- Invasive species
- New species for region

- **Crustacean species points:**

a) inability to age individuals prevents to use standard finfish assessment methods;
b) length-structured model based on stochastic growth by molt increases uncertainty;
c) spatial distribution should be take into account for sedentary and semi-sedentary species.

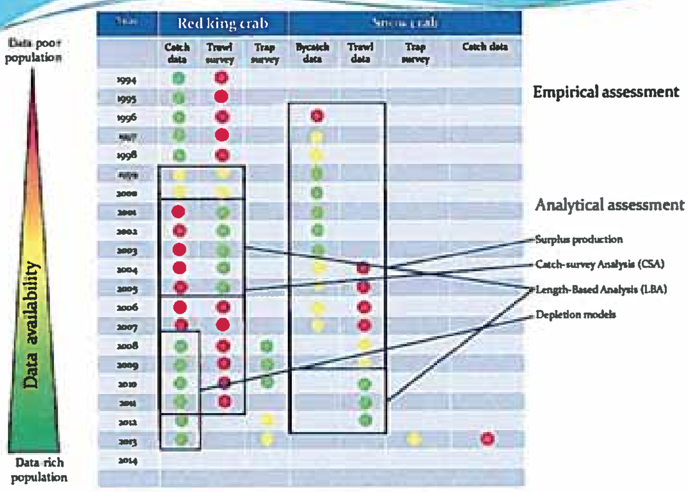
- **Invasive species points:**

a) no initial (virgin) biomass stock and unknown carrying capacity (K);
b) no any equilibrium assumptions for stock parameters under exponential population growth;
c) large observation errors as for low-abundance populations (during acclimatization stage).

- **New species points:**

a) no or short exploitation history;
b) short observation history;
c) data poor -> data rich population (simple -> complex model)

Data availability



Data vs Model

Red king crab — Snow crab

1990's

Time vector

2010's

Data poor approach

Surplus production model (Bayesian & Robin Hood Approach):
Abundance index (Number of bycatch observation, Survey Index),
Catch or no catch, Hypothetical value of Carrying Capacity (K) and Growth rate (r). The "Robin Hood" approach (in which assessments from data-rich species or population are used to inform assessments of data-poor species).
Depletion Models (Leslie and DeLury):
Catch and Catch-per unit efforts. Good VMS data from 2008.

Data medium approach

Catch-Survey Analysis (CSA):
Male 2-4 cohorts (Prerecruits I & II, Recruits and Postrecruits),
Total catch,
Stochastic growth; Several parameters in AD Model Builder or OpenBUGS (Bayesian approach)

Data rich approach

Length-Based Analysis (LBA):
Male and female 10-20 cohorts, Catch composition,
Stochastic growth, handling mortality;
Over 200 parameters in AD Model Builder.

Data poor approach

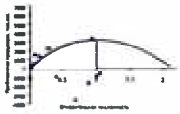
Surplus production model with Bayesian Approach

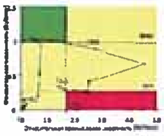
Pros:

1)Low data requirement;
2) Simple and understandable conception for fishery management;
3) Stochastic version with risk analysis and reference points.

Cons:

1) Mostly based on our assumptions than data (no virgin stock before fishery)
2) No recruitment assessment and prediction potential is very low.
3) Confidence interval is very wide and accuracy is low.





Total and natural mortality of red king crab (*Paralithodes camtschaticus*) in Norwegian waters: Catch curve analysis and indirect estimation methods

Kristin Windsland

The red king crab (*Paralithodes camtschaticus*) is native to the Bering Sea but was deliberately introduced to the Barents Sea during the 60's. Since then, the red king crab has spread to Norwegian waters and crab densities have increased sufficiently to support a coastal fishery. Information about total and natural mortality, which is important to ensure adequate management, is lacking. Estimates of annual total mortality (Z) were calculated using length-converted catch curves in three time periods of different levels of exploitation. Separate analyses were run on trap and trawl data as well as on original and CPUE-corrected data. Natural mortality was estimated using a linear regression of total mortality and exploitation level and by using indirect methods based on life-history parameters. There was a significant increase in Z throughout the consecutive time periods in both sexes. In males, the increase coincided with the increase in exploitation level. The increase in female mortality, which was not explained by exploitation level, is probably an effect of the increase in male mortality. The natural mortality (M) estimated using indirect methods, averaged 0.19 for both sexes. The estimated M using linear regression was 0.35/0.39, which may be an overestimate.

Total and natural mortality of red king crab (*Paralithodes camtschaticus*) in Norwegian waters:

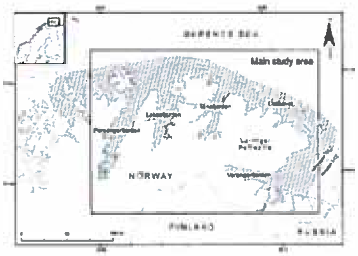
Catch curve analysis and indirect estimation methods

Kristin Windsland

HAVFORSKNINGSINSTITUTTET
INSTITUTE OF MARINE RESEARCH

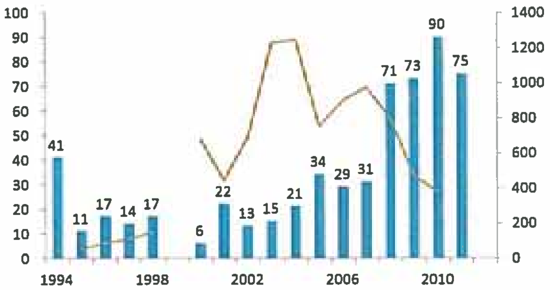
Data and study area

Length frequencies from 1995-2012



Study area:
•Varangerfjorden
•Tanafjorden
•Laksefjorden
•Porsangerfjorden

Introduction



Aims and methods

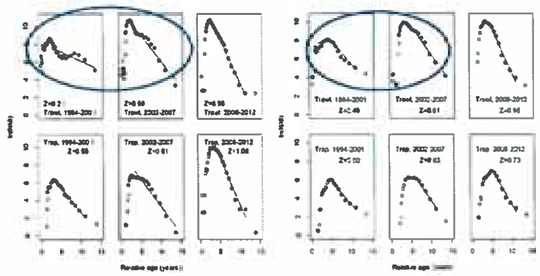
- Estimate total mortality using length-converted catch- curves (LCC)
  - Time period (Research, early commercial, late commercial)
  - Sex
  - Gear (Trap/trawl)
  - CPUE corrected data

Aims and methods

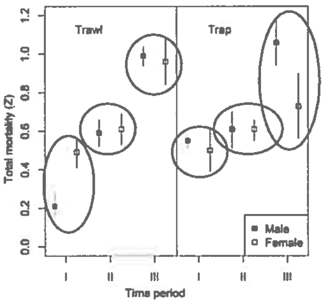
- Estimate natural mortality (M) by linear regression of total mortality (Z) and harvest rate (% of legal male population)
- Estimate natural mortality using indirecte estimation methods
  - Pauly (1980) — Linf, k, T
  - Jensen (1996) — k
  - Alverson and Carney (1975) — k, Life span
  - Hoenig (1983) — Life span
  - Quinn and Deriso (1999) — Life span

Results - Total mortality (Z) by LCC

Males Females



Results - Total mortality (Z) by LCC



Indication of small increase in Z from period I to period II

Large increase i Z from period II to period III

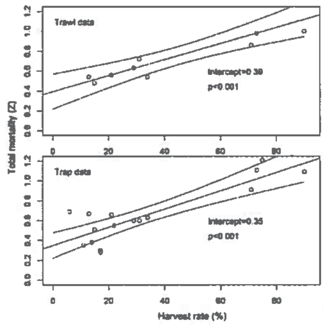
Male mortality is consistent with harvest rate

Unexpected rise in female mortality

Results - Natural mortality (M)

Linear regression

- M=0.35-0.39
- Consistent with studies in native areas
- Estimates are high considering live span
- Overestimation due to unaccounted bycatch mortality



Results - Natural mortality (M)

Indirect estimation methods

Source	M Female	M Male	Parameters
Hoenig (1983)	0.22	0.22	Life span
Quinn and Deriso 1999	0.23	0.23	Life span, p
Alverson and Carney 1975	0.14	0.12	Life span, k
Jensen (1996)	0.35	0.33	k
Pauly (1980)	0.20	0.20	Linf, k, Temp.
AVERAGE	0.22	0.22	
Linear regression Trawl	-	0.39	
Linear regression Trap	-	0.35	

Results – Fishing mortality (F)

Trap		M		F	
Period	Z	Regression	Ind. methods	Regression	Ind. methods
I	0.55			0.2	0.33
II	0.61	0.35	0.22	0.26	0.39
III	1.06			0.71	0.84

Summary and conclusion

- Increase in male Z is consistent with harvest rate
  - Exceeds 1.0 in period III
- Increase in female Z supports theory of Hjelset and others: Female survival is dependent on male survival
- Estimates of natural mortality range from 0.22-0.39

Thank you for your attention

Evaluation of the red king crab management

Guro Gjelsvik

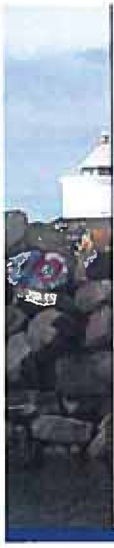
The management of red king crab in Norway has been regulated nationally since 2008. Since then the objective of the king crab management is to limit further spreading of king crab i Norwegian waters and maintain lowest possible stock outside quota regulated area and thus reduce risk for damaging effects on the ecosystem. At the same time the king crab stock inside the quota regulated area should be managed in a way that enhances employment and activity in the industry in the area. As these management objectives should be evaluated after five years, this work has now started in the Directorate of Fisheries.

The main issue will be evaluation of the established strategy. The strategy is to maintain a high harvest level inside the quota area to keep the stock at low level to prevent spreading. Outside the quota regulated area decimation catch has been carried out since 2010, in addition to free catch since 2004. Some other issues in evaluation will be conditions for participation in the quota regulated catch, the border for the quota regulated area and control measures for more effective control. The evaluation report will also include updated knowledge of the stock development and distribution, and the effects of the king crab on the eco system.

DIRECTORATE OF FISHERIES

Evaluation of the red king crab management

Tromsø, 12. march 2014



Introduction of red king crab to Norway

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- First red king crab in Norwegian waters: Varangerfjord 1977
- Increasing by-catch during the 80s
- Fisheries with gillnets and lines after cod, haddock and lumpfish in eastern Finnmark
- Problems with loss of gear, catch and time
- Spring 1992 turning point

From research to commercial catch

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- 1994-2001: Limited catch for scientific purposes. Norway and Russia agreed on yearly quota divided equally
- From 2002: Commercial catch joint managed in the fishery commision
  - Except west of 26°E: Free catch and discard ban from August 2004
- From 2007: National management

National management from 2007

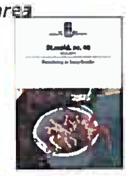
DIRECTORATE OF FISHERIES

- Report to The Norwegian Parliament

St.meld. nr. 40 (2006-2007) Forvaltning av kongekrabbe

➡ *Adopted by the Parliament 3. march 2008*

- *Objective to limit further spreading of king crab i Norwegian waters and lowest possible stock outside quota area*
- *Reduce risk for damaging effects on the ecosystem*
- *Manage the king crab stock inside the qouta area in a way that enhance employment and activity in the industry in the area*



The report meant a change of course for the management in Norwegian waters
Management should be evaluated after 5 years

Measures to limit spreading

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- Experience from the Bering Sea shows that high explotation level can contribute to reduction in crab stock, but not totally prevent spreading
- Low stock levels can represent lower spreading risk

➡ Through a continous high harvesting pressure is it possible to maintain stock level on such a low level that further spreading is prevented

Area of quota regulation

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Quota area

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- New borders for the quota area (including a northeren border, adjusted in 2010)
- Increased participation – establishment of an open group
- Allowing catches of females
- Quotas on damaged males
- Depth limitation removed
- Allowing recreational catches
- Allowing by-catches of king crab

Decimation catch since 2010

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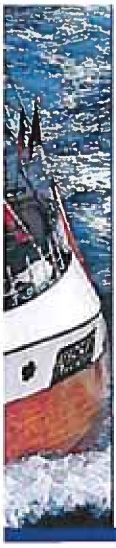
West of 26°E:

- Earlier the catches where not continous.
- Free catch and discard ban not enough to reduse stock level
- Catch effort needs to be large and continous



Main principals in fisheries mangement

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- Sustainable use of marine resources
- Ecosystem based approach
- Appropriate regulations
- Effective control and enforcement

Regulation

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- The regulation of the catch of king crab is on hearing each year
  - Participation access
  - Quotas
  - Minimum size
  - Start of season
  - Control measures
  - Other elements
- Department of Trady, Industy and Fisheries decide legislation

The evaluation process

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- Evaluation after 5 years
- Extended hearing in 2013
- Focus on development and experiences since 2008

Quota and catches

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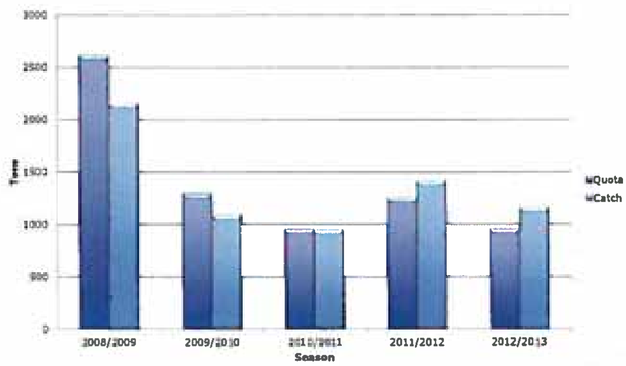

First-hand value and average price per kilo

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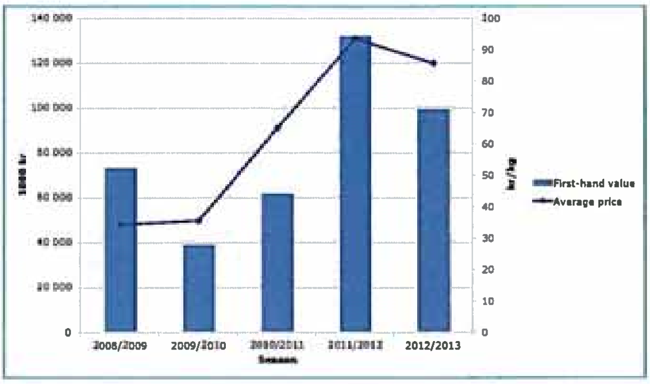

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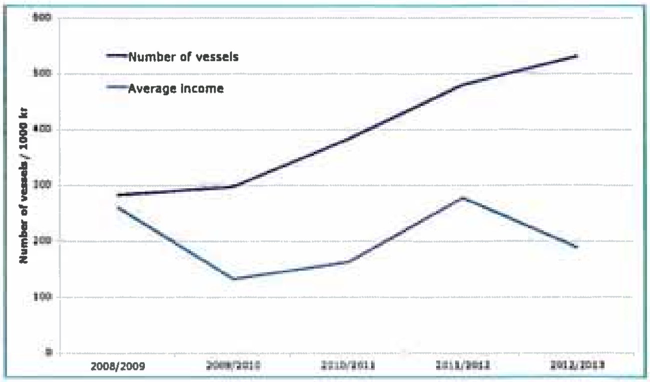

Outside qouta area

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Year	Catch	Vessels	First-hand value 1000 kr	Kr/kg
2013	272	185	16 023	58,83
2012	284	202	17 749	62,50
2011	356	215	19 354	54,37
2010	909	154	23 868	26,26
2009	4 439	220	86 916	19,58
2008	3 035	228	62 537	20,61

Some issues in the evaluation

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- Evaluation of established strategy
- Conditions of participation in quota regulated catch
  - Profitability
  - Intention for troubled fishermen
  - Approval scheme for vessels
  - Quotas – ladder?
- Current borders for quota area
  - Måsøy

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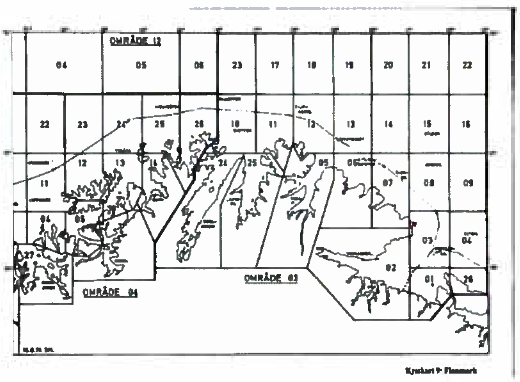

IMR contributes

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- Stock development, distribution and new knowledge

- Effects on the eco system
  - Effects of crab on bottom fauna
  - Effects on bottom spawning fish
  - Predation on the king crab
  - Spreading (migration, larvae)
  - Parasites and diseases ?

Challenges with control and enforcement

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- Control of landings
- Control at sea – cooperation with the coastguard

Measures for more effective control
- AIS/Satellite tracking
- Electronic reporting