Translated from Norwegian

(Logo and letterhead of the Norwegian Institute of Marine Research)

Snow Crab on the Norwegian Continental Shelf in the Barents Sea

Status and advice for 2021

Benthic resources and processes:
Ann Merete Hjelset
Carsten Hvingel
Hanna Ellerine Helle Danielsen
Jan H. Sundet

Fish Capture:
Odd-Børre Humborstad
Terje Jørgensen
Svein Løkkeborg

November 2020

Advice Snow Crab

The Norwegian Institute of Marine Research's advice for 2021

Catch alternative: The total catch in 2021 should not exceed 6500 tons. This corresponds to an estimated maximum probability of 35% that fishing mortality exceeds F_{msy}, and ensures low risk regarding a fall in population below B_{msy} by the end of 2021. Alternative catch alternatives with associated projections and risk calculations are:

	Catch alternatives for 2021 (tons)					
	4500	5000	5500	6000	6500	7000
Population probability < B_{lim}	<1%	<1%	<1%	<1%	<1%	<1%
Population probability < B_{msy}	17%	19%	20%	21%	23%	25%
Fishing mortality probability > F_{msy}	7%	12%	18%	25%	34%	43%
Fishing mortality probability > F_{lim}	1%	2%	2%	4%	6%	9%
Population change 2020 to 2021	-2%	-4%	-5%	-9%	-11%	-15%
Fishing mortality change 2020 to 2021	0%	+6%	+15%	+22%	+30%	+38%

In order to ensure maximum as well as sustainable long-term fishery, fishing mortality should not have more than a 35% probability of exceeding F_{msy}. Over time, the population should be around B_{msy} to ensure maximum sustainable yield and contribute to stable and predictable quotas.

Quota flexibility: Transfer of quota from future quota years should not cause the current year's total catch quota to exceed the advice regarding maximum catch.

Minimum size: The minimum size of 95 mm shell width for male crabs will continue to ensure high value catches and protect the reproductive potential of the population.

Protection period: Closure of the snow crab fishery during the period 1 July to 30 September should be maintained in order to protect crabs that are moulting shells.

Ghost fishing: Requirements regarding the use of rot cord (untreated cotton twine) in the crab pots to prevent ghost fishing in the event of fishing gear loss, with associated unintentional mortality and unacceptable animal welfare.

Management objectives

The management objective for snow crab on the Norwegian continental shelf (ref. Ministry of Trade and Industry and Fisheries) is *a sustainable harvest that provides a basis for societal value creation, based on the knowledge of how species affect each other in the ecosystem*. This is to be achieved by balancing the sub-objectives:

1) maximising the long-term catch yield, and 2) minimising the risk of unwanted ecosystem effects.

Commercial fishing area
Commercial fishing for snow crab takes place in a delimited area on the Norwegian continental shelf. Outside this area, the density of crab is currently too low and not of fishery interest. Therefore, the population advice for 2021 only applies to the delimited sub-area shown in Figure 1.

The basis for the advice
The Norwegian Institute of Marine Research uses the following considerations as a basis in order to achieve the management objectives:

Sub-objective 1. The maximum sustainable yield is achieved by optimising catch volume and catch rates. The compromise between the highest possible catch volume and catch rate is reached through an exploitation where fishing mortality is slightly below F_{msy}. Over time, this will be consistent with a population close to B_{msy}. A population at this level will ensure high production and at the same time act as a buffer for variable recruitment, and promote fishery stability.

The snow crab population is relatively well protected against a recruitment shortage caused by fishing (depletion of the spawning population), as long as the size at sexual maturation in female crabs is significantly lower than the minimum size for male crabs, and that soft crabs and egg-bearing female crabs are released alive. Therefore, fishing only for large males will normally ensure adequate production of fertilised eggs. A relatively high minimum size makes it possible to exploit the crab relatively hard. This means that the majority of what is recruited to the catchable population is taken out each year. The risk of such a strategy will be a more unpredictable fishery that varies with the large fluctuations in recruitment. It is not likely that such a strategy is desirable for the seafood industry, despite the fact that high exploitation can be justified based on biological considerations. A desire for fishery stability and longevity therefore requires that the standing population of snow crab above the minimum size is so large that it can act as a buffer against the variations in recruitment.

Based on the above considerations, the qualitative management objectives have been reformulated to the following measurable references:

- F_{msy}: The fishing mortality that provides maximum sustainable yield and should have a maximum of 50% probability of going above F_{msy}. Normally, this probability should be less than 35%.
- B_{msy}: The population size that provides maximum sustainable yield (MSY). The population should be at a level close to B_{msy} to ensure maximum production and contribute to fishery stability.
- Minimum size: The snow crab size that ensures the reproductive potential of the population is not reduced.
- Fishing season: The period of the year that maximises the economic value per male crab caught and provides protection during the moulting period.

Sub-objective 2. Generally, we have little knowledge about the effects of snow crab on the ecosystem. Modelling indicates little effect on other commercial fishery resources, but it seems to have an impact on benthic fauna. A reduction in the amount of snow crab is therefore the only measure that can minimise the impact on benthic fauna. The Norwegian Institute of Marine Research and others are working to increase the level of knowledge about possible ecosystem effects.

Status 2020, Summary

Population size
The snow crab population has increased significantly since 2010. The biomass of snow crabs with a shell width larger than 95 mm is estimated to be just above B_{msy} in 2020.

Fishing mortality
Fishing mortality in 2020 is estimated to be below F_{msy}.

Protection period
Protection during periods when there are a lot of soft crabs (moulting) will reduce catch-related mortality (handling of catch) and one avoids harvesting crab of low product quality. There is no new information indicating a change to the protection period of 1 July to 30 September.

Spread
Snow crab have spread northwards and westwards in the Barents Sea, and are probably found in all suitable habitats on the Norwegian continental shelf in 2020. However, it is currently difficult to predict which areas will achieve catchable densities of snow crab; it depends on factors such as habitat, depth, temperature and available food.

Future perspectives
The snow crab is new to the Barents Sea ecosystem, and the population is likely to continue to grow. However, the ongoing increase in temperature of Arctic waters could affect the distribution of and recruitment to the snow crab population in our waters.

Ecosystem effects
The biomass of snow crabs has gradually become large in the Barents Sea, and it is therefore reasonable to assume that the crab will have an effect both as a predator of benthic animals and as prey for fish. Studies show that snow crab eat a variety of organisms and is itself eaten by cod, haddock, American plaice and thorny skate. We have some studies that indicate that snow crab can affect the benthic fauna. Investigations show that snow crab can also be a carrier of various parasites. Based on current knowledge, there is little to suggest that fishing for snow crab or the snow crab itself will have negative effects on other fishing resources.

Origin
Snow crab was first found on Goose Bank in the south-eastern part of the Barents Sea in 1996. The main hypothesis is that snow crab has spread by migrating west from the Chukchi Sea, north of the Bering Strait, along the north coast of Russia and into the Barents Sea. Preliminary genetic analyses support this.

Advice background

Snow crab has now been recorded across large parts of the Barents Sea and the Kara Sea (Figure 1) and in the area around Svalbard, but most of the population continues to be found on the Russian continental shelf in the Barents Sea. On the Norwegian continental shelf, the population density is highest in the areas around the Central Bank, and this is where commercial fishing takes place. The Norwegian Institute of Marine Research has carried out a survey to map the distribution of snow crab on the Norwegian continental shelf. These investigations, together with individual finds of snow crab northwest and southwest of Spitsbergen, show that large parts of potential snow crab habitat are about to be colonised. However, the density of crabs outside the areas where fishing is currently practiced is too low for them to be of commercial interest. It is expected that the distribution and density of snow crab will continue to increase to the west and to the north.

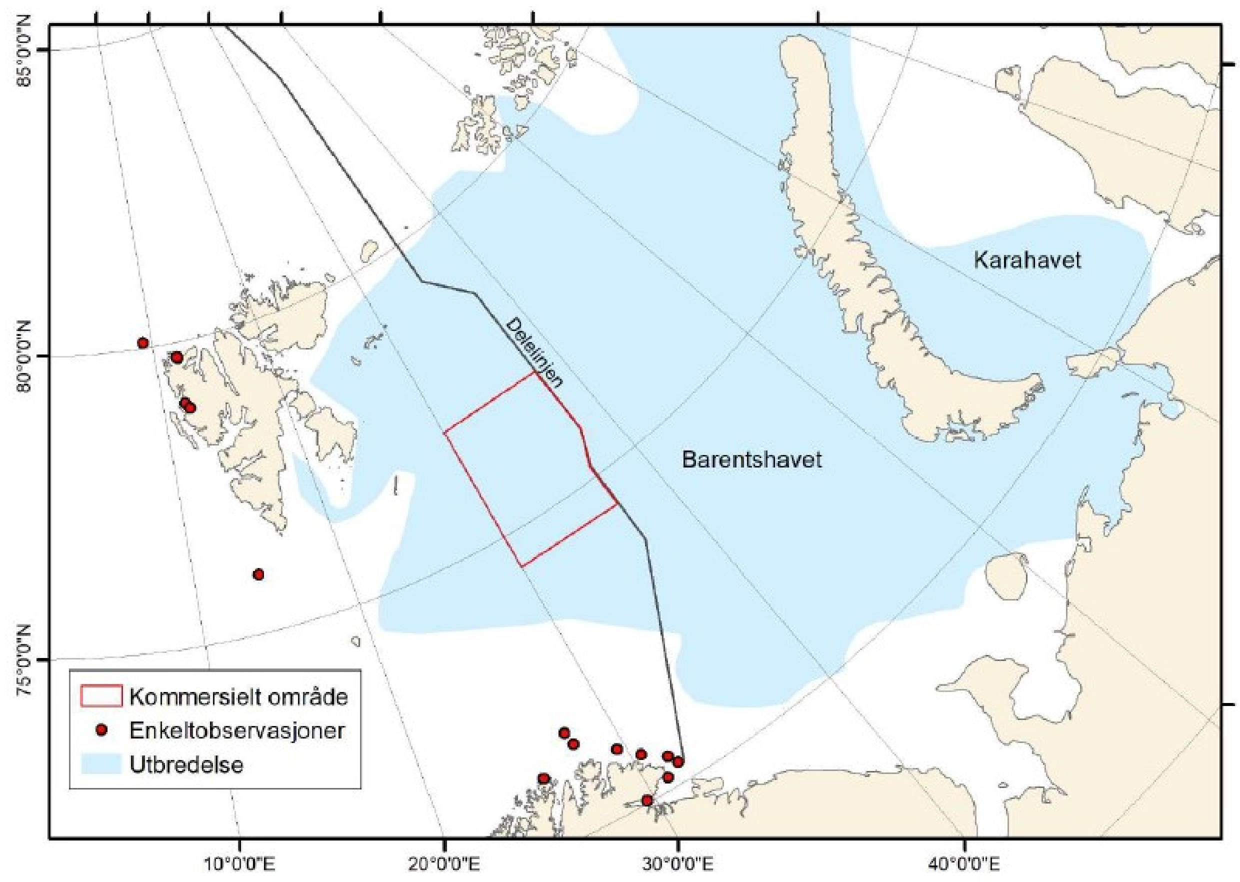


Figure 1
Kara Sea
Barents Sea
Delimitation line
Commercial fishing area
Individual observations
Distribution

Figure 1: Status of continuous distribution of snow crab in the Barents Sea and the Kara Sea, and individual observations made along the coasts of Troms, Finnmark and on the west coast of Svalbard. The area for commercial fishing is marked on the map.

Data sources

The advice is based on data from the joint annual Norwegian/Russian Ecosystem Survey in the Barents Sea, the Norwegian Institute of Marine Research's snow crab survey, crab fishing logbooks and landing data from the fishery, as well as other research on snow crab in the Barents Sea and other areas of sea conducted by the Norwegian Institute of Marine Research or other institutions.

This year's snow crab survey was carried out in the area where snow crab fishing takes place, during the period 25 June - 9 July 2020 (Figure 2 and Figure 3, to the right). The methodology used to monitor the snow crab population is constantly evolving. It is based on a methodology that has been tried and tested when monitoring the red king crab population along the coasts of Troms and Finnmark. In order to get the most comprehensive coverage of the population, Agassiz trawls, a video sledge and crab pots were used during the survey (Figure 2). The area that is considered a commercial fishing area and for which quota advice is given was divided into areas based on depth. The video stations were distributed randomly within the areas, with most stations located in the areas just south and north of the Central Bank. The video sledge transmitted directly to the vessel, and we could observe and count the number of snow crabs in real time. Benthic substrate and other observations were also noted. A haul was also made with the Agassiz trawl at approximately every other video station. As much as was possible, the trawl was dragged along the same track as where the video sledge was dragged. No trawling stations were planned in the shallowest areas or in areas where it is known that there are unfavourable seabed conditions for Agassiz trawls. We chose instead to use the video sledge in these areas. The crab pot stations were placed in areas where it was assumed that good catches could be made based on data from electronic crab fishing logbooks from the fishery. Despite the fact that the survey took place at the same time as fishing was being conducted, we achieved good coverage in the areas south and north of the Central Bank, while we had to reduce the number of stations on the outskirts of the area.

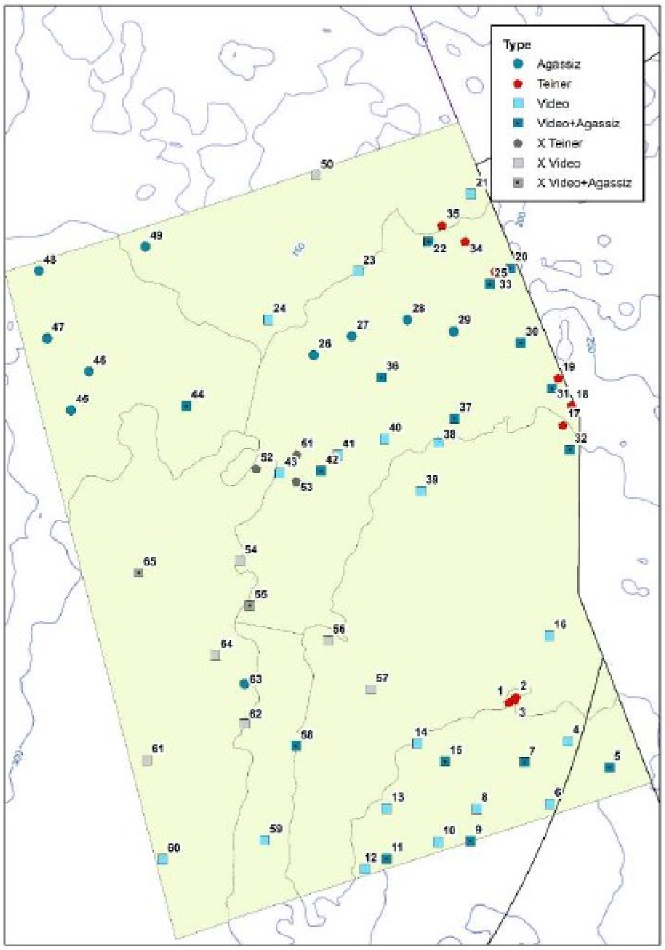
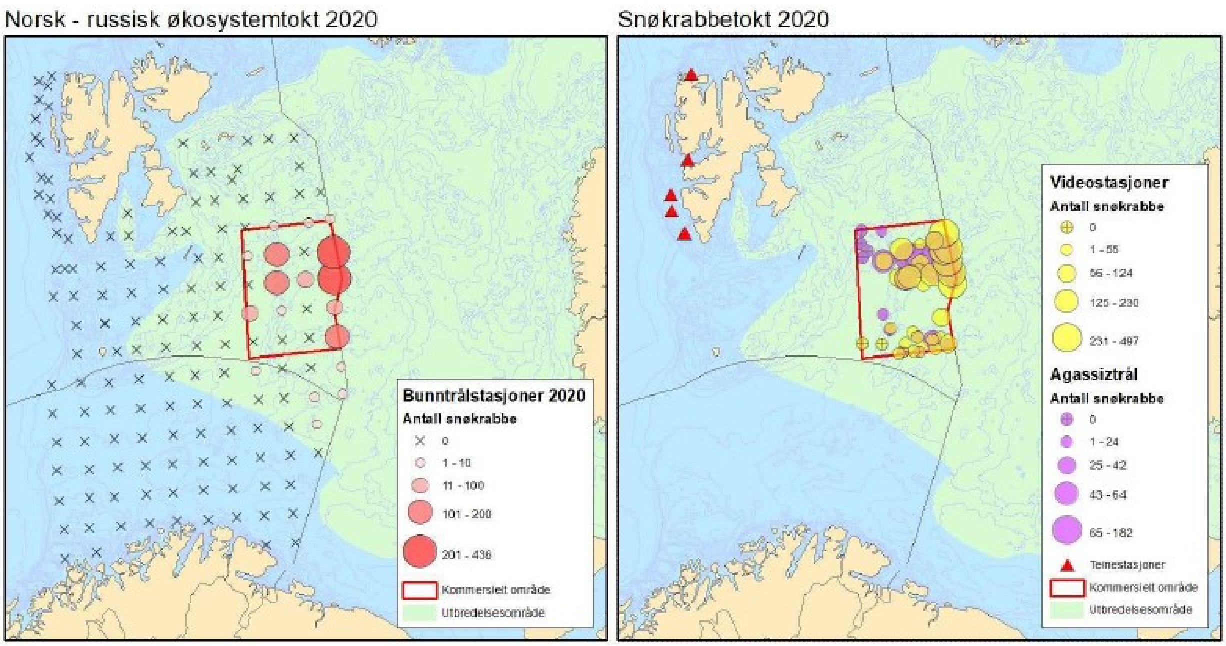


Figure 2
Agassiz
Crab pot
Video
Video+Agassiz
X Crab pots
X Video
X Video+Agassiz

Figure 2: Planned and implemented stations for the snow crab survey in June and July 2020. The stations are distributed over the area for which quota advice is given. The stations are marked with different symbols and colours according to the equipment used (see legend in figure). Stations that had to be left out of the survey are shown in grey and are marked with an X.

The joint annual Norwegian/Russian Ecosystem Survey uses a permanent station network that covers the entire Barents Sea and is carried out during the period August - October (Figure 3, to the left). Pelagic trawls and bottom trawls are used, and plankton samples are taken. Data from the bottom trawl are used in the advice given on snow crab, while samples of plankton are used to follow the distribution of snow crab larvae. During some years, Ecosystem Survey coverage is limited in the northern areas and the areas around Svalbard by drift ice. In recent years, there has been variable coverage on the Russian continental shelf, mainly due to challenges with the research vessel used. This year, the survey has not been completed on the Russian continental shelf, and we only show the status on the Norwegian continental shelf. This year's Ecosystem Survey, which covers large parts of the Norwegian continental shelf (Figure 3, to the left), shows no significant change in the distribution of snow crab compared with previous years. We have experienced that this survey mostly catches snow crab in areas that have relatively high densities.



Joint annual Norwegian/Russian Ecosystem Survey 2020	Snow Crab Survey 2020
Figure 3 Bottom trawl stations 2020 Number of snow crab 0 1-10 11-100 101-200 201-436 Commercial fishing area Population area	Video stations Number of snow crab 0 1-55 56-124 125-230 231-497 Agassiz trawl Number of snow crab 0 1-24 25-42 43-64 65-182 Crab pot stations Commercial fishing area Population area

Figure 3. Surveyed stations and catches of snow crab in the Barents Sea on the Norwegian continental shelf from the joint annual Norwegian/Russian Ecosystem Survey 2020 (left). Surveyed stations and catches of snow crab on the Norwegian continental shelf from the Snow Crab Survey 2020 (right). The commercial fishing area is marked on the maps.

Fishery

The first commercial catch of snow crab was landed in 2012. Up to and including 2016, much of the fishing took place on the Russian continental shelf in the Loop Hole, but from 1 January 2017, the Russian continental shelf in the Loop Hole was closed to non-Russian vessels. After 2017, Norwegian fishing has mainly taken place in a concentrated area north and south of the Central Bank in the Fishery Protection Zone around Svalbard as well as in the Norwegian Economic Zone and in the Norwegian part of the Loop Hole. Reported fishing positions from Norwegian snow crab vessels during the period 2012-2016, and from 2017 to November 2020, show that the fishing grounds have not changed significantly during the four years following the closure of snow crab fishing in the Loop Hole (Figure 4).

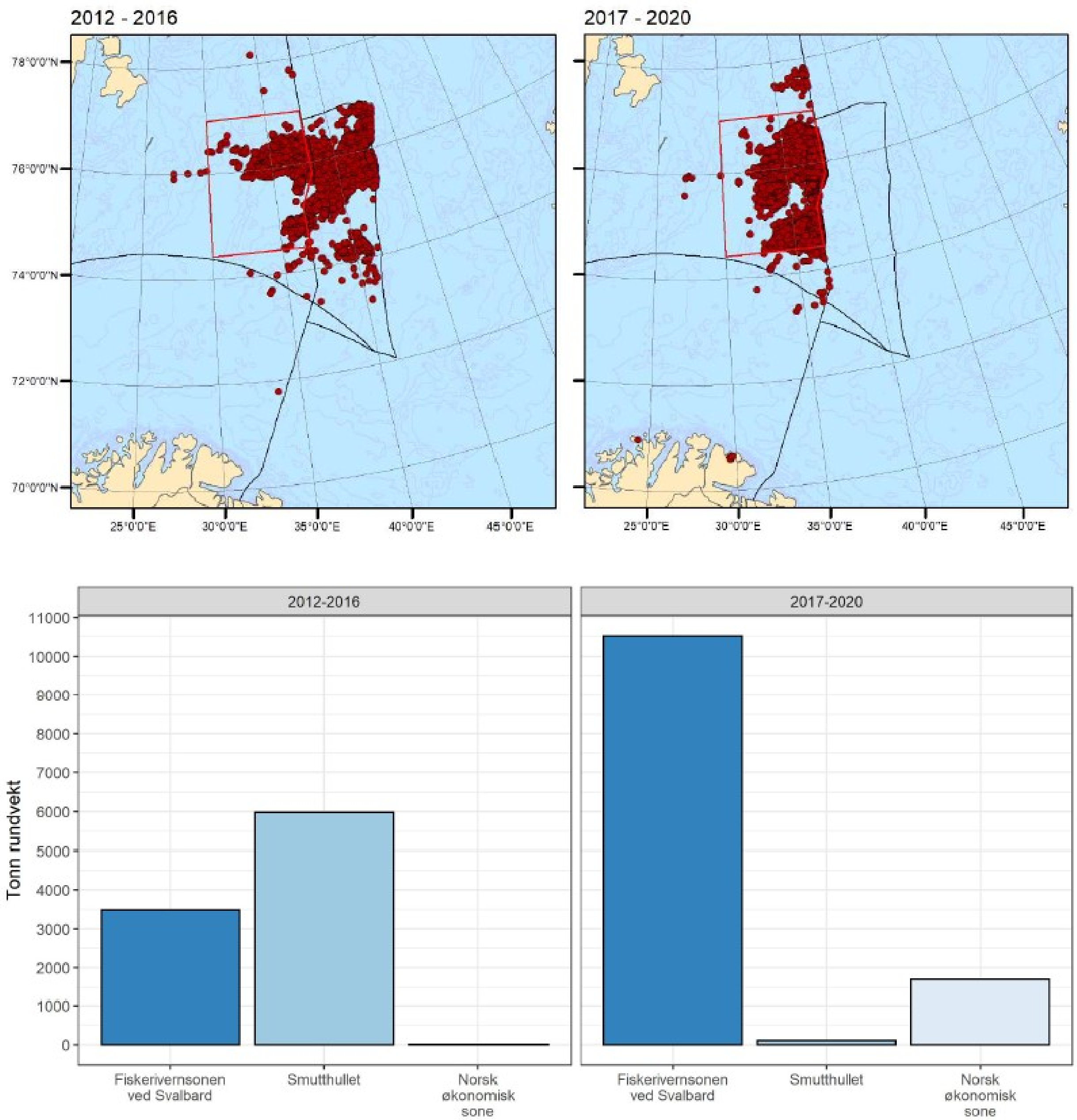


Figure 4 (upper)	

Figure 4 (lower) 2012-2016 Round weight (tons) Fishery Protection Zone around Svalbard The Loop Hole Norwegian Economic Zone	2017-2020 Fishery Protection Zone around Svalbard The Loop Hole Norwegian Economic Zone

Figure 4. Catch positions from the Norwegian fisheries divided into two periods, 2012 - 2016, 2017 - 2020 (upper panel). Landings in tons distributed over the three most used areas in the Barents Sea for the same two periods (lower panel). The data is taken from the Norwegian Directorate of Fisheries' electronic crab fishing logbooks and may contain errors.

In 2017, catch restrictions (introduction of quotas and area regulations) were introduced in Norwegian fisheries (Table 1). The minimum catch size was previously a shell width of 100 mm, but this was reduced to a shell width of 95 mm as of 10 July 2020. The rest of the year's quota is therefore fished with a reduced minimum size. Since 2018, a protection period has been introduced during the summer months (Figure 5). In 2019, the entire quota of 4000 tons was caught during October, and data from the crab fishing logbooks show that 3405 tons of the year's 4500-ton quota have been caught as of 11 November 2020.

Tabell 1. Anbefalte fangstalternativ for norsk kvote, fastsatte kvoter og fangster av snøkrabbe (tonn) i Barentshavet i perioden 2012 – 2020 fordelt på nasjoner.

	Fangstalternativ (tonn)	*Fastsatte kvoter (tonn)*		Landet (tonn)			Totalt landet (tonn)
År	Norsk	*Norsk*	*Russisk*	Norge	Russland	EU-land	
2012		-	-	2	0	0	2
2013		-	-	189	62	0	251
2014		-	-	1 800	4 104	2 300	8 204
2015		-	*1 100*	3 482	8 895	5 763	18 140
2016		-	*1 600*	5 290	7 520	3 690	16 500
2017	3 600 – 4 500	*4 000*	*7 840*	3 153	7 780	2	10 847
2018	4 000 – 5 500	*4 000*	*9 840*	2 804	9 728	-	12 532
2019	3 500 – 5 000	*4 000*	*9 840*	4 038	9 840	-	13 878
2020	< 5 500	*4 500*	*13 250*	*3 405	**10 500		*13 905

** per 11. november 2020 **per 29.oktober 2020*

Table 1. Recommended catch alternatives for the Norwegian quota, fixed quotas and catches of snow crab (tons) in the Barents Sea during the period 2012 - 2020 by nation.

	Catch alternative (tons)	Fixed quotas (tons)	Landed (tons)	Total landed (tons)
Year	Norwegian	Russian	Norway Russia EU-countries	

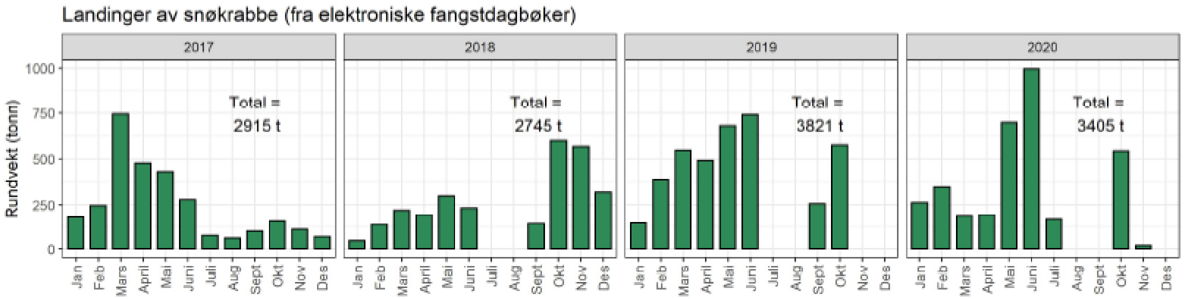


Figure 5
Landings of snow crab (from electronic crab fishing logbooks)
Round weight (tons)

Figure 5. Landings of snow crab in the Norwegian part of the Barents Sea based on electronic crab fishing logbooks. Data from October and November 2020 are incomplete. The weight is estimated on board and may differ from the official landing figures in Table 1.

Russian fishery has taken place on the Russian continental shelf east of the Loop Hole after it was closed for fishing in 2017 (Figure 6). Higher quotas and larger landings over the past 4 years reflect larger quantities of catchable snow crab in the Russian zone (Table 1).

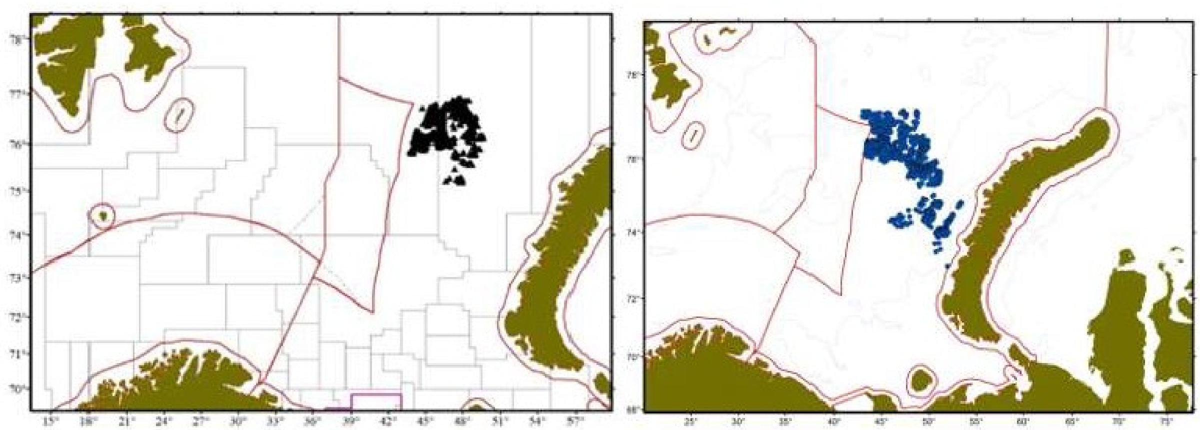


Figure 6

Figure 6. Catch positions from the Russian snow crab fishery for 2018 (left) and 2020 (right).

Fishery catch rates on the Norwegian continental shelf

Fishermen keep electronic crab fishing logbooks, and they were also required to report effort (number of pots per string) from May 2015. On average, each boat fishes using 200 pots per string. The data from the crab fishing logbooks allow us to calculate a catch rate index that shows the average catch per pot per month scaled to the average catch per pot for the entire period. After access to the Loop Hole was closed (January 2017), the catch rate index gradually declined, with the exception of an increase in March 2017, and it remained at a lower level until the spring of 2018 (Figure 7). After the fishery was closed in the summer of 2018, we saw an increase in the catch rate index with a decline during the winter. Catch rates picked up again during the spring of 2019 and peaked in May. The fishing in 2020 has followed somewhat of the same pattern as in 2019. The winter seasons can be characterised by a lot of ice which makes it difficult to get to the best fishing areas. One explanation for the increase in the catch rate index is that when the ice retreats, the catch rate index increases again. Low values for October and November may be due to delays in reported data and non-delivery. It is expected that the quota for 2020 will be caught during the year. As of 2020, 42 Norwegian boats have been given permission to fish for snow crab, but only 11 vessels have been active as of November this year.

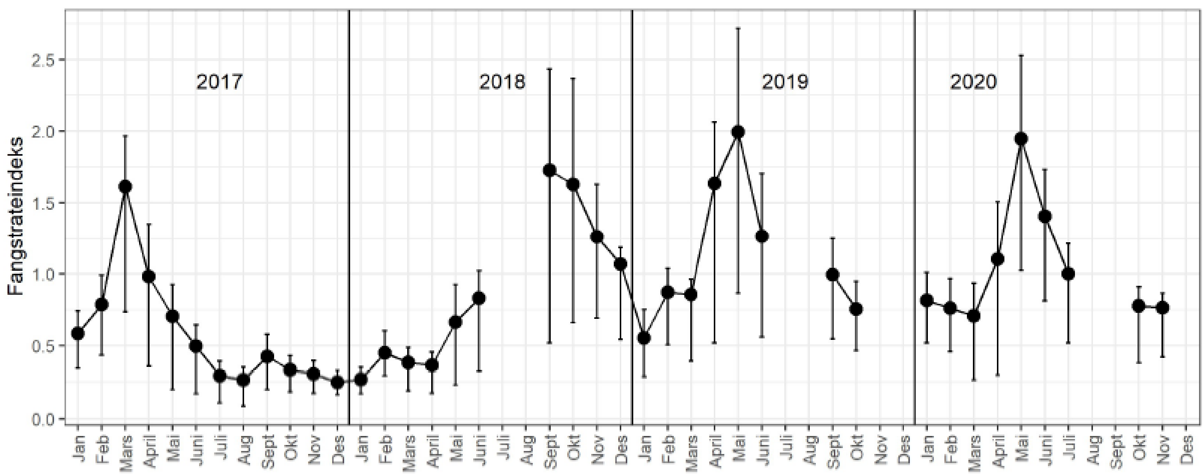


Figure 7
Catch rate index

Figure 7. Catch rate index calculated from electronic crab fishing logbooks. The index is the average catch per pot per month scaled to the average catch per pot for the entire period of 2017 to November 2020. Data from October and November 2020 may be incomplete.

Population Assessment

This year's population assessment is based on data from the joint annual Norwegian/Russian Ecosystem Survey, fishery catch data (Table 1), existing knowledge from the populations on Canada's east coast and in the eastern Bering Sea, and data from the Snow Crab Survey. Analyses of Barents Sea cod's consumption of snow crab have been used as an additional measurement for population development and catch rate from electronic crab fishing logbooks (Figure 8).

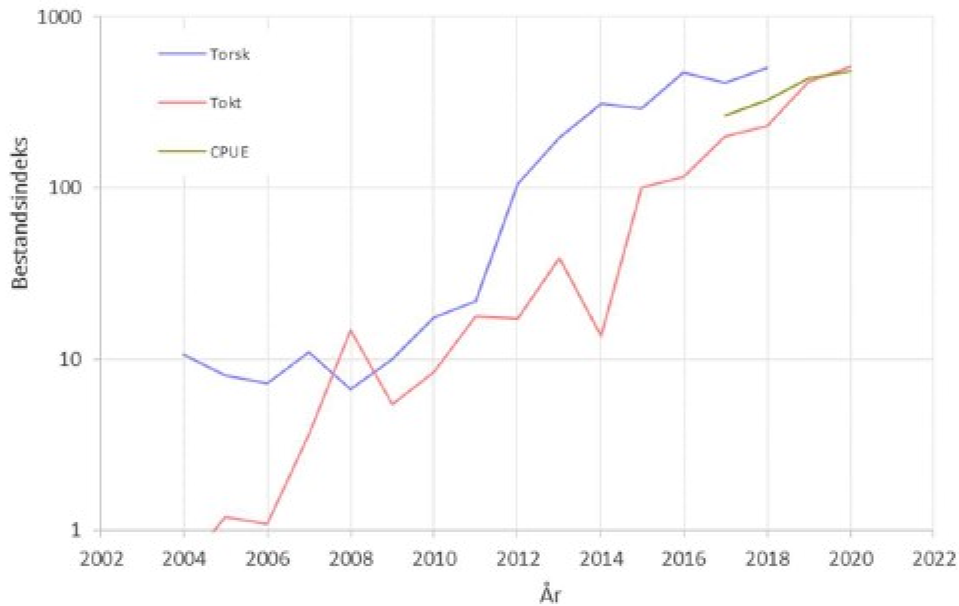


Figure 8 Population index Cod Survey CPUE

Figure 8. Biomass index based on data from the joint annual Norwegian/Russian Ecosystem Survey in the Barents Sea (2004-2020), analyses of the amount of snow crab found in cod stomachs (2004-2018) and catch rates (CPUE) from electronic crab fishing logbooks (2017-2020).

Calculation methodology

The total expanse of the area covered by the population calculations (Figure 1) is 50,000 km^2, and the majority is considered suitable snow crab habitat (depth between 100-500 metres, benthic temperature -1 to +4 ºC). With these delimitations, the habitat size is estimated to be 45,000 km^2 and the model parameters are therefore scaled to this area.

The population indices (Figure 8) are calibrated in a mathematical model that is used to describe population development and make forecasts and risk analyses. The model assumes a logistical population growth and is a so-called Bayesian model which, in addition to population and landing data, can use other relevant information (Hvingel and Kingsley 2006). These are entered as a probability distribution for the relevant variables (so-called 'priors') such as carrying capacity (K) and maximum sustainable yield (MSY) (Figure 9). The less data we have, the more these priors will drive the model.

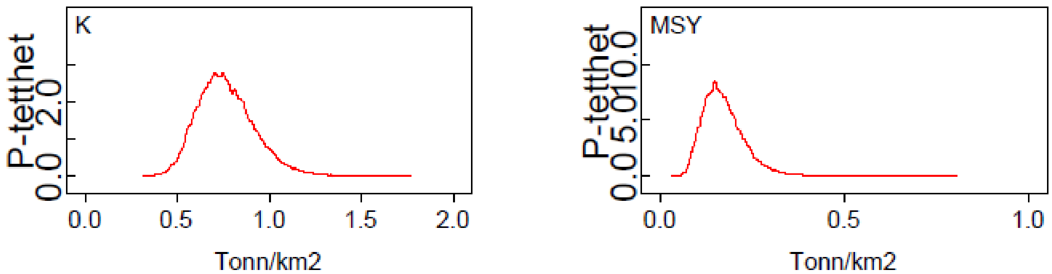


Figure 9
P-density
Tons/km^2

Figure 9. Model input data: Priors given with probability density (P-density) for carrying capacity (K) and maximum sustainable yield (MSY), based on snow crab population estimates in Canada.

The model calculates population sizes in relative rather than absolute values. MSY (maximum sustainable yield) is used as a reference point. In the following, both population size and fishing mortality are stated on a relative scale, where the value 1 corresponds to the biomass and fishing mortality corresponding to MSY, respectively.

Reference points used in the description of population status and degree of exploitation:

- MSY = Maximum sustainable yield/maximum production.
- B_{msy} = Population size (biomass) that gives MSY. In the model, this is a relative value equal to 1.
- Carrying capacity = the maximum population size that the ecosystem can maintain without a fishery. In the model, this is a relative value equal to 2.
- B_{lim} = 0.3B_{msy} (the precautionary principle was used as the marginal value for population size, usually a limit for closure or sharp reduction in fishing).
- F_{msy} = Fishing mortality (degree of exploitation) that gives MSY, i.e., the exploitation that drives the population towards B_{msy}.
- F_{lim} = 1.7F_{msy} is the fishing mortality that drives the population towards B_{lim} (0.3B_{msy}).

The model is able to perform a reasonably good simulation of the data (Figure 10). The model's capacity to reproduce the historical development in the snow crab population gives reason to believe that it can also be used to make projections, at least over a shorter time perspective. Quality assurance of the model's ability to make good projections can only be performed when one has longer time series data.

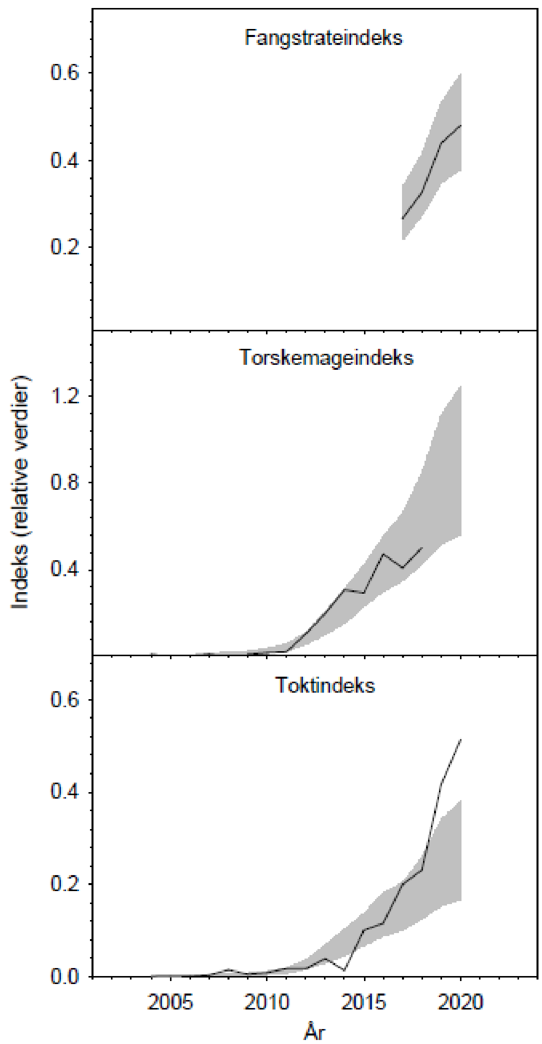


Figure 10
Index (relative values)
Catch rate index
Cod stomach index
Survey index
Year

Figure 10. Observed index values (black line) and 80% confidence interval (grey area) of the model's corresponding estimate.

Population development, fishing mortality and projections

After a period of approximately 15 years following the first discovery of snow crab in the Barents Sea, the population index increased rapidly (Figure 11 A). This increase has also continued after fishing picked up after 2012 (Figure 11 B). It is highly probable that the population (B) in 2020 is above B_{msy} (15% probability that $B<B_{msy}$ (Table 2)). Fishing mortality is lower than F_{msy}, and there is only a 5% probability that F is above F_{msy} (Table 2).

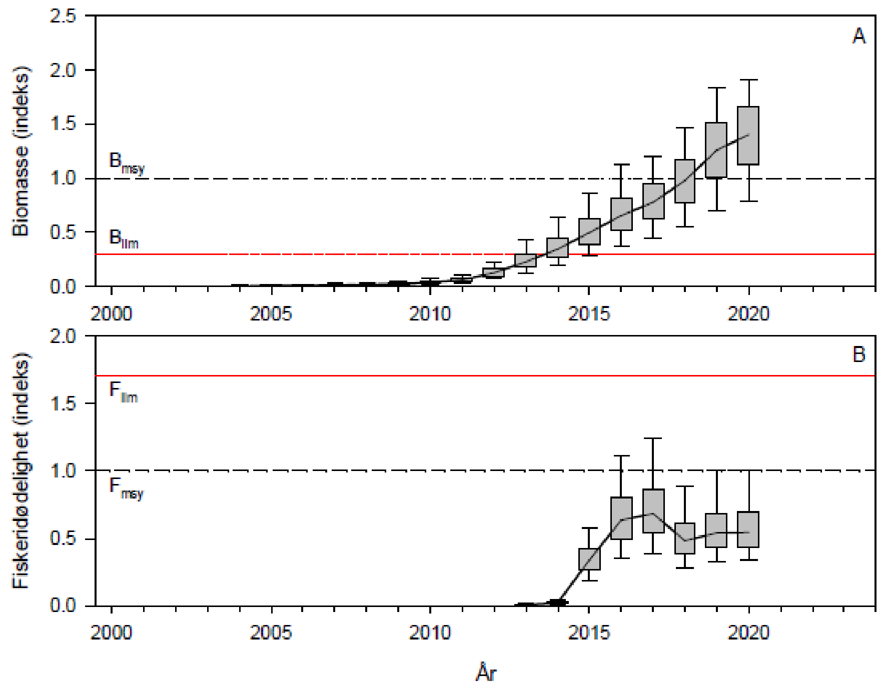


Figure 11 (upper) Biomass (index)	
Figure 11 (lower) Fishing mortality (index)	

Figure 11. Development in relative population size (A) and fishing mortality (B) for snow crab (shell width ≥95 mm) in quota-regulated area on the Norwegian continental shelf. Black dashed horizontal lines indicate biomass (B_{msy}) and fishing mortality (F_{msy}), respectively, which provide maximum sustainable yield. Solid red lines indicate the marginal values for population size (B_{lim}) and fishing mortality (F_{lim}). Vertical lines show 95% confidence intervals, while vertical columns show interquartiles (25th – 75th percentile).

Table 2. Population status for snow crab in quota-regulated area on the Norwegian continental shelf 2019-2020 (for description of reference points, see text). The risk is given as calculated probabilities in percent.

Status	2019	2020*
Population probability < Blim	0.0%	0.0%
Population probability < Bmsy	24.4%	15.2%
Fishing mortality probability > Fmsy	5.0%	5.2%
Fishing mortality probability > Flim	0.1%	0.1%
Population size (B/Bmsy), median	1.26	1.41
Fishing mortality (F/Fmsy),	0.54	0.55
**Estimated catch = 4500 tons*		

Projection

Projections and catch alternatives for 2021 were analysed (Table 3). In order to meet the defined management criteria (the risk of fishing mortality exceeding F_{msy} must not exceed 35% and the population must be close to B_{msy}), 2021 catches can amount to a maximum of 6500 tons. Therefore, we recommend that catches on the Norwegian continental shelf during 2021 do not exceed 6500 tons (Table 3).

Table 3. Catch alternatives for snow crab in quota-regulated area for 2021. Risks associated with the catch alternatives and stated as probabilities in percent.

	Catch alternatives for 2021 (tons)					
	4500	5000	5500	6000	6500	7000
Population probability < Blim	<1%	<1%	<1%	<1%	<1%	<1%
Population probability < Bmsy	17%	19%	20%	21%	23%	25%
Fishing mortality probability > Fmsy	7%	12%	18%	25%	34%	43%
Fishing mortality probability > Flim	1%	2%	2%	4%	6%	9%
Population change 2020 to 2021	-2%	-4%	-5%	-9%	-11%	-15%
Fishing mortality change 2020 to 2021	0%	+6%	+15%	+22%	+30%	+38%

In the long term, it is expected that the spread of snow crab will continue further west and north in the Barents Sea. During the past year, no new individual finds of snow crab have been reported outside the areas where they have been found in the past. In the allocation letters for 2019 and 2020, respectively, the Norwegian Polar Institute has been asked to collaborate with the Norwegian Institute of Marine Research in order to carry out a survey of snow crab around Svalbard. In connection with an Iceland scallop survey in June 2020, 5 strings of snow crab pots were laid out in order to search for snow crab on the west coast of Spitsbergen (Figure 3, to the right). No snow crab was caught at these stations. However, this area should be investigated further at the next opportunity and the large fjords on the western and northern coasts of Spitsbergen should also be investigated.

Access to food does not seem to be a limiting factor regarding the spread of snow crab since they have a very varied diet. Changes in benthic temperature may have the greatest effect on the further distribution of the population since the different life stages have different temperature preferences. The youngest life stages prefer cold water, but they seek out temperatures that are a little higher when they reach sexual maturity. Benthic temperatures measured on the survey with Kristine Bonnevie during the summer of 2020 showed negative temperatures in all areas where snow crab was caught. On a snow crab survey conducted during the summer of 2019, 22 plankton net hauls were made, primarily along the delimitation line between Norway and Russia. Snow crab larvae (stage 1) were found and verified at 20 of the stations. This means that larvae had hatched or were hatching during the survey (Hjelset et al. in prep). Larval drift will help to spread the snow crab population if the larvae are transported to areas with suitable habitat.

It is currently difficult to make long-term population assessment forecasts for the delimited area. A general projection of expected catch development in the entire Barents Sea, given a sustainable fishery, indicates a steady increase as snow crab spread further onto the Norwegian continental shelf and the density increases.

Knowledge status and the biology of snow crab in the Barents Sea

Effects and monitoring of snow crab

The large amounts of snow crab now found in the Barents Sea indicate that the crab plays a significant role in the ecosystem, both as a predator of other benthic animals and as prey in its larval and benthic stages. Snow crab probably affects the different parts and species in the ecosystem differently, but few studies have been conducted on this.

In a study by Bakanev (2016), snow crab was found in the temperature interval -1.9 to 9.3 °C, and the highest densities were found in the temperature interval between -1.5 and 3.0 °C. This indicates that temperature will be important for the further spread of snow crab to the southern and western parts of the Barents Sea (ICES 2018). Studies by Holt et al. (2019 and 2020) show that there has been an increase in snow crab in the diet of cod in recent years, and that this increase is related to the fact that snow crab distribution has increased. Changes in the distribution of cod may limit the further spread of snow crab if the habitats overlap a lot in time and space, as an effect of climate change (ICES 2018, 2019; Holt et al. 2020).

Based on current knowledge, there is little to suggest that snow crab will have significant negative effects on other fishing resources in the Barents Sea. Stomach analyses show that snow crab eat a wide variety of organisms, where bivalves and polychaetes seem to dominate (Sundet et al. 2020, Zakharov et al. 2020). Russian studies show that snow crab grazing has led to a decline in other benthic animals in areas where there have been large numbers of crab, primarily in the eastern areas of the Russian part of the Barents Sea (Jørgensen 2017). A recent study from the Norwegian continental shelf shows changes in the faunal composition and function of benthic animals in an area where there is a high density of snow crab (Michelsen et al. 2020). The effect of a comparable species, the red king crab, shows that in benthic communities where adult individuals of red king crab graze, changes in both total biomass and faunal composition are evident. In areas that experience extensive grazing, a shift has been found from (larger) slow-growing polychaetes to (smaller) fast-growing species. Both species diversity and the biomass of the prey community have been reduced (Oug et al. 2011, 2017). The effects of snow crab on benthic communities will be a key topic in the further work on monitoring snow crab in the ecosystem.

The Norwegian Institute of Marine Research has recently carried out a study investigating whether snow crab leads to increased blood parasite infection in cod in the Barents Sea. This work shows that snow crab act as a host for the leeches that carry the blood parasite, and that there is a higher infection in cod caught in high-density snow crab areas compared to areas where snow crab is less prevalent (Nunkoo et al. submitted).

Crab pots are used when fishing for snow crab, and crab pot fishing itself has little impact on the ecosystem apart from the problems associated with lost gear and ghost fishing. It also seems that there is little or no bycatch of other species when using crab pots.

Moulting and growth in snow crabs

The snow crab grows gradually through several stages of moulting, from the pelagic larval stages to fully-grown, sexually mature individuals. Snow crabs stop growing when they reach sexual maturity. When the crab completes its final stage of moulting and becomes sexually mature, a morphological change occurs in both sexes. In males, the claws increase in size relative to the shell. It is difficult to see with the naked eye when male crabs reach morphological sexual maturity. Therefore, it is important to measure shell width and claw height in order to establish this. Females change the shape of their abdomens so that they are able to carry fertilised eggs. Males are generally larger than females when sexual maturation and the final stage of moulting occur. However, the size of sexually mature snow crabs in the Barents Sea varies between 40 mm and 160 mm shell widths for males (Figure 12), and 38 and 100 mm for females (Danielsen et al. 2019). It is believed that it can take 8 to 10 years for a male crab to reach catchable size (above the minimum size). After completing their final stage of moulting, snow crabs live for a maximum of 5 to 8 years (Fonseca et al. 2008).

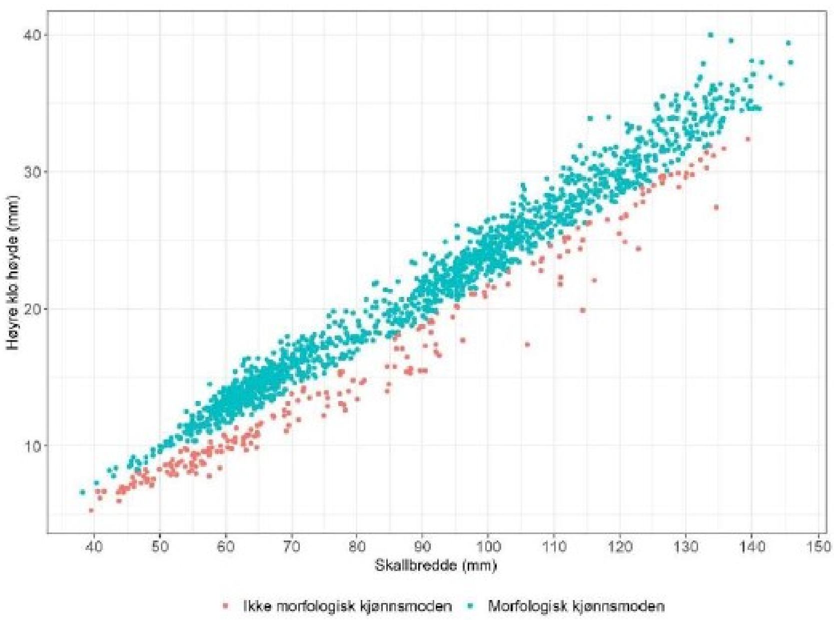


Figure 12
Right claw height (mm)
Shell width (mm)
Not reached morphological sexual maturity
Reached morphological sexual maturity

Figure 12. The relationship between shell width and claw height which shows whether snow crabs are sexually mature. The range for sexually mature and immature male crabs overlaps a lot. Data from this year's Snow Crab Survey.

After moulting occurs, there is a period where crabs have softer shells and lower meat yields, and they are vulnerable to external stresses such as those experienced when being caught. These crabs are called soft crabs. The larger crabs normally moult once a year, while smaller snow crabs moult up to twice a year. The smallest crabs are not of interest in terms of fishing, and they rarely enter crab pots. There is much to suggest that the moulting period for larger snow crabs takes place during the spring and early summer in the Barents Sea. During the Norwegian Institute of Marine Research's Snow Crab Survey in June and July, we observed crabs that had recently moulted (Figure 13), and we used the video sledge to observe several areas where empty shells could be seen on the seabed. This indicated that moulting had occurred recently. Variations in temperature can affect the start of the moulting period.

The Norwegian Institute of Marine Research uses a shell age scale as an approximate measurement of how much time has passed since moulting last occurred. For each crab, we record a shell age using a subjective scale from 1 to 5 based on the appearance and quality of the shell. Directly after moulting occurs, the new shell is very soft and leathery and the crab's body is slack and out of shape when taken out of water. This is called shell age 1 and this condition only lasts a short time. Within 72 hours, the shell begins to harden and it becomes relatively hard after approximately two weeks. In the period immediately after moulting, the crab is calm and does not enter crab pots. Such crabs were observed on the Snow Crab Survey during the summers of 2019 and 2020. In the transition to shell age 2, the crab will still have a very thin and fragile shell, and the muscles do not fill out the whole shell. The process of hardening the shell and gaining a higher meat yield that fills the entire shell can take up to 9 months after moulting occurs. When the crab reaches shell age 3 (approximately 9 months after moulting), it will have a hard and light shell that is often fouled with other organisms. These crabs have the highest meat yields and the greatest economic fishing value. Shell ages 4 and 5 are old crabs that are beginning to reach the end of their lifespan and are not of commercial interest. Meat yield will also begin to decrease in these crabs. It is difficult to distinguish between the different shell ages on this scale, especially between the late stage in shell age 2 and the early stage in shell age 3.

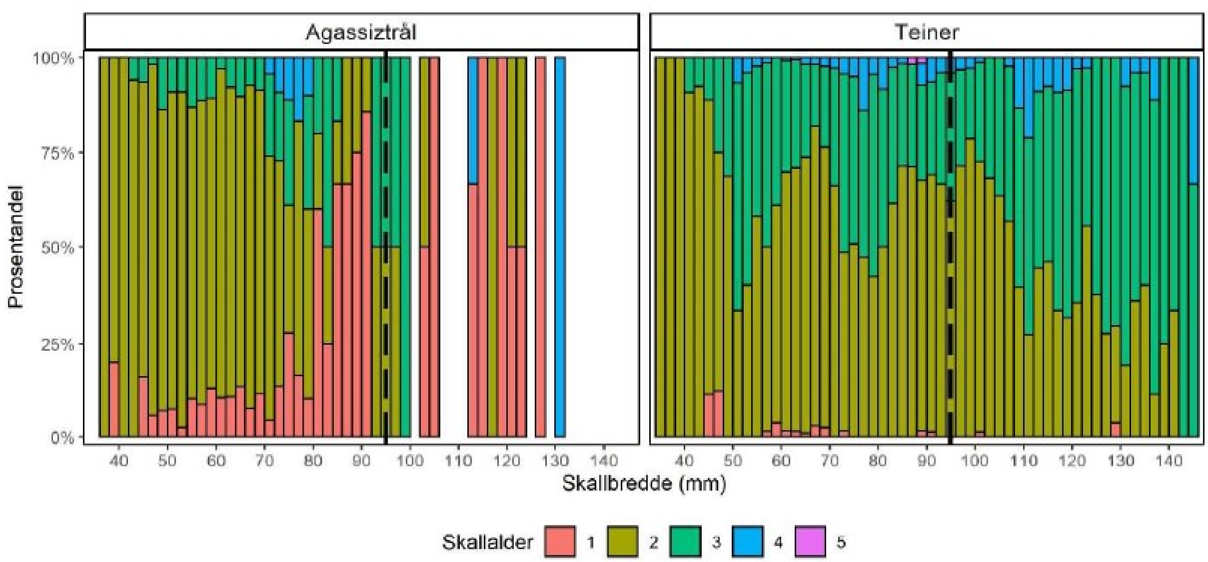


Figure 13 Agassiz trawl Percentage	Crab pots Shell width (mm) Shell age

Figure 13. The figure shows the percentage distribution of shell age in male crabs caught during the 2020 Snow Crab Survey. The figure on the left shows the distribution of shell age in trawl-caught crabs and the figure on the right shows the distribution of shell age in crabs caught in pots. New minimum size for snow crab on the Norwegian continental shelf marked with a dashed line.

The distribution of shell age in snow crabs caught in pots differs from those caught with trawls (Figure 13). The Agassiz trawl catches more soft crabs because it is an active piece of fishing gear and the crabs are unable to escape. Shell age 1 has also been observed among crabs caught using pots, and there is also a large proportion of crabs with new shells that enter pots, especially above the minimum size. Given the time of year the survey took place and observations made from the video sledge, it may indicate that snow crabs behave more calmly when they are in the process of moulting or are about to moult. Observations of spawning pairs on video may also indicate this. This helps to substantiate that the snow crab moulting period probably takes place from June onwards.

Protection period

Fishery registrations in July and August 2017 sometimes showed high numbers of soft crabs, and that the proportion of soft crabs can vary from one area to another throughout the fishing grounds. Soft crabs are not of commercial interest and are therefore discarded if caught during fishing. It is known that handling soft crabs can cause injuries. Another potential problem with fishing for crabs that have recently moulted and have low meat yields is that they may have a lower weight in relation to their size. This may lead to higher exploitation regarding the number of individuals since the quota is measured in tons. Crabs that are caught shortly after the moulting period will be considered of poorer quality by the buyer due to a lower meat yield.
A study by Solstad et al. (under preparation) showed that snow crab had the highest meat yield during the period from February to April, which is consistent with the hypothesis that most crabs of catchable size moult during early summer and require up to 9 months to achieve a high degree of meat yield. A means used both in Alaska and Canada to protect snow crab during and directly after moulting is a period of protection in connection with moulting. This type of protection has also been used in the Norwegian part of the Barents Sea in recent years. Continuation of a protection period of 3 to 4 months of closed fishing in the summer will protect snow crab during a vulnerable period and the quality/meat yield will increase throughout the autumn. Given the uncertainty surrounding the moulting period, a protection period should be maintained in the Barents Sea in accordance with the precautionary principle during the period 1 July - 30 September.

Minimum size

The minimum size regarding the capture of snow crab is linked to two conditions: 1) ensuring reproductive potential and 2) avoidance of overfishing. Reproductive potential is safeguarded by ensuring that there are a sufficient number of sexually mature female and male crabs left in the population after fishing. Therefore, the minimum size is often set somewhat larger than the average size of sexually mature snow crabs. If the exploitation rate is low, the minimum size can be set low. At a higher exploitation rate, the minimum size should be set correspondingly higher to ensure that there are a sufficient number of sexually mature male crabs below the minimum size. In Canada and Alaska, the minimum size regarding the capture of crabs is 95 and 78 mm, respectively. These minimum sizes are primarily set on the basis of market criteria, and this also seems to work well in relation to recruitment. There are currently no signs of reduced egg counts in female crabs in these populations, which could indicate a lack of sexually mature males. Even in areas where the exploitation of male crabs has been particularly high, only female crabs with a lot of eggs can be found.

The reduction in minimum size from 100 to 95 mm shell width is based on market requirements for a certain size of crab and has no biological reference. Due to the fact that a large proportion of male crabs in the Barents Sea become sexually mature at smaller sizes, we believe reducing the minimum size to 95 mm shell width will have little biological significance. However, monitoring should take place to see whether this reduces the reproductive potential of the population. Very few female crabs have a shell width above 95 mm, which means that the spawning population of females will be protected to a large extent even with a reduced minimum size.

Origin
Snow crab was first found on Goose Bank in the south-eastern part of the Barents Sea in 1996. There are two hypotheses of how snow crab has spread to the Barents Sea: 1) migration from the east, and 2) introduction via ballast water. Based on the genetic studies conducted on crabs in the Barents Sea, there is nothing to suggest that there has been an introduction via ballast water (Dahle et al., manuscript).

Technological fishery assessments regarding snow crab fishing

Snow crab in the Barents Sea is caught mainly using conical pots that have an entrance at the top. Norwegian fishing vessels are able to fish with up to 9000 crab pots per vessel, and the pots must be checked at least once every third week. The pots are most often placed in strings of 200 or 400 units, and the distance between individual pots is typically 25 metres.

Ghost fishing
Lost crab pots have the potential to continue fishing (even after the bait is gone), so-called ghost fishing. If captured crabs fail to escape, they will die after a certain period of time (Hébert et al. 2001). No surveys have taken place regarding the loss of crab pots in the Barents Sea, and the extent is therefore unknown. However, 1200 snow crab pots were retrieved on the Norwegian Directorate of Fisheries' clean-up voyage in 2019, and 2400 snow crab pots were retrieved in 2020, which indicates that the problem is extensive. Loss of fishing gear may be caused by several things, for example floats/buoys being cut by vessel propellers or ice, being compromised by other adjacent strings of pots, getting snagged on the seabed, and gear conflicts with trawlers. Lost fishing gear also leads to littering and can further lead to new losses if new fishing gear is placed in the same area and gets snagged. In 2018, the Norwegian Directorate of

Fisheries cleaned up 8600 snow crab pots (81 strings) that had been in situ for 1 and a half years (Langedal and Kalvenes 2018), where the Norwegian Institute of Marine Research also participated in order to collect catch data (Humborstad et al., in. prep.). All the strings had catches. The total catch was estimated at 15,000 individuals, but there was large variation in the number of pots with catches per string and the number of crabs per pot between the strings. As much as 97% of the catches in the pots was alive. These results provide an important insight into the potential for ghost fishing regarding lost snow crab pots, even after being in the ocean for a long time. Similar studies from other areas show that self-baiting and hidden exploitation can be a challenge in snow crab fishing (Hébert et al. 2001).

To prevent lost fishing gear from continuing to fish for a long time after being lost, solutions can be installed where escape holes are activated after a certain amount of time in the sea. The use of biodegradable twine (rot cord) to tie together openings in the crab pot netting or to hold hatches in place is a simple and effective method that is mandatory in several pot fisheries in North America, and in Norway when fishing for lobster and crab (recreational fishing). Maximum allowable twine diameter varies between fisheries. In the Norwegian lobster fishery, which is a seasonal fishery lasting 2 to 3 months, the maximum allowable twine diameter is 3 mm. In the Canadian snow crab fishery, it is mandatory to use rot cord with a maximum diameter of 4 mm. In Canada, the snow crab fishery is seasonal with a duration of 2 to 4 months, while the Norwegian snow crab fishery has a duration of up to 9 months. Apart from a short trial lasting three months, the Norwegian Institute of Marine Research has not measured the lifespan of rot cord in the Norwegian snow crab fishery. Biodegradation rate measurements have been made on the same type of rot cord that is used in the Canadian fishery. These measurements were taken off the coast of Finnmark and showed that the twine had degraded after approximately 6 months in the sea. Canadian trials have shown a similar rate of biodegradation even at temperatures below 0 ºC (Winger et al. 2015). However, these measurements do not take into account twine chafing caused by handling and crabs. Therefore, it is assumed that the practical lifespan will be shorter than 6 months. Consequently, when 4 mm cotton twine is used, it will be necessary to change the twine at least once during the fishing season in the Norwegian fishery. It is expected that the use of thinner twine will require additional twine changes. Due to the fact that a large number of crab pots are used per vessel in the snow crab fishery, this will be a labour-intensive process. At the same time, the potential amount of time where ghost fishing occurs in the event of fishing gear losses will be relatively long when using 4 mm twine. One alternative that is being worked on is a container solution with a panel of rot cord. This allows one to quickly change the twine and it also means that thinner twine can be used, which in turn gives shorter ghost fishing time in the event of fishing gear loss. The container solution requires further development and must be tested in commercial fishing.

It is recommended that technological development work should continue in order to prevent loss of fishing gear in the first place, and to prevent unintentional mortality, poor animal welfare and hidden exploitation in the event of fishing gear loss.

Other research requirements
There are currently no requirements regarding pot design, escape routes or the minimum mesh size in snow crab pots. All female crabs, undersized crabs and soft crabs must be released, but no surveys have been conducted on survival rates or frequency of injuries during onboard sorting and subsequent release. It is desirable that as much sorting takes place as possible at fishing depths through the use of mesh size or escape openings adapted to the minimum crab size. In 2019, a survey of selection in crab pots was carried out using round escape openings of 100 and 115 mm in diameter. Both escape openings resulted in a large reduction in catches, including crabs that were above the minimum size. In addition, the 100 mm escape opening was not effective in sorting out undersized crabs. An alternative method is to use escape gaps and exploit the relationship between shell width indicating minimum size and shell height (Broadhurst et al., 2018). In 2020, a survey was carried out using escape gaps installed in standard crab pots, but in a similar way to circular escape openings, the escape gaps also resulted in a reduction in catches above the minimum size. However, a lower proportion of undersized crabs were caught. It is further recommended that procedures are developed regarding the gentle release of undersized crabs so that as many as possible survive release.

Studies on catch efficiency show that crab pots with an entrance at the top are ineffective. In 2019, trials were carried out using the same type of conical pots, but with a small mesh size. These crab pots resulted in significantly higher catch rates of oversized crab, but also many undersized crab. In 2020, escape gaps were installed in the small-mesh pots. This resulted in significant increases in oversized crab catches compared to standard crab pots, while the proportion of undersized crabs was approximately at the same level. Work that leads to increased efficiency will reduce the required number of pots and thus have positive effects on the environment and bait consumption, and it is recommended that this be carried out.

References

Bakanev S.V. 2016. The snow crab stock assessment methods. Stock dynamics. In: Snow crabs *Chionoecetes opilio* in the Barents and Kara Seas (eds by K.M. Sokolov, Pavlov V.A., Strelkova N.A. et al.). Murmansk: PINRO press: 158-166. (In Russian).

Broadhurst, MK., Millar, RB., Hughes, B. 2018. Utility of multiple escape gaps in Australian *Scylla serrata* traps. Fisheries research, 204, 88-94.

Danielsen HEH., Hjelset AM., Bluhm BA., Hvingel C., Agnalt A-L. 2019. A first fecundity study of the female snow crab *Chionoecetes opilio* Fabricius, 1788 (Decapoda: Brachyura: Oregoniidae) of the newly established population in the Barents Sea. Journal of Crustacean Biology doi:10.1093/jcbiol/ruz039

Dahle, G., Sainte-Marie, B., Hardy, SH., Farestveit, E., Agnalt, A.L. Snow crab in the Barents Sea – introduction by ballast water or invasion from the East? (manuscript)

Eriksen, E.; Benzik, A.N., Dolgov, A.V., Skjoldal, H.R., Vihtakari, M.J., Johannesen, E., Prokhorova, T.;,Keulder-Stenevik, F.J., Prokopchuk, I., Strand, E. Diet and trophic structure of fishes in the Barents Sea: the Norwegian-Russian program "Year of stomachs" 2015 - establishing a baseline

Fonseca DB., Sainte-Marie B., Hazel F. 2008. Longevity and change in shell condition of adult male snow crab *Chionoecetes opilio* inferred from dactyl wear and mark-recapture data. Transactions of the American Fisheries Society 137:1029-1043 doi:10.1577/t07-079.1

Hébert, M., Miron, G., Moriyasu, M., Vienneau, R., DeGrâce, P. 2001. Efficiency and ghost fishing of snow crab (Chionoecetes opilio) traps in the Gulf of St. Lawrence. Fisheries Research, 52, 143-153. https://doi.org/10.1016/S0165-7836(00)00259-9

Hjelset, AM, Danielsen, HEH, Westgaard, J-I, Agnalt, A-L. 2020. Taxonomic and genetic confirmed findings of snow crab (*Chionoecetes opilio*) larvae in the Barents Sea (in prep).

Holt RE, Bogstad B, Durant JM, Dolgov AV, Ottersen G 2019. Barents Sea cod (*Gadus morhua*) diet composition: long-term interannual, seasonal, and ontogenetic patterns. ICES Journal of Marine Science 76:1641-1652 doi:10.1093/icesjms/fsz082

Holt RE, Hvingel, C., Agnalt, A-L, Dolgov A.V, Hjelset AM, Bogstad, B. (2020) Snow crab (*Chionoecetes opilio*), a new food item for North-East Arctic cod (*Gadus morhua*) in the Barents Sea? ICES Journal of Marine Science (in press)

Humborstad, OB., Eliassen Krøger, L. Hjelset, A.M., Løkkeborg, S., Siikavuopio, S., Wiech, M. (in prep). Catches in abandoned snow crab pots in the Barents Sea.

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

ICES, 2018. Report of the Arctic Fisheries Working Group (AFWG), 18–24 April 2018, Ispra, Italy. ICES CM 2018/ACOM:06. 534 pp.

ICES, 2019. The Working Group on the Integrated Assessments of the Barents Sea (WGIBAR). ICES Scientific Reports. 1:42. 157 pp. http://doi.org/10.17895/ices.pub.5536.

Michelsen, HK., Cochrane, S., Borgersen, G, Oug, E., Fredriksen, R., Renaud, P.E., Coll, M. Structural and functional effects of the invasive snow crab on benthic ecosystems in the Barents Sea. Poster, The Norwegian Association of Marine Scientists (NHF) 2020

Nunkoo, I, Hemmingsen, W., McKenzie, K., Karlsbakk, E., Arneberg, P. 2020. The Barents Sea snow crab (*Chionoecetes opilio*) invasion and *Trypanosoma murmanense* infections in cod (*Gadus morhua*). *Submitted*

Jørgensen, LL. 2017. Assessment of vulnerable benthic habitats in the northern Barents Sea; trawled benthic animals from the annual Ecosystem Survey. Report from the Norwegian Institute of Marine Research 19-2017.

Langedal, G. and Kalvenes, O. 2018. Clean-up of abandoned snow crab pots. Report from the Norwegian Directorate of Fisheries.

Oug, E., Cochrane, S., Sundet, J.H., Norling, K. & Nilsson, H.C. 2011. Effects of the invasive red king crab (*Paralithodes camtschaticus*) on soft bottom fauna in the Varangerfjorden, northern Norway. Mar Biodiv. 41: 467-479. DOI 10.1007/s12526-010-0068-6

Oug, E., Sundet, JH., Cochrane, SKJ. 2017. Structural and functional changes of soft-bottom ecosystems in northern fjords invaded by the red king crab (*Paralithodes camtschaticus*). Journal of Marine Systems, 2017. Doi: 10.1016/j.jmarsys.2017.07.005

Sundet, JH., Tranang, CA., Nilssen, EM., Jenssen, M. (in prep). Stomach content of the snow crab (*Chionoecetes opilio*) from the Barents Sea.

Winger, PD., Legge, G., Batten, C. and Bishop, G. 2015. Evaluating potential biodegradable twines for use in the snow crab fishery off Newfoundland and Labrador. Fisheries research, 161, pp.21-23. https://doi.org/10.1016/j.fishres.2014.06.007

Zakharov, DV., Manushin, IE., Nosova, TB., Strelkova, NA., Pavlov, VA. 2020. Diet of snow crab in the Barents Sea and macrozoobenthic communities in its area of distribution. ICES Journal of Marine Science doi:10.1093/icesjms/fsaa132