THE WORKING GROUP ON THE INTEGRATED ASSESSMENTS OF THE BARENTS SEA (WGIBAR)

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i Executive summary

Since the 1980s, the Barents Sea has gone from a situation with high fishing pressure, cold conditions and low demersal fish stock levels, to the current situation with high levels of demersal fish stocks, and warm conditions.

Ecosystem state: The ongoing warming was associated with increased water and air temperature, larger area covered by Atlantic (>3°C) and Mixed (0-3°C) warm water masses and decreased ice coverage both during winter and summer. The warming was also associated with increased primary and secondary (macro zooplankton such as krill and jellyfish) production, increased fish recruitment (age 0) which triggers positive development of fish stocks (cod, haddock, deep water redfish, capelin and herring). Increased production and adequate fishing pressure in relation to stock size led to cod and haddock stock size increasing to record high levels and the capelin stock withstanding the high predation level. Large fish stocks have distribution ranges extending further north, where feeding environmental conditions were suitable due to warming. The number of whales, which use the Barents Sea as summer feeding area, increased or stabilized in last decades. Several seabirds populations from coastal colonies stay or migrate in to the Barents Sea to feed and moult, possibly increased in total number. Arctic fish and benthos communities showed opposite trends, decreased in numbers and distribution most likely due to increased predation and competition pressure from boreal species. A true arctic fish, polar cod, showed decreased stock size and recruitment failure in the traditional area, the south-eastern Barents Sea. Reduction of ice cover and warmer temperature condition in addition to increased predation from a large cod stock are some of reasons for the polar cod stock decrease.

Human pressure: The assessment for several commercially important stocks indicated that the stocks has been fished sustainably and have remained well above precautionary reference limits. The present (2016–2021) minke whale quota is considered precautious, conservative, and protective for the minke whale population in the Northeast Atlantic. Catches of harp seals in recent years have been much lower than the quotas. The AIS tracking of vessel in the Barents Sea in August, 2012 to 2018, indicated an increased fisheries effort east of Svalbard and also an increase in passenger vessels to the Svalbard area. The effect on the marine ecosystem of the increased tourist traffic is not known, but the possibility for more littering is a potential risk. Large-scale monitoring of marine litter since the 2010, showed that plastic dominated number of observations with marine litter, while textile, paper, rubber and metal was observed occasionally.

Expected changes in the coming years: Oceanic systems have a "longer memory" than atmospheric ones. According to the expert evaluation, the Atlantic water temperature in the Murman Current is expected to decline slightly but remain typical of warm years. Due to high temperatures and low sea-ice extent in recent years, the ice coverage of the Barents Sea is expected to remain below normal.

Most of the commercial fish stocks found in the Barents Sea stocks are at or above the long-term level; the exceptions are polar cod and Sebastes norvegicus. The shrimp abundance is relatively stable and above the long-term level. The abundance and distribution area of snow crab is increasing. Based on the current abundance and age structure of the main commercial stocks, the following lines of development are possible: a new haddock outburst may take place, as the 2016 and 2017 year classes so far seem to be of the same order of magnitude as the strong 2004–2006 year classes; the abundance of young herring is currently the highest since 2005, and this may affect the capelin recruitment in 2018–2019 negatively; the westward expansion of snow crab leads to higher overlap between cod and snow crab and thus predation by cod on snow crab may slow down in addition to higher temperatures the rate of increase of the snow crab stock. If the sea

temperature increases further, this may allow further north and eastwards expansion of several stocks. For example, cod has almost reached it maximal distribution and polar cod will be negatively affected by other species moving into typical polar cod areas.

The WGIBAR group updated most of the time-series data and established additional time-series for the oceanographic conditions, mesozooplankton and 0-group fish, based on WGIBAR-subareas for the Barents Sea. The WGIBAR working group provides knowledge of the status, changes, relationships, and processes in the ecosystems to the Joint Russian-Norwegian Fisheries Commission, the Joint Russian-Norwegian Environmental Commission, the Norwegian Ministry of Climate and Environment, fisheries organizations, and different ICES working groups and disseminates their results at scientific conferences and by scientific publications and public papers.

ii Expert group information

Expert group name	The Working Group on the Integrated Assessments of the Barents Sea (WGIBAR)
Expert group cycle	Multiannual fixed term
Year cycle started	2017
Reporting year in cycle	3/3
Chair(s)	Elena Eriksen, Norway
	Anatoly Filin, Russia
Meeting venue(s) and dates	16-18 March 2017, Murmansk, Russia (26 participants)
	9-12 March 2018, Tromsø, Norway (18 participants)
	12-14 February, 2019, Murmansk, Russia (23 participants)

1 Term of Reference a)-d)

ToR	Description	Background	Science Plan topics addressed	Duration	Expected Deliverables
a	Prepare relevant datasets that can be used to describe and analyse fluctuations and changes in the Barents Sea ecosystem	Science and advisory requirements	6.1; 2.2; 2.4	Year 1,2 and 3	Updated multivariate datasets (Year 1,2 and 3). Develop new spatially disaggregated time-series (Year 1 and 2)
b	Prepare an annual report on the status and trends of the Barents Sea ecosystem based on integrated analysis of multivariate datasets and other relevant information	Science and advisory requirements	1.3; 2.1; 6.5	Year 1, 2 and 3	Annual reports of the status, drivers, pressures, trophic interactions and expected changes
c	Identify knowledge gaps and priority research items that when addressed, can improve future integrated ecosystem assessments	Science and advisory requirement	2.1; 6.5	Year 1, 2 and 3	Annual status reports
d	Explore the use of available ecosystem and multispecies models as an analytical tool in integrated ecosystem assessment for the Barents Sea	Science and advisory requirements	1.3; 1.4	Year 1, 2	Annual meeting report
e	Provide recommendations to improve the monitoring of the Barents Sea ecosystem for integrated ecosystem assessments	Science and advisory requirements	3.1; 3.2	Year 1	Annual meeting reports

2 Summary of Work Plan

Year 1   Prepare relevant datasets and other relevant information, including pollution, that can be used to describe fluctuations and changes in the Barents Sea ecosystem and prepare an annual report on the status and trends of the Barents Sea ecosystem based on integrated analysis of multivariate datasets.

Present and discuss available ecosystem and multispecies models as an analytical tool in integrated ecosystem assessment for the Barents Sea.

Identify knowledge gaps and priority research items that can improve future integrated ecosystem assessments and provide recommendations to improve the monitoring.

Map collaboration partners, their needs and advantage from the cooperation.

Year 2   Prepare relevant datasets and other relevant information that can be used to describe fluctuations and changes in the Barents Sea ecosystem and prepare an annual report on the status and trends of the Barents Sea ecosystem based on integrated analysis of multivariate datasets.

Identify knowledge gaps and priority research items that can improve future integrated ecosystem assessments.

Explore the use of the ecosystem /multispecies models as an analytical tool in integrated ecosystem assessment for the Barents Sea.

Year 3   Prepare relevant datasets and other relevant information that can be used to describe fluctuations and changes in the Barents Sea ecosystem and prepare an annual report on the status and trends of the Barents Sea ecosystem based on integrated analysis of multivariate datasets.

Identify knowledge gaps and priority research items that when addressed, can improve future integrated ecosystem assessments.

3   List of Outcomes and Achievements of the WG in this Delivery Period

WGIBAR prepared relevant datasets and other relevant information, including pollution and marine litter, to describe fluctuations and changes in the Barents Sea ecosystem and prepared an annual report "The state and trends of the Barents Sea ecosystem", which is available on ICES WGIBAR as separate document.

Since the 1980s the Barents Sea has gone from a situation with high fishing pressure, cold conditions and low demersal fish stock levels, to the current situation with high levels of demersal fish stocks, reduced fishing pressure and record warm conditions. The main points for 2018 are listed in executive summary.

New spatial time-series for oceanography, mesoplankton and 0-group fish were prepared for the WGIBAR. These new time-series were based on subareas defined in 2017 (see report from WGIBAR 2017). Description and estimation of new time-series were included in the report or as working document (Annex 4 in WGIBAR report 2018).

Most of the scientific work relevant to WGIBAR is done by other projects at IMR/PINRO or other institutions. Because of the way WGIBAR is funded there is little intersessional work done by WGIBAR as a group.

List of relevant publications:

Dalpadado P., Hop H., Rønning J., Pavlov V., Sperfeld E., Buchholz F., Rey A., Wold A. 2016. Distribution and abundance of euphausiids and pelagic amphipods in Kongsfjorden, Isfjorden, and Rijpfjorden (Svalbard) and changes in their relative importance as key prey in a warming marine ecosystem. Polar Biology DOI 10.1007/s00300-015-1874-x

Eriksen, E., Gjøsæter, H., Prozorkevich, D., Shamray, E., Dolgov, A., Skern-Mauritzen, M., Stiansen, J.E., Kovalev, Yu., Sunnanaa K. 2017. From single species surveys towards monitoring of the Barents Sea ecosystem. Progress in Oceanography http://dx.doi.org/10.1016/j.pocean.2017.09.007

Eriksen, E, Bogstad, B., Dolgov, A.V., and Beck, I.M. 2017. Cod diet as an indicator of Ctenophora abundance dynamics in the Barents Sea. Marine Ecology Progress Series, https://doi.org/10.3354/meps12199

Eriksen, E., Skjoldal, H.R. Gjøsæter, H. and Primicerio R. 2017. Spatial and temporal changes in the Barents Sea pelagic compartment during the recent warming. Progress in Oceanography 151: 206-226, *http://dx.doi.org/10.1016/j.pocean.2016.12.009*

Jørgensen 2017. Trawl and temperature pressure on Barents benthos. FEATURE ARTICLE – ICES, 11 July 2017.

Jørgensen, LL., Archambault P., Blicher M., Denisenko N., Guðmundsson G., Iken K., Roy V., Sørensen J., Anisimova N., Behe C., Bluhm B.A., Denisenko S., Denisenko N., Metcalf V., Olafsdóttir S., Schiøtte T., Tendal O., Ravelo A.M., Kędra M., Piepenburg D. 2017. "Benthos" In: CAFF. State of the Arctic Marine Biodiversity Report. Conservation of Arctic Flora and Fauna, Akureyri Iceland

Gjøsæter, H., Wiebe, P. H., Knutsen, T., and Ingvaldsen, R. 2017. Evidence of diel vertical migration of mesopelagic sound-scattering organisms in the Arctic. Frontiers in Marine Science.

Haug, T., Bogstad, B., Chierici, M., Gjøsæter, H., Hallfredsson, E. H., Høines, Å. S., Hoel AH., Ingvaldsen R.B., Jørgensen L.L., Knutsen T., Loeng H., Naustvoll L.J., Røttingen I., Sunnanå K., Loeng, H. 2017. Future harvest of living resources in the Arctic Ocean north of the Nordic and Barents Seas: A review of possibilities and constraints. Fisheries Research, 188, 38-57.

Ingvaldsen, R. B., Gjøsæter, H., Ona, E., and Michalsen, K. 2017. Atlantic cod (Gadus morhua) feeding over deep water in the high Arctic. Polar Biology.

Knutsen, T., Wiebe, P. H., Gjøsæter, H., Ingvaldsen, R., and Lien, G. 2017. High Latitude Epipelagic and Mesopelagic Scattering Layers - A Reference for Future Arctic Ecosystem Change. Frontiers in Marine Science.

Grøsvik, B.E., Prokhorova, T., Eriksen, E., Krivosheya, P., Horneland, P.A., Prozorkevich, D. 2018. Assessment of marine litter in the Barents Sea, a part of the joint Norwegian-Russian ecosystem survey. Front. Mar. Sci., 06 March 2018. https://doi.org/10.3389/fmars.2018.00072

4   Progress Report of ToRs a) – e)

4.1   Progress report on ToR a

In 2018, monitoring of Barents Sea by the Joint IMR-PINRO Ecosystem Survey in autumn (BESS) was not completed, and lack of coverage in the southeastern and central eastern Barents Sea did not allow to continue of several time-series. We, therefore, updated some of the time-series data (ICES 2014a) and spatial time-series for covered polygons only (Annex 4, ICES 2018).

The time-series were standardized to zero mean and unit variance and presented as plot for abiotic time-series, biotic (plankton and 0+ of fish and fish stocks size) and fisheries data. Statistical analyses were taken on time-series and showed significant trends. Time-series used by the group presented in Annex 5.

The state and trends of the Barents Sea ecosystem in 2018 presented in Annex 4. Long term trends for several ecosystem components were analysed and discusses (the report, Annex 4). Abundance for several fish stocks was averaged for 15 subareas within the Barents Sea and three periods (2004-8, 2009-13, 2014-17) and mapped (the report, Annex 4).

4.2   Progress report on ToR b

The followed presentations focusing of status of different ecosystem components and pressures were given during the meeting:

Hydrography, Alexander Trofimov

The situation for 2018 was presented for the following parameters: temperature (water and air), salinity, sea ice coverage, NAO index, index for storm activity, Atlantic water inflow and areas of Atlantic, Arctic and mixed waters.

Plankton, Espen Bagøien

The situation was presented with the most recent data on net primary productivity as estimated by using satellite data, biomass of mesozooplankton, occurrence of Calanus glacialis and Calanus finmarchicus in sections, abundance of euphasiids, abundance of amphipods and abundance of jellyfish.

0 group fish, Elena Eriksen

Abundance and distribution of 0 group of cod, haddock, NSS herring, capelin polar cod, and redfish based on TIBIA/WGIBAR areas was presented. Traditional way to estimated 0-group abundance indices were not possible in 2018 due to lack of coverage during the BESS.

Pelagic fish, Dmitry Prozorkevicn

Status and development of the Barents Sea pelagic fish stocks were presented.

In 2018, the area of juvenile herring and polar cod distribution was not covered well.https://www.hi.no/tokt/okosystemtokt_i_barentshavet/survey_reports/survey_report_2018/nb-no. Therefore, the survey indices on these species were not calculated. Biomass of age 1-2 for young herring was calculated based on the last ICES assessment, and biomass of young herring in 2018 in the Barents Sea was the highest since 2005, and well above the long-term average. The main capelin distribution area was well covered, but some areas where young capelin can be distributed has not been surveyed. The total capelin stock was estimated

to be approximately 1.6 million tonnes, which is below the long term mean level. Blue whiting abundance in the Barents Sea reflect stock condition and depends also from sea temperatures. The survey coverage of blue whiting during BESS 2018 was completed, but final estimates will be available later.

Demersal fish, Bjarte Bogstad

Status and development of the stocks was presented for cod, haddock, deep sea (beaked) redfish, long rough dab and saithe. Data on diet and fish growth were presented also for cod, capelin, and polar cod.

Benthos, Natalia Strelskova/ Lis Lindal Jørgensen

Status and trends of the benthos biomass and snow crab and shrimp population abundances were presented. Two interaction drivers was discussed 1) Fisheries, temperature) and snow crab impact on benthos, 2) temperature impact on the snow crab distribution of the Barents Sea.

Marine mammals, Nils Øien

Status and trends of the marine mammal observation based on ecosystem survey in August-September 2017 and monitoring survey 2018.The summer abundance of minke whales in the Barents Sea has recently increased from a stable level of about 40,000 animals to more than 70,000 animals. Also, humpback whale has increased their summer abundance in the Barents Sea from a low level prior to year 2000 to about 4,000 animals thereafter. The other cetacean populations have remained stable in numbers. In 2018, 2119 individuals of nine species of marine mammals were sighted during the Barents Sea Ecosystem Survey (BESS) in August-October 2018, as well as an additional 77 individuals which were not identified to species.

Non-commercial fish, Edda Johannesen, Tatyana Prokhorova and Raul Primicerio

The poor coverage at BESS 2018 did not allow comparison with previous years. Catch rates by zoogeographic groups was averaged for 15 subareas within the Barents Sea and three periods (2004-8, 2009-13, 2014-17) and mapped. A decline of arctic fish in the central Barents Sea and an increase of mainly boreal species in the northern Barents Sea are evident.

Seabirds, Per Fauchald

Status and development of the seabirds population were presented. Recent tracking studies (see seatrack.seapop.no) show that after the breeding season, most of the populations of kittiwakes, puffins, little auks, Brünnich's guillemots and common guillemots from colonies along the Norwegian and Russian coasts stay or migrate in to the Barents Sea to feed and moult, possibly increasing the total number of birds in the area in August and September. The population of common guillemot was decimated in the 1980s mainly due to a collapse in the capelin stock combined with low abundance of alternative prey. The population has increased steadily since then. The status and trends of the large populations of seabirds in the Eastern Barents Sea is less known.

What is mean 'food-wed assessment' and how it is related to 'integrated ecosystem assessment' and to 'stock assessment' by B. Planque (by Skype)

Food-web assessment could be relevant to IEA and can provide hindcasts and forecasts of food-web development under fishing and ecological scenarios/assumptions. Food-web models based on Chance & Necessity (CaN) easy to be communicated, use data from various sources, account for uncertainties and could be used in a participatory framework.

Causal and common trend analyses by H.K. Solvang

The common trends among the WGIBAR data were estimated by a classification and similarity analyses (Solvang et al. 2008) and presented and discussed for the group.

The WGIBAR report "The state and trends of the Barents Sea ecosystem"is used as a status for the Barents Sea ecosystem by the Norwegian-Russian environmental commission, as well as by the Work Programme for the Norwegian - Russian environmental cooperation associated with the Joint Russian Norwegian Environmental Commission. In addition, several annual reports made separately in Norwegian and Russian by IMR and PINRO make use of the WGIBAR report on the state of the BS. Furthermore, the Arctic Fisheries Working Group (AFWG), the main stock assessment working group for the Barents Sea use information from the report in their report each year.

4.3   Progress report on ToR c

During the WGIBAR meeting in 2016 -2019, the following research questions relevant for the state of the Barents Sea and management were identified:

The Barents Sea has been on a warming trend since 1980 with shorter oscillations between warm and cooler years. 2016 was the warmest year on record exceeding 2006 and 2012 as the two most recent warm years. The warming has been associated with an expansion of Atlantic and mixed (0-3°C) water masses and a near disappearance of Arctic water (defined as water with sub-zero temperature) and strong reduction in winter sea ice. Skagseth with colleagues are working with a paper about heating of the Barents Sea and consequences.

The oceanographic changes that are taking place has implications for all life forms in the Barents Sea both in the water and on the seafloor. There are many research questions related to distribution and population dynamics of single species and their interactions in foodwebs and communities. One particular question concerns the dominant herbivore copepod in the northern Barents Sea, *Calanus glacialis*, which has its habitat in the cold Arctic water. How will this copepod cope under warmer conditions with less sea ice and extended period of predation by planktivorous fish? Some model predictions are that *C. glacialis* will not do well and lead to a decrease in production of large mesozooplankton in the northern Barents Sea (Slagstad et al. 2011).

Associated with the decline in Arctic water, the transitional mixed water (0-3°C) has increased. An important question is whether this habitat is suboptimal for both *C. finmarchicus*, which thrives on the warm side, and *C. glacialis*, which is found in cold Arctic water. The declining trend in mesozooplankton biomass on the Central and Great Banks may be an indication that change in oceanographic conditions associated with warming has made these waters less favorable for the Calanus species.

Another question relates to the flow of Atlantic Water both into the Barents Sea, i.e. the bifurcation into the BSO branch and Fram Strait branch, and within the Barents Sea, i.e. the separation between a southern and northern flow (towards Central Basin and Hopen Trench, respectively). The flow of Atlantic Water to and within the Barents Sea is important for both the climatic state of the Barents Sea and the advection of passively floating biota (such as plankton and fish eggs and larvae). Monitoring of the separation of the flow within the Barents Sea is currently lacking. While model results exist, the validation of modelled flow patterns is also lacking due to the lack of measurement data. Furthermore, the mechanizms governing the variability in the flow patterns are not yet understood.

Russian and joint time-series reveal an increasing trend in krill (euphausids) over the last 10-15 years. This is likely related to warming and improved habitat conditions for advected krill, notably *Meganyctiphanes norvegica* and *Thysanoessa inermis* (Eriksen et al. 2016, 2017). The increased amount of krill plays important roles in the ecosystem as food for a range of consumers, including fish, seabirds and marine mammals. We need better understanding of the spatial ecology and trophic role of the dominant krill species in the Barents Sea ecosystems. This includes to

what extent the krill species reproduce in the Barents Sea, as opposed to being advected in from the adjacent Norwegian Sea.

Pelagic hyperiid amphipods, notably the large Arctic species *Themisto libellula*, have shown an opposite trend to that of krill, with a pronounced decrease in the Barents Sea over the most recent decades. Like for the krill species, we need better understanding of the biology and ecology of the dominant pelagic amphipods in the Barents Sea. They are to large extent omnivores and carnivores and play dual roles as prey for and food competitors with planktivorous fish such as capelin, juvenile herring and polar cod.

The cod stock is still at a high level and capelin, which is a key prey item, is increasing from a low level. Increased overlap between cod and capelin in summer, where cod has been able to follow capelin on its seasonal feeding migration to the northern Barents Sea, has resulted in increased predation by cod which eventually lead to the collapse of the capelin stock in 2015. The estimated consumption of capelin by cod in 2016 was still fairly high although cod has been shifting to take more alternative prey composed of other fish species and benthos. One important research issue is to what extent the large cod stock will prevent the recovery of the capelin stock by continuing to exert strong predation pressure. Another issue is the predation pressure from cod on the alternative prey. These include small Arctic fish (sculpins, snailfishes, eelpouts and others) which may not be so abundant and form high biomass. Will the large cod stock deplete these prey resources over the next few years, and will this in turn affect the feeding conditions and the overall status of the cod stock? May we witness a marked decrease in the condition and size of the cod stock in near future? These are questions that require our attention as we plan cruises and research activities.

Fisheries effort in space in addition to time.

The impact of fisheries on commercial fish stocks are traditionally measured by annual or quarterly indices for biomass and numbers of catch, age of the stock, size and length-at-age classes, landing biomass and bycatch, as well as bycatch and analyses of total stock, spawning stock, recruitment and fishing mortality. These data are important information for setting quotas for further fisheries on each commercial stock, through the information on stock development and long-time trends.

What is missing is the inclusion of spatial components to the present fisheries analyses. The spatial components, preferably in two dimensions (area and depth) would add valuable information on the impact by fisheries within specific area of the full range of the stock. It would be more precise information on where the fisheries impact on target stocks and bycatch/benthos is high or limited. By analysing fisheries effort over time and space, it would be possible to detect shifts in the high-impact fishing area, which also would provide information on possible shifts on impact on special fractions of the target stock, on bycatch stocks and benthic societies.

This is information of value for integrated ecosystem analyses, in particular in times with rapid shifts in climate and ice cover. In addition, economics and resource use by the fishing fleet would data be of interests in societal and commercial analyses, the time and effort by the fishing fleet in time and space would be needed.

The data from VMS-tracking (which linked with logbook data) the international fishing fleet include spatial information. This information is not yet utilized, while the spatial distribution of species are well established in both surveillance data collection, in population analyses and in several ecosystem models. The gap concerning spatial analyses of bottom trawl efforts through time can be filled. By developing routines and methods to transform these data and make them available for statistical use for spatial fisheries effort, including changes in time and space, with

informative maps to support this information. Added to the time-series already included in fisheries analyses, this will allow for three-dimensional analyses, adding useful information to IEA analyses, also including economic and societal analyses.

4.4 Progress report on ToR d

As of now, WGIBAR consists of researchers from IMR and PINRO, the institutions that do most of the monitoring of the BS ecosystem. Since 2018, professors from the Norwegian Arctic University in Tromsø (UiT), Raul Primicerio and senior scientist from Norwegian Institute for Nature Research, Per Fauhald has been a member of the group and will be responsible for multivariate analyses (Raul) and seabirds (Per).

The group evaluated ecosystem models and summarized in 2017. During the 2016-2019, several ecosystem modelers from IMR and UiT were invited to the annual meeting, where they presented the models (opportunities and limitations). The group agreed that ecosystem models could be used to increase understanding of ecosystem functioning and interaction, which is key for the WGIBAR. However, the group have no ability to develop the models due to limited resources (funding and personnel) but would like to support the modelers with data and knowledge.

4.5 Progress report on ToR e

Provide recommendations to improve the monitoring of the Barents Sea ecosystem for integrated ecosystem assessments.

4.5.1 IMR PINRO long term monitoring plan and surveys therein

IMR and PINRO have evaluated and developed a long-term monitoring strategy for the Barents Sea. The strategy is the outcome of meetings and document in:

Report from the meeting between experts from PINRO and IMR to discuss survey optimization in the Barents Sea (Svanhovd 13-16 January 2014)

Report from the meeting between experts from PINRO and IMR to discuss further develop a joint monitoring program in the Barents Sea (Murmansk, 17-18 October 2017)

Protocol of the Annual Meeting between Russian and Norwegian scientists (March meeting Norway 13-15 March 2018)

Protocol of the Annual Meeting between Russian and Norwegian scientists (March meeting Russia 12-14 March 2019)

The implementation of the long-term monitoring plan started in 2019-2020.

The plan aim to monitor status of and changes in the Barents Sea ecosystem. The monitoring plan include ecosystem surveys conducted in different seasons, reflecting the main processes (important oceanographic and biological processes). The winter ecosystem survey (February-March) reflects spawning migration of key Barents Sea fish species and oceanographic condition. A summer ecosystem survey (as a part of the summer international ecosystem survey for the Nordic Seas, IESNS), reflecting indices of juvenile herring and plankton, that determine the characteristics of the feeding season. The autumn ecosystem survey (late August-October) reflects the recruitment, feeding success and annual production (biomass) level. The long-term monitoring plan includes the following ecosystem surveys and time frames:

- A joint IMR/PINRO winter ecosystem survey of at least 120 vessel days, covering area from the eastern Barents Sea west to Lofoten
- The part of the ICES coordinated international summer ecosystem survey for the Nordic Seas (IESNS) covering the southern Barents Sea (about 30 vessel days)
- A joint IMR/PINRO autumn ecosystem survey of at least 180 vessel days covering entire Barents Sea and continental slope

Evaluation of main surveys

The Barents Sea winter survey (February)

The winter survey was started in 1981, as a combined acoustic and bottom trawl survey. The aim was to establish a time-series both for "swept area abundance" and acoustic abundance for cod and haddock. In the period 1981-1993 only southern areas were covered; Main Areas A, B, C and D, (strata 1-12) in the Figure 4.5.1. In the early 90-ies it was observed that the distribution of these species expanded further north, and in 1994 the survey was extended to cover also Main Areas D', E and S (strata 13-23). In 2014 the survey was further extended to cover Area N (strata 24, 25 and 26). In some years the coverage has been incomplete. The survey results have been used in stock assessments at AFWG and WGIBAR.

In the first years, measuring cod and haddock had priority, but most of the common fish species were recorded and measured. After 2007 all fish species are measured. In case of uncertain species determinations, samples have been frozen and analysed by experts after the survey.
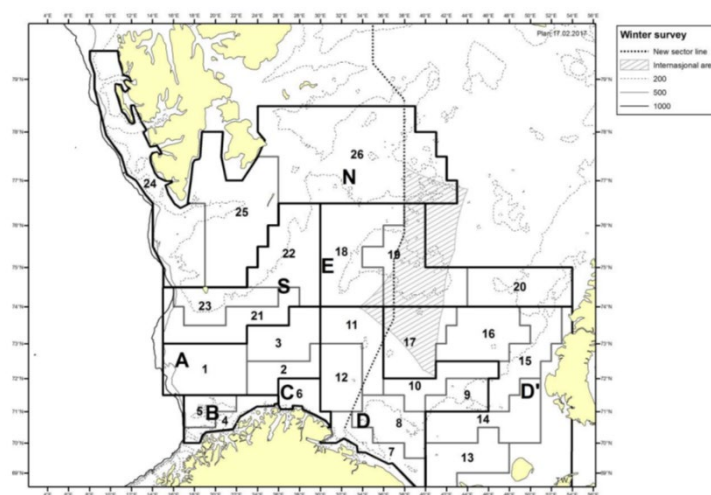

Figure 4.5.1. Strata (1-23) and areas (A, B, C, D, D', E and S) used for swept-area estimations and acoustic estimations with StoX. Additional strata (24-26, main area N) are covered since 2014, but not yet included in the standard time-series.

The survey coverage at the winter survey was expanded in 2014 to west of Svalbard and to northwards to cover the larger extent of the cod and haddock distributions.

ICES coordinated international summer ecosystem survey for the Nordic Seas

So far, the data from ICES coordinated international summer ecosystem survey for the Nordic Seas (IESNS) has not been available to the WGIBAR group, but WGIBAR will take steps to access these data and include them in the evaluation of the Barents Sea Ecosystem state.

The Joint Barents Sea Ecosystem Survey (BESS)

The ecosystem survey is a cooperation between IMR and PINRO and has been run annually in August-October since 2004. The ecosystem survey covers the whole Barents Sea shelf and samples all main ecosystem components allowing the study of spatial overlaps and interactions (see

Annex 4 in the report "State and trends in the Barents Sea 2018). Eriksen et al. 2017 described the development of Barents Sea monitoring from single species (or fishery) surveys focused on target species/groups to integrated ecosystem surveys aimed to describe the status and main changes in the Barents Sea ecosystem.

In 2018, monitoring by the Joint IMR-PINRO Barents Sea Ecosystem Survey in autumn (BESS) was planned similarly to previous years. New tasks were also planned. These include the collection of samples of microplastic, the study of the age of the Barents Sea waters, the acidity of water etc.

However, due to technical problems on the Russian vessel, the time of survey was greatly reduced. This resulted in poor coverage of the eastern part of Barents Sea and insufficient data for the continuation of several time-series. It also, resulted in inability to calculate the stocks indices for many commercial fish species.

Future prospects for the development of ecosystem research in the Barents Sea are to expand the survey area to the north and northeast, towards the fringes of the Barents Sea and into the Arctic ocean, in both Norwegian and Russian EEZs. This goes beyond the geographical boundaries of the Barents Sea, but is important as these areas are adjacent waters. Many species (e.g. Greenland halibut, shrimp, polar cod, snow crab) from the Barents Sea are distributed or are in the process of moving their distribution areas into these areas. Ice-free areas should therefore be investigated more thoroughly.

Another direction of research is efforts aimed at improving the quality of the monitoring and assessment of stocks of fish and invertebrates. To achieve this, we need to explore survey design and methodology. Different aspects, such as stratification, adjustment of effort (e.g. more trawling), and new gear technology, are discussed and tested out by the joint IMR-PINRO group coordinating BESS. Another matter is the need for evaluation of distribution of bottom fish in pelagic.

Full coverage of the Barents Sea area is an indispensable condition for BESS. It is very important to provide of appropriate survey efforts, improve of methodological development, and control of technical condition of the vessels

4.5.2 Other investigations and data relevant to the monitoring of the Barents Sea

The haddock stock in the Barents Sea is currently the world's largest and has expanded its distribution within the Barents Sea. In colder years winter temperatures determined year class strength, but this appear to no longer be the case. Drift and distribution of juveniles are probably important but spawning area coverage of haddock is lacking. The potential for expanding the Lofoton survey to cover haddock spawning should be considered.

Inflow of water and plankton into the Barents Sea is an important driver for fluctuations in the Barents Sea. Data on oceanographic conditions (upstreams) should be made available to WGIBAR by WGOH.

4.6 Cooperation

Cooperation with other WGs

- Stock assessment groups in particular AFWG and WGWIDE
- Other IEA groups in particular WGINOR and WGICA
- WGSAM, WGOH, WGECO

Cooperation with management structures

- The Joint Russian-Norwegian Fisheries Commission, in charge of joint fisheries management in the Barents Sea.
- The Joint Russian-Norwegian Environmental Commission, in charge of joint environmental management in the Barents Sea.
- The Norwegian Ministry of Climate and Environment, in charge of Norwegian holistic ecosystem-based management plan for the Norwegian part of the Barents Sea.
- Arctic council

Cooperation with other IGOs
- Relevant groups within the Arctic Council. PAME/ICES workshop (Seattle).
- Norwegian monitoring group under the Norwegian Management Plan
- Norwegian Fishery reference fleet (coastal and sea)

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Annex 2: Agenda for WGIBAR 2019

Annual ICES WGIBAR meeting
11-15 February 2019, Murmansk, Russia
AGENDA OF THE MEETING

February 11, Monday Arrival of the Norwegian delegation.

February 12, Tuesday (PINRO)

09:00 – 12.00 Plenary

Opening of the meeting, adopting of the agenda and practical information (A. Filin, E. Eriksen)

Ecosystem status and trends: (15 min per presentation)

Oceanography (V. Lien, A. Trofimov)

Plankton (E. Bagøien, I. Prokopchuk)

Fish recruitment (E. Eriksen, T. Prokhorova)

Pelagic fish (D. Prozorkevich, B. Bogstad)

Benthos (N. Strelkova, L. Jørgensen)

10:30-11:00 *Coffee & Tea break*

Demersal fish (B.Bogstad, A. Russkikh)

Sea mammals (N.Øyen, R. Klepikovskiy)

Seabirds (P. Fauchald)

Fish trophic interactions (B. Bogstad, A. Dolgov)

Non-commercial fish (E. Johannesen, T. Prokhorova)

12:00:13:00 Lunch

13:00-17:00

Discussion of the current state and long-term trends of the Barents Sea ecosystem

Integrated analysis of multivariate data sets and time-series analyses

Identify knowledge gaps for improvement of future integrated ecosystem assessments (ToR *c*)

Update the status description for ecosystem components to the report (ToR *b*)

February 13, Wednesday (PINRO)

09:00 – 12:00. Plenary presentations (20 min per presentation)

What is mean 'food-wed assessment' and how it is related to 'integrated ecosystem assessment' and to 'stock assessment' (B. Planque, by Skype)

Causal and common trend analyses (H.K. Solvang)

Fourteen years in the Barents Sea: first insights from an ecosystem-scale exploration (B. Husson)

Presentation of the BARENTS-RISK project (M. Skern-Mauritzen, by Skype)

10:30-11:00 *Coffee & Tea break*

11.00-12.00

Discussion on the methods and tools for the integrated ecosystem assessments.

Produce recommendations to improve the monitoring of the Barents Sea ecosystem (ToR *e*)

12:00– 13:00 Lunch

13:00-17:00 Practical work by groups

Prepare description of ecosystem status and long-term trends to the report (Anex 5)

Integrated analysis of multivariate data sets and time-series analyses

Describe research questions, analyze multivariate data set and give current state of knowledge pertaining to these questions discuss

February 14, Thursday (PINRO)

09:00-16:00 Practical work by groups

Prepare the status description of the Barents Sea ecosystem to the report

Updating the WGIBAR database

Writing the chapters on ToR *c.d,e.*

16:00-17:00 Plenary

Summing up the results of the meeting

Future work, next meeting, new chairs

February 15, Friday

Departure of the Norwegian delegation

Annex 3: Resolutions

Working Group on Integrated Assessments of the Barents Sea (WGIBAR)

2016/MA2/SSGIEA03   A Working Group on the Integrated Assessments of the Barents Sea (WGIBAR), chaired by Elena Eriksen, Norway, and Anatoly Filin, Russia, will work on ToRs and generate deliverables as listed in the Table below.

	MEETING DATES	VENUE	REPORTING DETAILS	COMMENTS (CHANGE IN CHAIR, ETC.)
Year 2017	16–18 March	Murmansk, Russia	Interim report by 30 April 2017	
Year 2018	9–12 March	Tromsø, Norway	Interim report by 30 April 2018	
Year 2019	12–14 February	Murmansk, Russia	Final report by 29 April 2019	

ToR descriptors

TOR	DESCRIPTION	BACKGROUND	SCIENCE PLAN CODES	DURATION	EXPECTED DELIVERABLES
A	Prepare relevant datasets that can be used to describe and analyse fluctuations and changes in the Barents Sea ecosystem	Science and advisory requirements	6.1	Year 1,2 and 3	Updated multivariate datasets (Year 1,2 and 3). Develop new spatially disaggregated time-series (Year 1 and 2)
B	Prepare an annual report on the status and trends of the Barents Sea ecosystem based on integrated analysis of multivariate datasets and other relevant information	Science and advisory requirements	1.3; 2.1; 6.5	Year 1, 2 and 3	Annual reports of the status, drivers, pressures, trophic interactions and expected changes
C	Identify knowledge gaps and priority research items that when addressed, can improve future integrated ecosystem assessments	Science and advisory requirement	3.1, 3.2	Year 1, 2 and 3	Annual status reports
D	Explore the use of available ecosystem and multispecies models as an analytical tool in integrated ecosystem assessment for the Barents Sea	Science and advisory requirements	2.5; 5.3; 6.1;	Year 1, 2	Annual meting report
E	Provide recommendations to improve the monitoring of the Barents Sea ecosystem for integrated ecosystem assessments	Science and advisory requirements	3.1, 3.2	Year 1	Annual meeting reports

Summary of the Work Plan

Year 1	Prepare relevant datasets and other relevant information, including pollution, that can be used to describe fluctuations and changes in the Barents Sea ecosystem and prepare an annual report on the status and trends of the Barents Sea ecosystem based on integrated analysis of multivariate datasets.
	Review and discuss available ecosystem and multispecies models as an analytical tool in integrated ecosystem assessment for the Barents Sea
	Identify knowledge gaps and priority research items that can improve future integrated ecosystem assessments and provide recommendations to improve the monitoring.
	Map collaboration partners, their needs and advantage from the cooperation.
Year 2	Prepare relevant datasets and other relevant information that can be used to describe fluctuations and changes in the Barents Sea ecosystem and prepare an annual report on the status and trends of the Barents Sea ecosystem based on integrated analysis of multivariate datasets.
	Identify knowledge gaps and priority research items that can improve future integrated ecosystem assessments.
	Explore the use of the ecosystem /multispecies models as an analytical tool in integrated ecosystem assessment for the Barents Sea.
Year 3	Prepare relevant datasets and other relevant information that can be used to describe fluctuations and changes in the Barents Sea ecosystem and prepare an annual report on the status and trends of the Barents Sea ecosystem based on integrated analysis of multivariate datasets.
	Identify knowledge gaps and priority research items that when addressed, can improve future integrated ecosystem assessments.
	Summarize literature from the last few years on the Barents Sea ecosystem

Supporting information

Priority	High, the IEA WGs are seen as key strategic steps toward implementing the ecosystem approach to investigation and harvesting in the differen ecosregions
Scientific justification	Term of Reference a) and b)
	The annual report of the status and trends of the Barents Sea ecosystem, based on multivariate data and analyses, is the first step to understand ecosystem functionality, to detect early signals on major changes in the Barents Sea ecosystem and to uncover knowlegde gaps.
	Term of Reference c)
	In the process of assessing the state of the Barents Sea some knowlegde gaps will become evident. Research effort could then be targeted towards filling these gaps, either by WGIBAR or by other research projects.
	Term of Reference d)
	Several models (multispecies and ecosystem) are developed or under development for the Barents Sea. Exploring these models as analytical tools in understanding the ecosystem dynamics and human impact in the Barents Sea will help bridge the gap between integrated ecosystem assessment and advice and will also allow

WGIBAR to interact with other groups working on similar issues (e.g. stock assessment WGs in the Barents Sea, multispecies groups such as ICES WGSAM)

Term of Reference e)

When knowlegde gaps are detected, monitoring could be targeted and improved in order to fill the knowlegde gaps. This will link science and monitoring and increase the relevance of both to the assessment of the Barents Sea ecosystem.

Resource requirements	The research programmes which provide the main input to this group are already established, and resources are already committed.
Participants	12-15 people are expected to attend
Secretariat facilities	SharePoint site, secretariat support for reporting.
Financial	No financial implications.
Linkages to ACOM and groups under ACOM	It is very important to link this group to ACOM and ensure cooperation between science and advice
Linkages to other committees or groups	IEASG, all IEA groups, stock assessment groups (e.g. AFWG, NIPAG, and WGWIDE), WGSAM, WGECO
Linkages to other organizations	Arctic Council, Norwegian-Russian Enviromental Commission Norwegian Russian Fisheries Commission

Annex 4: The state and trends of the Barents Sea ecosystem in 2018

Edited by Elena Eriksen and Anatoly Filin

Contributing Authors (Alphabetic):

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Contents

1   Summary

Since the 1980s, the Barents Sea has gone from a situation with high fishing pressure, cold conditions and low demersal fish stock levels, to the current situation with high levels of demersal fish stocks, and warm conditions.

Ecosystem state: The ongoing warming were associated with increased water and air temperature, larger area covered by Atlantic (>3°C) and Mixed (0-3°C) warm water masses and decreased ice coverage both during winter and summer. The warming was also associated with increased primary and secondary (macro zooplankton such as krill and jellyfish) production, increased fish recruitment (age 0) which trigger positive development of fish stocks (cod, haddock, deep water redfish, capelin and herring). Increased production and adequate fishing pressure in relation to stock size led to cod and haddock stock size increasing to record high levels and the capelin stock withstanding the high predation level. Large fish stocks have distribution range extending further north, where feeding environmental conditions were suitable due to warming. The number of whales, which use the Barents Sea as summer feeding area, increased or stabilized in last decades. Several sea birds populations from coastal colonies stay or migrate in to the Barents Sea to feed and moult, possibly increasing the total number. Arctic fish and benthos communities showed opposite trends, decreased in numbers and distribution most likely due to increased predation and competition pressure from boreal species. A true arctic fish, polar cod, showed decreased of stock size and recruitment failure in the traditional area, the southeastern Barents Sea. Reduction of ice cover and warmer temperature condition in addition to increased predation from a large cod stock are some of reasons for the polar cod stock decrease.

Human pressure: The assessment for several commercial important stocks indicated that the stocks has been fished sustainably and has remained well above precautionary reference limits. The present (2016–2021) minke whale quota is considered precautious, conservative, and protective for the minke whale population in the Northeast Atlantic. Catches of harp seals in recent years have been much lower than the quotas. The AIS tracking of vessel in the Barents Sea in August, 2012 to 2018, indicated an increased fisheries effort east of Svalbard and also an increase in passenger vessels to the Svalbard area. The effect on the marine ecosystem of the increased tourist traffic is not known, but the possibility for more littering in a potential risk. Large-scale monitoring of marine litter since the 2010, showed that plastic dominated number of observations with marine litter, while textile, paper, rubber and metal was observed occasionally.

Expected changes in the coming years: Oceanic systems have a "longer memory" than atmospheric ones. According to the expert evaluation, the Atlantic water temperature in the Murman Current is expected to decline slightly but remain typical of warm years. Due to high temperatures and low sea-ice extent in recent years, the ice coverage of the Barents Sea is expected to remain below normal.

Most of the commercial fish stocks found in the Barents Sea stocks are at or above the long-term level. The exceptions are polar cod and Sebastes norvegicus. The shrimp abundance is relatively stable and above the long-term meanwhile, the abundance and distribution area of snow crab is increasing. Based on the current abundance and age structure of the main commercial stocks, the following lines of development are possible: a new haddock outburst may take place, as the 2016 and 2017 year classes so far seem to be of the same order of magnitude as the strong 2004–2006 year classes; the abundance of young herring is currently the highest since 2005, and this may affect the capelin recruitment in 2018–2019 negatively; the westward expansion of snow crab leads to higher overlap between cod and snow crab and thus predation by cod on snow crab may slow down in addition to higher temperatures the rate of increase of the snow crab stock. If

the sea temperature increases further, this may allow further north and eastwards expansion of several stocks, while e.g. cod has almost reached it maximal distribution and polar cod will be negatively affected by other species moving into typical polar cod areas.

The WGIBAR group updated most of the time series data and established additional time series for the oceanographic conditions, meso-zooplankton and 0-group fish, based on WGIBAR-sub-areas for the Barents Sea. The WGIBAR working group provide knowledge of the status, changes, relationships, and processes in the ecosystems to the Joint Russian-Norwegian Fisheries Commission, the Joint Russian-Norwegian Environmental Commission, the Norwegian Ministry of Climate and Environment, Fisheries organizations, different ICES working groups and disseminate the results at scientific conference and by scientific and public papers.

2   Temporal development

2.1   Subareas of the Barents Sea

By Hein Rune Skjoldal

The Barents Sea has been divided into 15 subareas or polygons (Figure 2.1.1). The divi-sion is based on topography and oceanography and is a modification (with some sub-division) of the system used by Eriksen et al. (2017) in a summary analysis of pelagic biomass. The four western areas, South-West, Bear Island Trough, Hopen Deep and Tor Iversen Bank, are areas covered mainly with Atlantic water and constitute the inflow region of Atlantic water with the splitting of the current branches east through the Kola Section (south of the Central Bank) and north in the Hopen Deep (west of the Central Bank).

A new time-series for the oceanographic conditions (temperature and salinity (1980–2017), mes-ozooplankton (1989–2017) and 0-group fish (six fish species, 1980–2017) were estimated based on new subareas for the Barents Sea. Description of data used, methods and results are presented as working document in Annex 4 in the WGIBAR Report 2018.
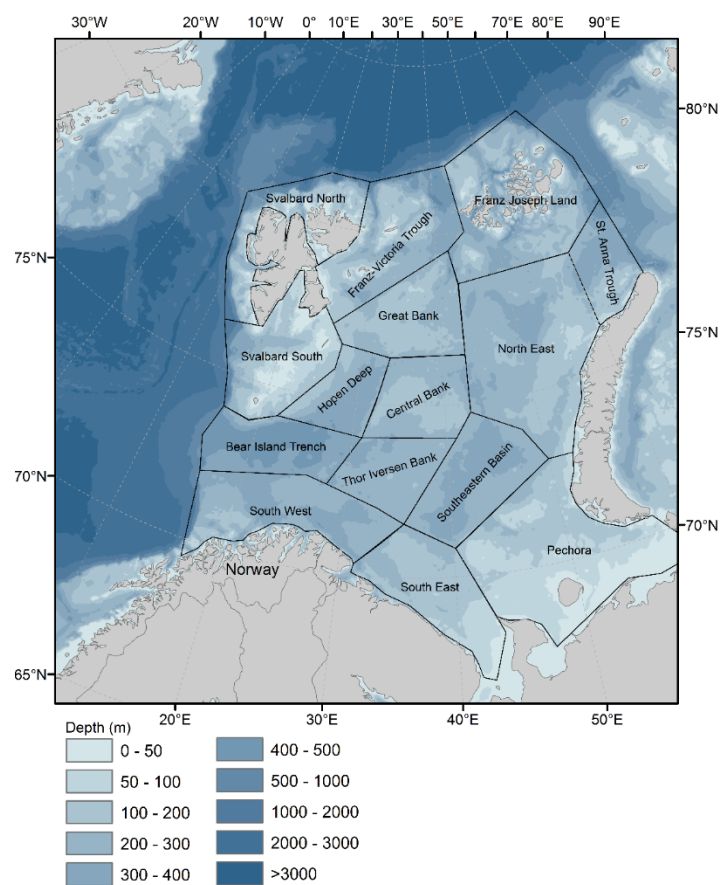
Figure 2.1.1. Map showing subdivision of the Barents Sea into 15 subareas (regions) used to calculate mean values and time-trends data from Barents Sea surveys.

2.2   Trend Analysis

By Elena Eriksen, Vidar Lien, Hiroko Solvang, Per Fauchald, and Berengere Husson

The ongoing warming were associated with increased water and air temperature, larger area covered by Atlantic and Mixed warm water masses and decreased ice coverage. The warming was also associated with increased macro zooplankton such as krill and jellyfish biomass, increased fish recruitment (age 0) which trigger positive development of fish stocks (cod, haddock, deep water redfish, capelin and herring). Increased production and adequate fishing pressure in relation to stock size led to cod and haddock stock size increasing to record high levels and the capelin stock withstanding the high predation level. Several sea birds populations from coastal colonies stay or migrate in to the Barents Sea to feed and moult, possibly increasing the total number.

Abiotic variables

Figure 2.2.1 clearly shows the warming of the Barents Sea during the period 1970–2017. Temperature related variables, such as temperature itself, the area occupied by Atlantic Water (T>3°C) and Mixed Water (0<T°C>3), and the ice area at minimum and maximum sea-ice extent all show a clear trend towards warmer conditions. The variables connected to the dynamics, i.e. the flow of Atlantic Water (e.g. BSO – the inflow of Atlantic Water to the Barents Sea) and the atmospheric forcing represented by the NAO does not show any clear trend. These results corroborate the findings that, while both the temperature and volume transport of the Atlantic Water into the Barents Sea con-tribute to the oceanic heat transport into the Barents Sea, they (temperature and volume transport) vary on different time-scales. While the volume transport fluctuates from year-to-year and even shorter time-scales, the temperature shows a clear signal of multidecadal variability, i.e. climate variability of addition to an underlying trend induced by climate change.
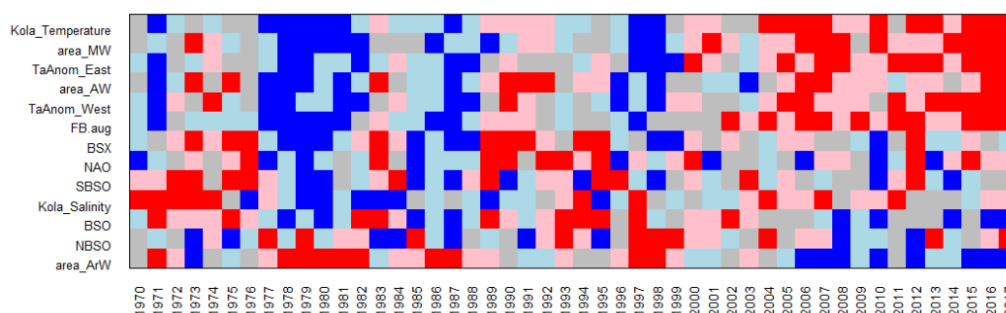
Figure 2.2.1. Time-series of annual means of abiotic variables in the Barents Sea sorted by trend. Blue means value below the 1970–2017 average and red means above the 1970–2017 average.

The eastern Barents Sea has experienced the largest warming trend over the last 47 years, with considerably less warming along the boundaries (ICES 2018). There is, however, a slightly different geographical pattern at different depth intervals, with the warming trend being skewed towards the south with depth. Here, one should note that the upper-layer is more in contact with the atmosphere and, thus, governed by the air-sea fluxes, whereas the deepest depth interval, i.e. 100–200 m, is more strongly dictated by advection of Atlantic Water. Furthermore, there is considerable interannual variability superimposed onto the underlying, multidecadal trend.

Overall, the temperature and salinity averaged over the whole Barents Sea and at different depth levels were lower in 2017 than in 2016, albeit above long-term average values (Figure 2.2.2), which is in line with the future expectations stated in last year's report.
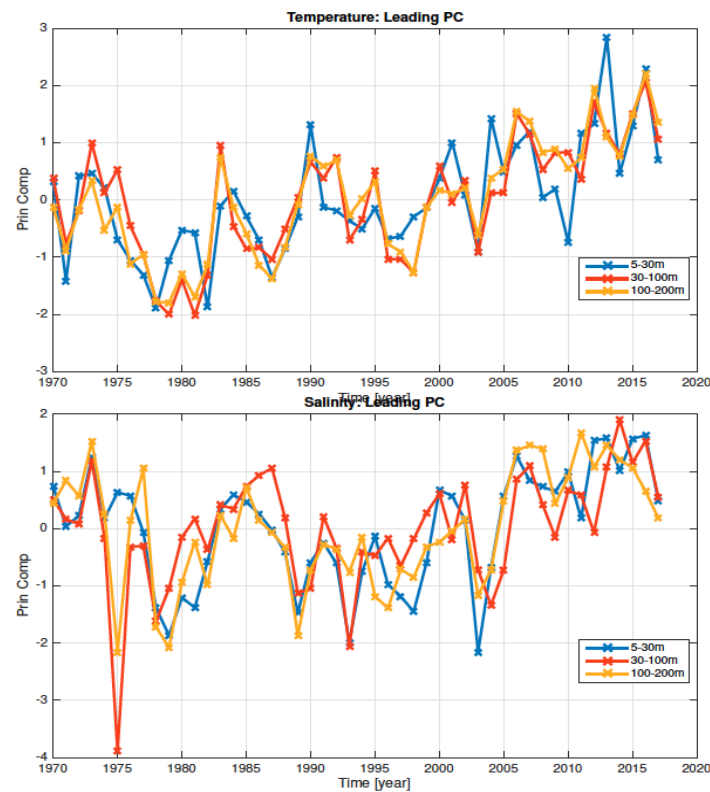
Figure 2.2.2. The leading EOF principal components for a) temperature and b) salinity. The scale of the y-axis is in degC but should be multiplied with the spatial loading.

Zooplankton and 0-group fish

Figure 2.2.3 shows a clear increase of krill, jellyfish and capelin, cod and haddock recruitment during the period 1988–2017, and the Mann-Kendall trend test showed that these positive trends were statistically significant. In contrast, polar cod, which is an arctic fish, showed a significant and negative trend, as these were at a high level during the 1990s and decreased in recent decades (Mann-Kendall trend test). However, neither zooplankton (all size fractions), nor herring or saithe recruitment show any clear trend.
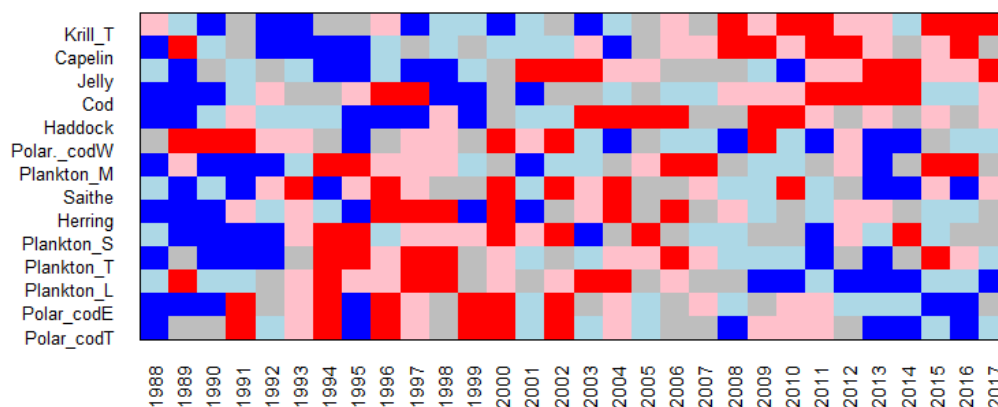
Figure 2.2.3. Time-series of zooplankton and 0-group fish amount in the Barents Sea sorted by trend. Blue means value below the 1988–2017 average and red means above the 1988–2017 average.

Pelagic and demersal fish

Figure 2.2.4 shows increasing trend of cod stock biomass (age 3+), haddock spawning stock and recruites (age 3), deepwater redfish (*S. mentelle*) stock and Greenland halibut stock during the

period 1990–2017, and the Mann-Kendall trend test showed that these positive trends were statistically significant. Recruitment to the fisheries exploited stocks (age 3) for cod does not show any clear trend. Polar cod stock was at high level in the beginning of 2000s and decreased after that. Herring biomass decreased since 2007 due to strong 2004 year class moved to the Norwegian Sea and since that, no strong year classes occurred.
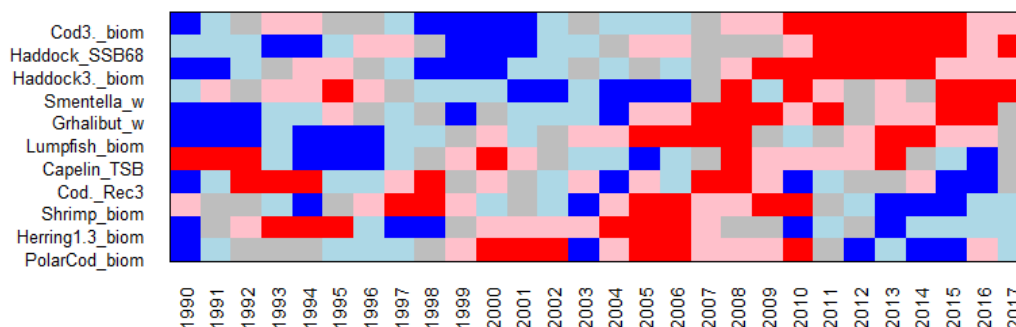
Figure 2.2.4. Time-series of fish biomass (both recruited at age 3, spawning and stock) and landings in the Barents Sea sorted by trend. Blue means value below the 1980–2017 average and red means above the 1980–2017 average.

Benthos

Figure 2.2.5 show increasing trend of snowcrab stock biomass during the period 2006-2017, and the Mann-Kendall trend test showed that these positive trends were statistically significant. The other parameters did not show any significant trends, most likely do to too short time series, but a change from mostly negative (before 2011) to more positive (from 2012) anomalies for the large animal-groups Porifera (sponges), Mollusca (bivalves, snails etc), and Echinodermata (sea stars, brittle stars, etc).
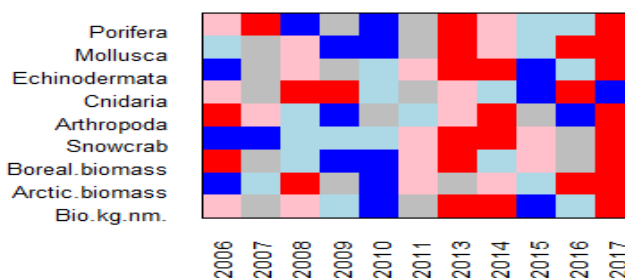
Figure 2.2.5. Time-series of bethos biomass in the Barents Sea sorted by trend. Blue means value below the 2006–2017 average and red means above the 2006–2017 average.

Sea birds

During the period 2004-2018 we found a positive northward trend in the spatial distribution (centre of gravity) of black-legged kittiwake and a negative trend in the abundance of this species (Mann-Kendal trend test). We found no significant trends in the northward displacement nor in the abundance of Brünnich's guillemot and Atlantic puffin (Figures 2.2.6).
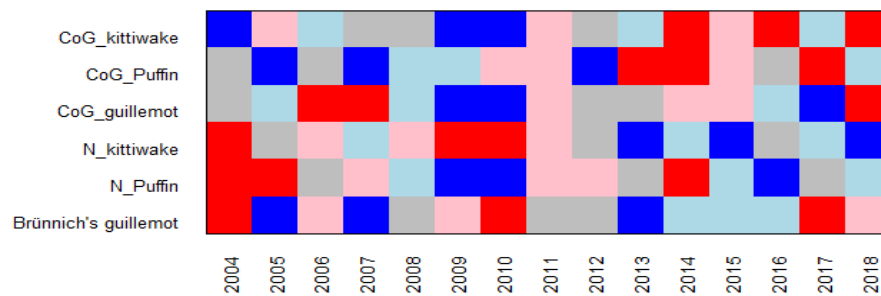
Figure 2.2.6. Time-series of sea birds abundance and spatial distribution (centre of gravity) in the Barents Sea sorted by trend. Blue means value below the 2004–2018 average and red means above the 2004–2018 average.

Human pressure

Human pressure decreased since 1970s in the Barents Sea. Figure 2.2.7 shows statistically significant decreasing trend in cod (ages 5-10), haddock (ages 4-7), capelin and shrimp fishing mortalities and capelin, Greenland halibut, polar cod and *S. mentelle* landings (Mann-Kendall trend test) during the period 1970–2016. Haddock landings showed increasing trend due to strong increase in haddock stock since 2005.
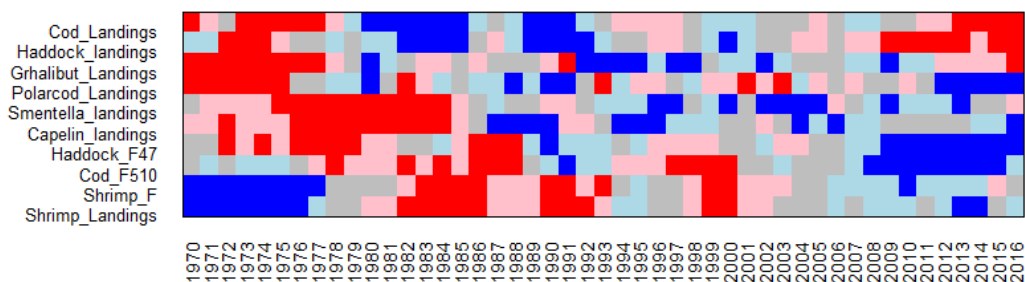
Figure 2.2.7. Time-series of fishing mortalities and landings in the Barents Sea sorted by trend. Blue means value below the 1970–2016 average and red means above the 1970–2016 average.

Common trend

Observed data mostly indicate nonstationary. For the time series analysis, a structural time series model, observation = trend component + cyclic component + noise, is applied (Harvey 1989, West and Harrison 1997). The trend component is modelled a structural trend model using stochastic differential equation (Kitagawa and Gersch 1996).
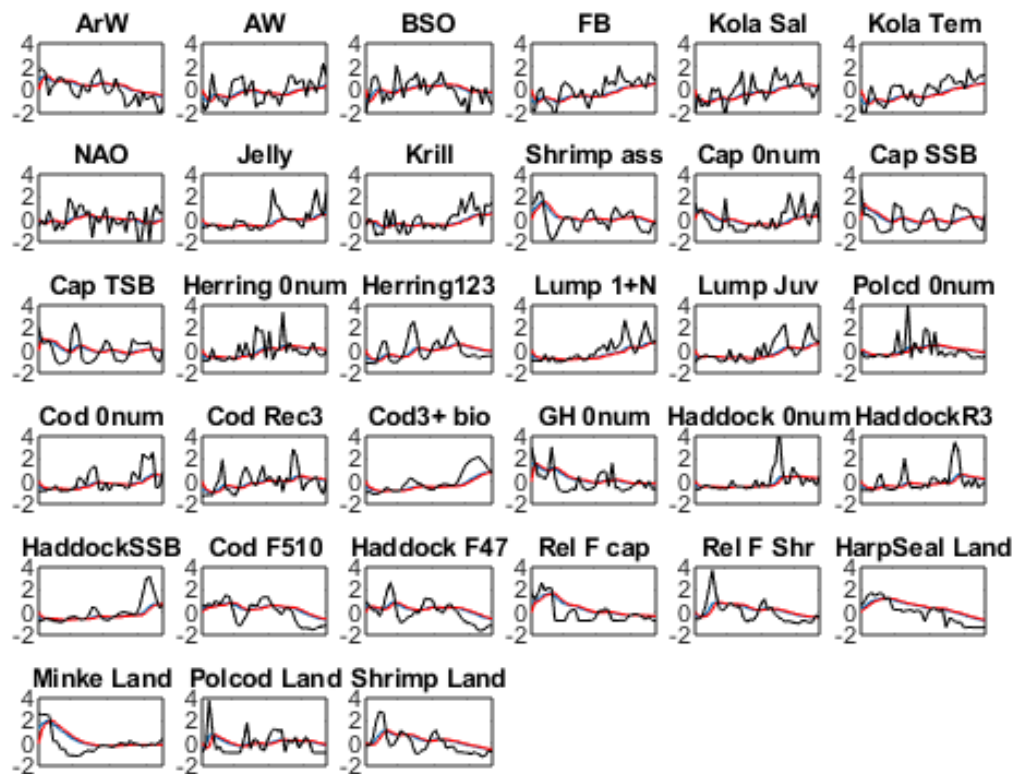
Figure 2.2.8. Estimated trend component (blue:filtering, red:prediction) by structural trend model.

The model is represented by a state space form and the state corresponding to trend is predicted and filtered by Kalman filter algorithm. Figure 2.2.8 show the original data, estimated prediction (red) and filtering values (blue).

For the estimated trends, the common trends among the data are estimated by a classification and similarity analyses (Solvang et al. 2008). The classified groups indicating rising, flat fluctuation and decline are summarized in Figure 2.2.9. The configurations are recognized as dominant common trend for the data. Change of the trends for biotic and human impact data during observed year could be investigated by the corresponded common trends for abiotic data. The cyclic components are obtained by extracting the trend component from the data. The obtained cyclic component are considered directional relationships among data by the feedback system analysis (Solvang and Subbey 2019).
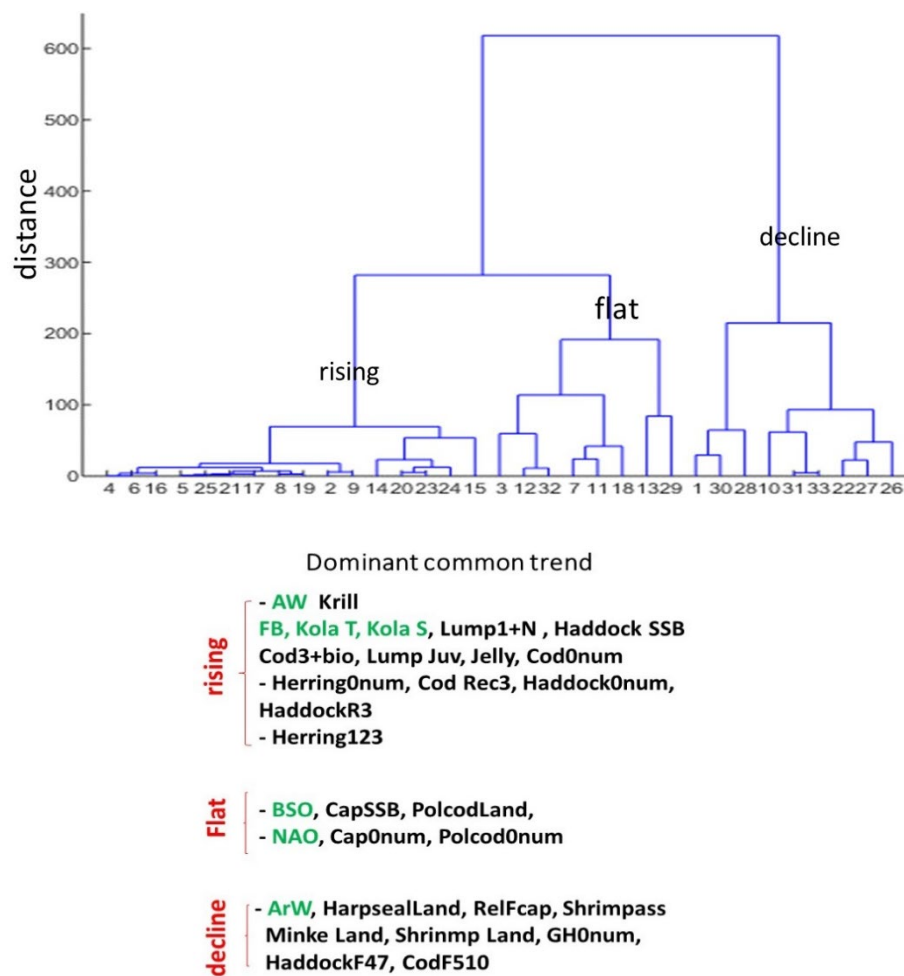
Figure 2.2.9 Dendrogram obtained by discriminant analysis procedure (Solvang, et al. 2008) and the obtained classified common trends' groups.

Reference

ICES. 2018. Interim Report of the Working Group on the Integrated Assessments of the Bar-ents Sea (WGIBAR). WGIBAR 2018 REPORT 9-12 March 2018. Tromsø, Norway. ICES CM 2018/IEASG:04. 210 pp.

Harvey, A.C. 1989. Forecasting, Structural Time Series Models and Kalman Filter, Cambridge University Press.

Kitagawa, G.and Gersch, W. 1996, Smoothness Priors Analysis of Time Series, Lecture Notes in Statistics, Springer-Verlag New York.

West, M. and Harrison, J. 1997, Bayesian Forecasting and Dynamic Models, Springer Series in Statistics, Springer-Verlag New York.

Solvang, H., Taniguchi, M., Nakatani, T., and Amano, S., Classification and similarity analysis of fundamental frequency patterns in infant spoken language acquisition, Statistical Methodology, 2008, 5, 187-208.

3 Current state of the Barent Sea ecosystem components

3.1 Meteorological and oceanographic conditions

by A. Trofimov (PINRO), V. Lien (IMR), A. Karsakov (PINRO), R. Ingvaldsen (IMR)

The air and water temperatures remained higher than average and typical of warm years, close to those in 2017. In autumn, the Atlantic waters (>3°C) covered relatively large area, but it decreased compared to 2017; the Arctic and cold bottom waters (<0°C) still covered rather small areas, the area of the former was close to that in 2017 but the area of the latter increased. Ice coverage was much lower than average and close to that in 2017. There was no ice in the sea from August to October; in December, the ice coverage was the lowest since 1951.

The Barents Sea is a shelf sea of the Arctic Ocean. Being a transition area between the North Atlantic and the Arctic Basin, it plays a key role in water exchange between them. Atlantic waters enter the Arctic Basin through the Barents Sea and the Fram Strait (Figure 3.1.1). Variations in volume flux, temperature and salinity of Atlantic waters affect hydrographic conditions in both the Barents Sea and the Arctic Ocean and are related to large-scale atmospheric pressure systems.

Figure 3.1.1. The main paths of Atlantic waters in the Barents Sea as well as Fugløya–Bear Island Section (1), Kola Section (2) and boxes in the northwestern (3) and northeastern (4) Barents Sea.

Air pressure, wind and air temperature

In 2018, the winter (December–March) NAO index was 0.30 that was much lower than in 2017 (1.47). Over the Barents Sea, southeasterly winds prevailed in January–March 2018 and westerly winds – during the rest of the year. The number of days with winds more than 15 m/s was higher than usual most of the year. It was lower than normal only in the western and central parts of the sea in January and February. In some months (May, June and September in the west of the sea, June and September – in the center as well as April, July and September – in the east), the

storm activity was a record high since 1981. For the whole year 2018, it was also a record high in the western (176 days) and central (161 days) Barents Sea.

Air temperature (http://nomad2.ncep.noaa.gov) averaged over the western (70–76°N, 15–35°E) and eastern (69–77°N, 35–55°E) Barents Sea showed that positive air temperature anomalies (relative to the base period of 1981–2010) prevailed over the sea during most of 2018, with the largest values (>4.0°C) in the eastern part in January, February and December (Fig. 3.1.2). In May and July, in the west, the anomalies were record high since 1948. Negative air temperature anomalies were observed over the Barents Sea only in March (–2.6°C in the west and –2.5°C in the east) (Fig. 3.1.2).
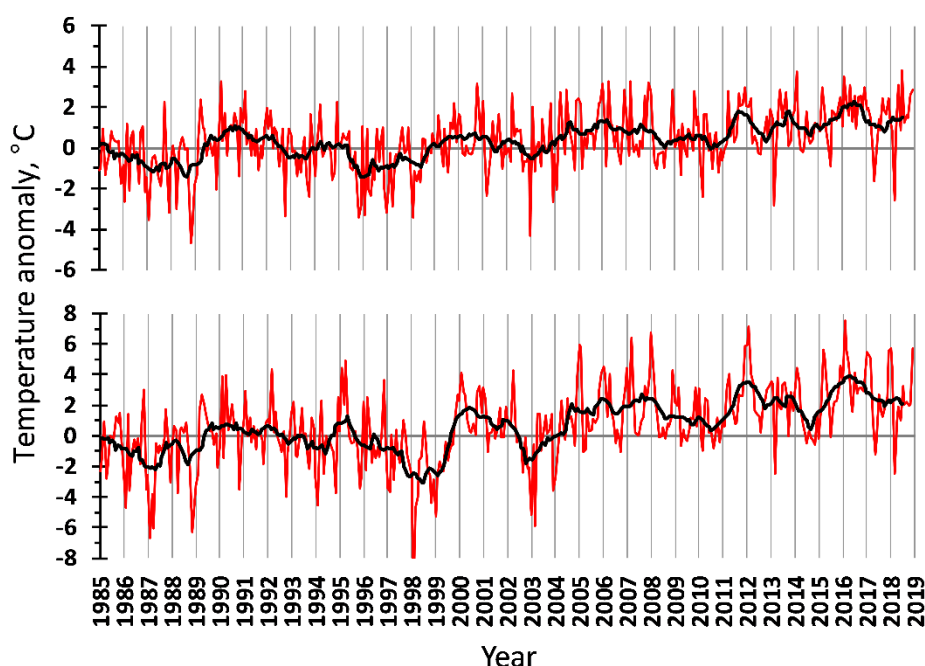
Figure 3.1.2. Air temperature anomalies in the western (upper) and eastern (lower) Barents Sea in 1985–2018. The red line shows monthly values, the black one – 11-month running means.

Ice conditions

Ice conditions in the Barents Sea in 2018 developed as in low-ice years. In January and February, the ice coverage (expressed as a percentage of the sea area) was respectively 20 and 17% lower than average (1981–2010) and close to that in 2017 (Fig. 3.1.3). The seasonal maximum of ice extent was, as usual, in April; the ice coverage was 53% that was 4% lower than average but 9% higher than in 2017. Ice melting started intensively in May. In summer (June–August), the ice coverage was 7–19% lower than average and 3–7% lower than in 2017. From August to October, there was no ice in the Barents Sea; in October, it happened for the first time since 1984. Freezing started in the last days of October. In November and December, the ice coverage was respectively 19 and 25% lower than average and slightly lower (by 2–3%) than in 2017. The December ice coverage reached a record low value (15%) for this month since 1951. Overall, the 2018 annual mean ice coverage of the Barents Sea was 13% lower than average as it was in 2017.
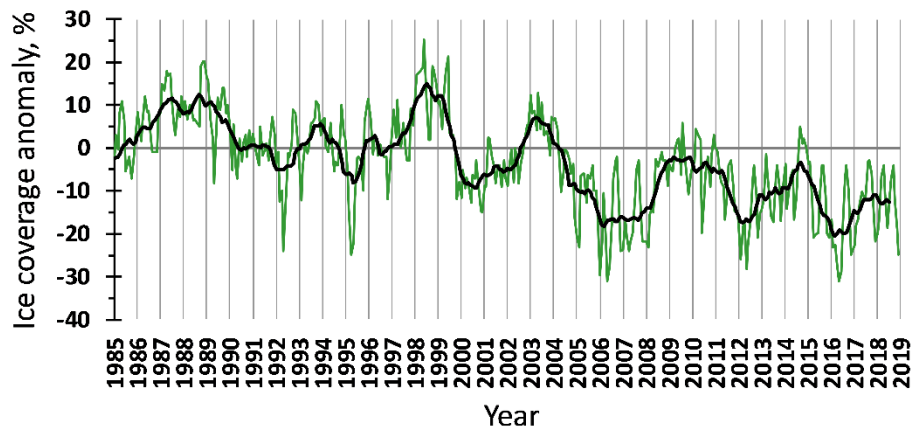
Figure 3.1.3. Ice coverage anomalies in the Barents Sea in 1985–2018. The green line shows monthly values, the black one – 11-month running means.

Currents and transports

The volume flux into the Barents Sea varies with periods of several years and was significantly lower during 1997–2002 than during 2003–2006 (Fig. 3.1.4). In 2006, the volume flux was at a maximum during winter and very low during fall. After 2006, the inflow has mostly been relatively low. Throughout 2015 and in winter 2016, the inflow was around 1 Sv larger than the long-term average (Fig. 3.1.4). The exception was March 2016, when the volume flux was temporarily smaller than average. The data series presently stops in May 2016, awaiting the processing of measurement data following new instrumentation in the mooring array, thus, no information about the subsequent period is available as of yet.
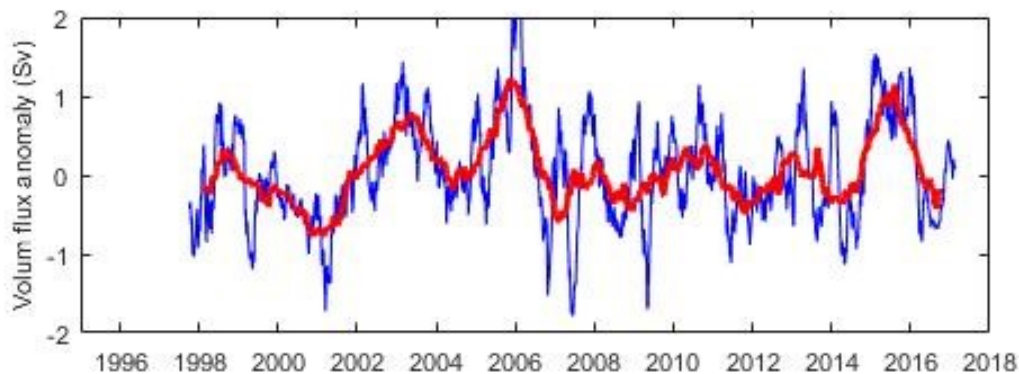
Figure 3.1.4. Observation-based volume flux anomalies (in Sverdrups) through the Fugløya–Bear Island Section. Blue line shows daily averages and red, thick line shows the filtered 12-month average.

Complementing the observed volume flux, numerical modeling suggests that the volume flux into the Barents Sea through the BSO was below average during the first four months of 2018, with a distinct, negative anomaly of more than 3 Sv (corresponding to 3 standard deviations below the seasonal average) in March (Fig. 3.1.5). A similar pattern is seen in the BSX, i.e., into the northern Kara Sea. Here, the anomaly in March was exceeding 3 Sv, corresponding to >3 standard deviations below the seasonal average. As a result, the inflow to the Barents Sea through the BSO was -0.5 Sv (i.e., net flow towards the west) in March, while the flow also reversed in the BSX, with a net flow of 1.5 Sv into the Barents Sea from the northern Kara Sea/St. Anna Trough. A seasonal low in the flow into the Barents Sea, and, hence, through the Barents Sea is consistent with observations showing a seasonal low, and sometimes a reversal of the flow through the BSO (i.e., net flow towards the west) in spring and most notably in April (Ingvaldsen

et al., 2004). However, this seasonal low is typically less pronounced in the model results (especially flow reversals), and as a consequence, the anomaly in the modelled volume fluxes in March 2018 were 3 standard deviations below the modelled seasonal average. This distinct, negative anomaly is also seen at the southern border of the Barents Sea, i.e., the flow towards the Kara Gate, while at the northern boundary between the Svalbard and Franz Josef Land archipelagos, the flow from the Barents Sea towards the Arctic was above the seasonal average throughout the year.

In May and June, the volume flux into the Barents Sea through the BSO was above average, while the flow through the BSX was close to the seasonal average. For the period July-September, the main flow through the Barents Sea (i.e., from the BSO to the BSX) was close to the long-term seasonal average. However, into the south-eastern Barents Sea (through SBSO), the flow was above average during late summer (Aug-Sep).

Note that the model has been found to be accurate for annual mean and standard deviation of the volume transports, while the modelled monthly averages are usually weakly, yet statistically significantly correlated with observations (Lien et al., 2013, 2016).
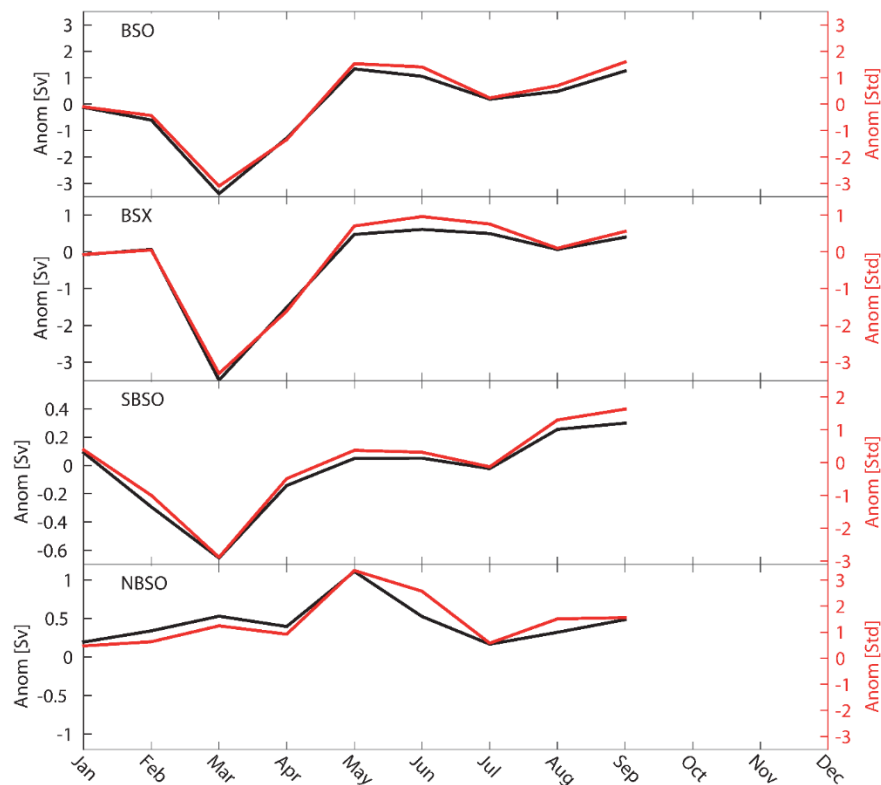
Figure 3.1.5. Modelled monthly volume flux anomalies in 2018 relative to average (black) and standard deviation (red) during the period 1961–1990 in the Barents Sea Opening (BSO), the Barents Sea Exit (BSX), between the Murman coast and Novaja Zemlja (SBSO), and between Svalbard and Franz Josef Land (NBSO).

Figure 3.1.6 shows modelled monthly average volume fluxes through some key sections during 2018 and for the long-term average (1960-2018). Most notably, there was a distinct, negative volume flux anomaly during March 2018, as also seen in Fig. 3.1.5. This anomaly is clearly seen upstream in the BSO and downstream into the Hopen Trench and into the Pechora Sea to the southeast, as well as in the north-eastern outflow area (BSX) and through the northern boundary between Svalbard and Franz Josef Land. However, the flow reversal in March is seen only as a modest, negative anomaly in the Kola section, where the largest anomaly was seen as a flow reversal in January. During May and June, the inflow through the BSO was above the long-term

average, leading to above average flow also through the Hopen Trench and Kola section during late spring and early summer.
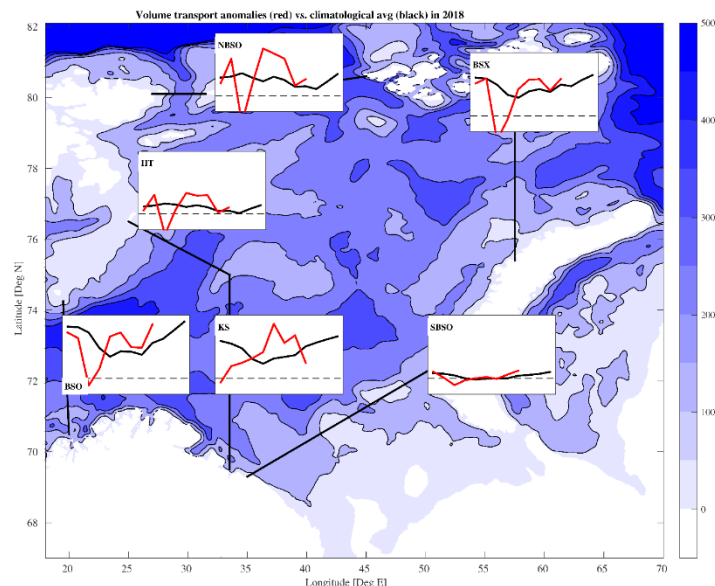

Figure 3.1.6. Modelled climatological (1960-2018; black) and 2018 (red) monthly average volume transports through the Barents Sea Opening (BSO), Hopen Trench (HT), Kola section (KS), Pechora Sea (SBSO), Barents Sea Exit (BSX), Svalbard – Franz Josef Land (NBSO). Scale on y-axis is -1 to 4 Sv in all plots. Positive values toward north/east.

Temperature and salinity in standard sections and northern boundary regions

The Fugløya–Bear Island Section covers the inflow of Atlantic and Coastal water masses from the Norwegian Sea to the Barents Sea, while the Kola Section covers the same waters in the southern Barents Sea. Note a difference in the calculation of the temperatures in these sections; in the Fugløya–Bear Island Section the temperature is averaged over the 50–200 m depth layer while in the Kola Section the temperature is averaged from 0 to 200 m depth.

In 2018, the temperature of Atlantic Water flowing into the Barents Sea through the Fugløya–Bear Island Section (50–200 m) started out 0.25°C above the long-term average in the beginning of the year, but decreased through the year and ended up at -0.03°C in the fall (Fig. 3.1.7). On average, the 2018 temperature was 0.5°C lower than that in 2017 (Fig. 3.1.7).
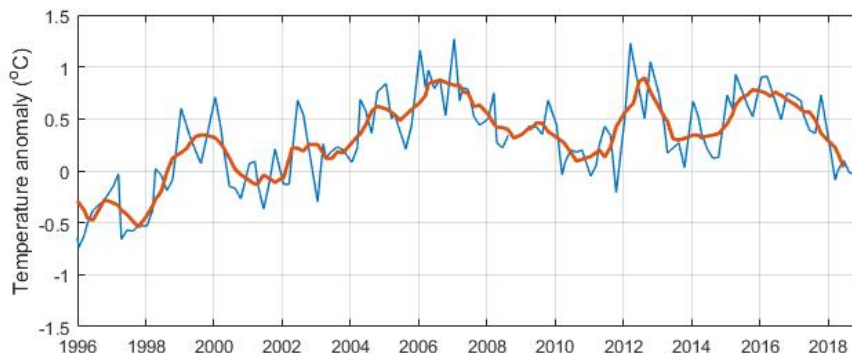
Figure 3.1.7. Temperature anomalies in the 50–200 m layer in the Fugløya–Bear Island Section.

Temperature of coastal and Atlantic waters in the Kola Section in 2018 was typical of warm and anomalously warm years. During the observation period of 2018, positive temperature anomalies in the 0–200 m layer in the coastal waters and Atlantic waters of the central part of the section (Murman Current) were smoothly decreasing from 1.2°C in January to 0.8°C in June in the coastal

waters and to 1.0°C in August in the Atlantic waters (Fig. 3.1.8). Whereas positive temperature anomalies of Atlantic waters in the outer part of the section (Central branch of the North Cape Current) first dropped from 1.4°C in February to 0.5°C in May and then abruptly increased up to 1.3°C in August, having reached a record high value for this month since 1951. Compared to 2017 (Karsakov et al., 2018b), the coastal waters and Atlantic waters of the central part of the section were 0.1–0.4°C colder in January–May and 0.1–0.2°C warmer in summer. The Atlantic waters in the outer part of the section were 0.1–0.8°C colder compared to 2017 in March–June, especially in April–May (by 0.6–0.8°C), and in other months, they were warmer (by 0.2°C in January, February and July, and by 0.6°C in August).

Throughout the observation period in 2018, salinity of coastal waters in the inner part of the Kola Section and Atlantic waters in the central part (Murman Current) was respectively 0.2 and 0.1 lower than average (Fig. 3.1.8). Whereas salinity of Atlantic waters in the outer part of the section (Central branch of the North Cape Current) was close to average from January to August 2018.
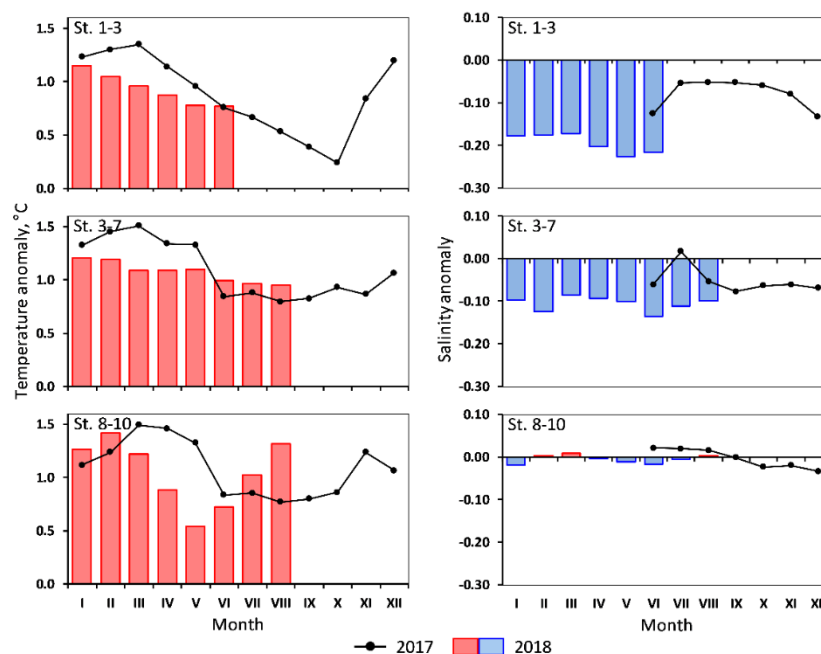
Figure 3.1.8. Monthly mean temperature (left) and salinity (right) anomalies in the 0–200 m layer in the Kola Section in 2017 and 2018. St. 1–3 – Coastal waters, St. 3–7 – Murmansk Current, St. 8–10 – Central branch of the North Cape Current.

In the northern Barents Sea (NW) the temperature increased in 2018 compared with the preceding year, with the temperature anomaly increasing from -0.18°C in 2017 to 0.30°C in 2018. In the northeastern Barents Sea, the temperature decreased, with a temperature anomaly of 0.19°C in 2018 compared with 0.74°C in 2017.

Spatial variation in temperature and salinity (surface, 100 m and bottom)

Sea surface temperature (SST) (http://iridl.ldeo.columbia.edu) averaged over the southwestern (71–74°N, 20–40°E) and southeastern (69–73°N, 42–55°E) Barents Sea showed that positive SST anomalies (relative to the base period of 1982–2010) prevailed in both areas during 2018 (Fig. 3.1.9). The largest positive anomalies (>2.0°C) were found in the southeast of the sea in July–September; the December SST anomaly in this area reached a record high value since 1982. The smallest positive anomalies (<0.5°C) were observed in the southwest of the sea in April, May and July, and in the southeast from March to June (Fig. 3.1.9).
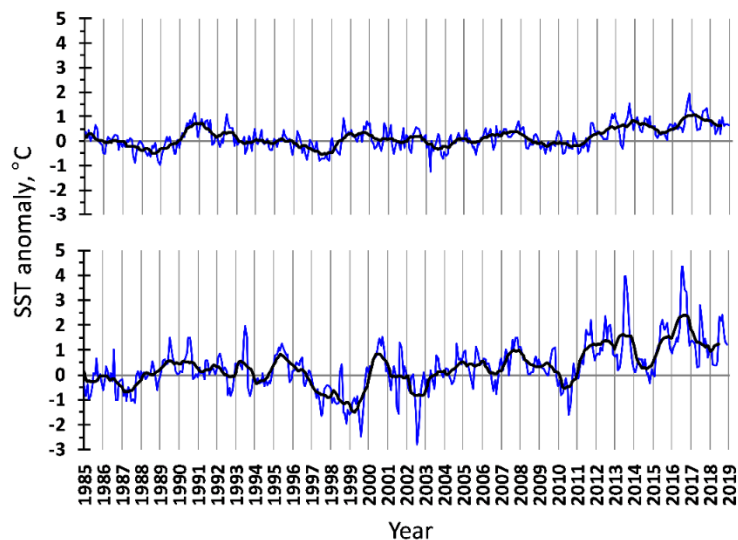
Figure 3.1.9. Sea surface temperature anomalies in the western (upper) and eastern (lower) Barents Sea in 1985–2018. The blue line shows monthly values, the black one – 11-month running means.

During August–September 2018, the joint Norwegian-Russian ecosystem survey was carried out in the Barents Sea. Surface temperature was on average 1.0°C higher than the long-term (1931–2010) mean in most of the sea (Fig. 3.1.10). The largest positive anomalies (>2.0°C) were mainly observed in the southeastern part of the Barents Sea as well as west and north of the Spitsbergen Archipelago. Small negative anomalies took place mostly in some areas in the southwest of the sea. Compared to 2017, the surface temperature was higher (by 1.0°C on average) in southern and northern parts of the surveyed area, especially north of the Spitsbergen Archipelago, and lower (by 0.7°C on average) – in the western and central parts, especially west of the Spitsbergen Archipelago (Fig. 3.1.10).
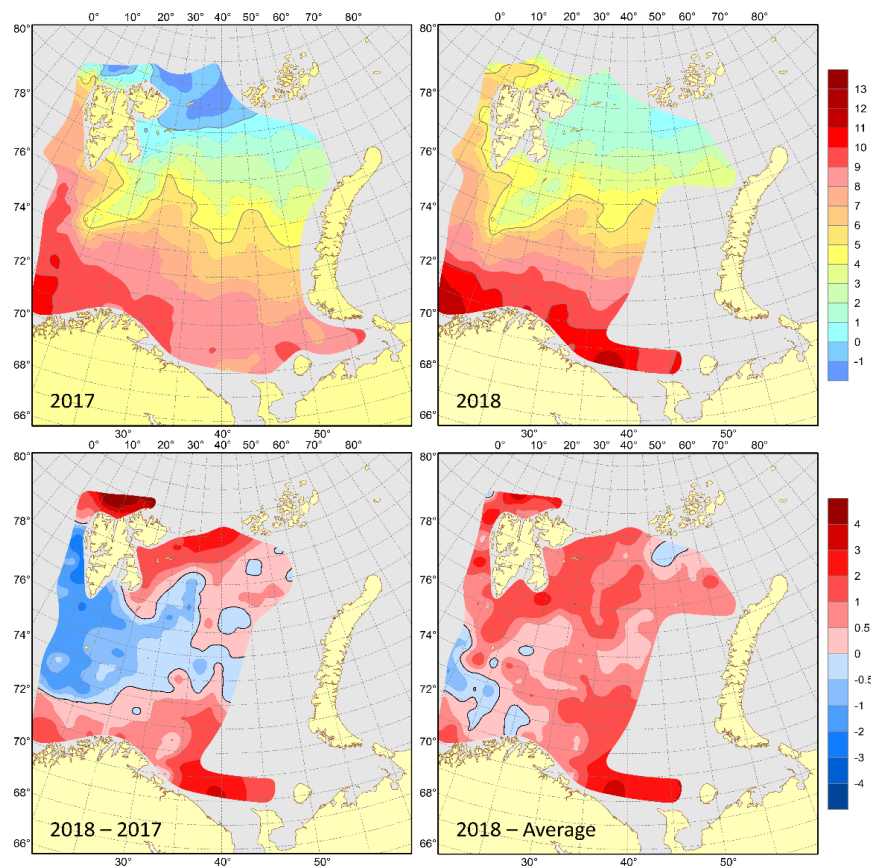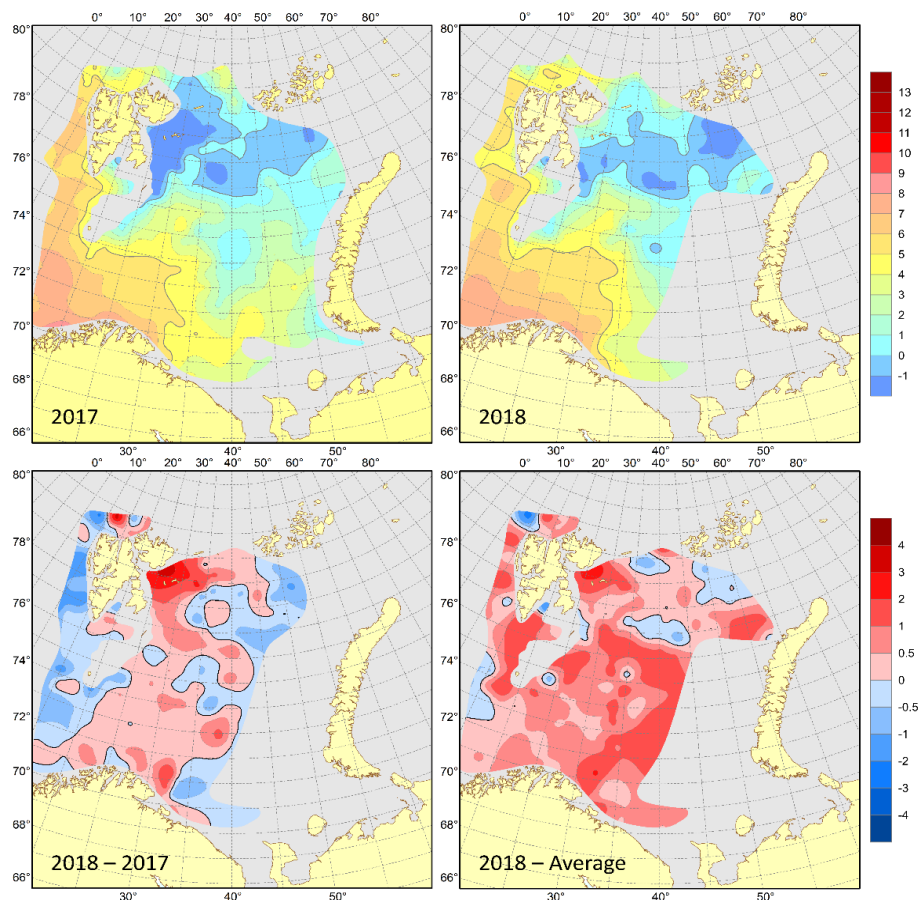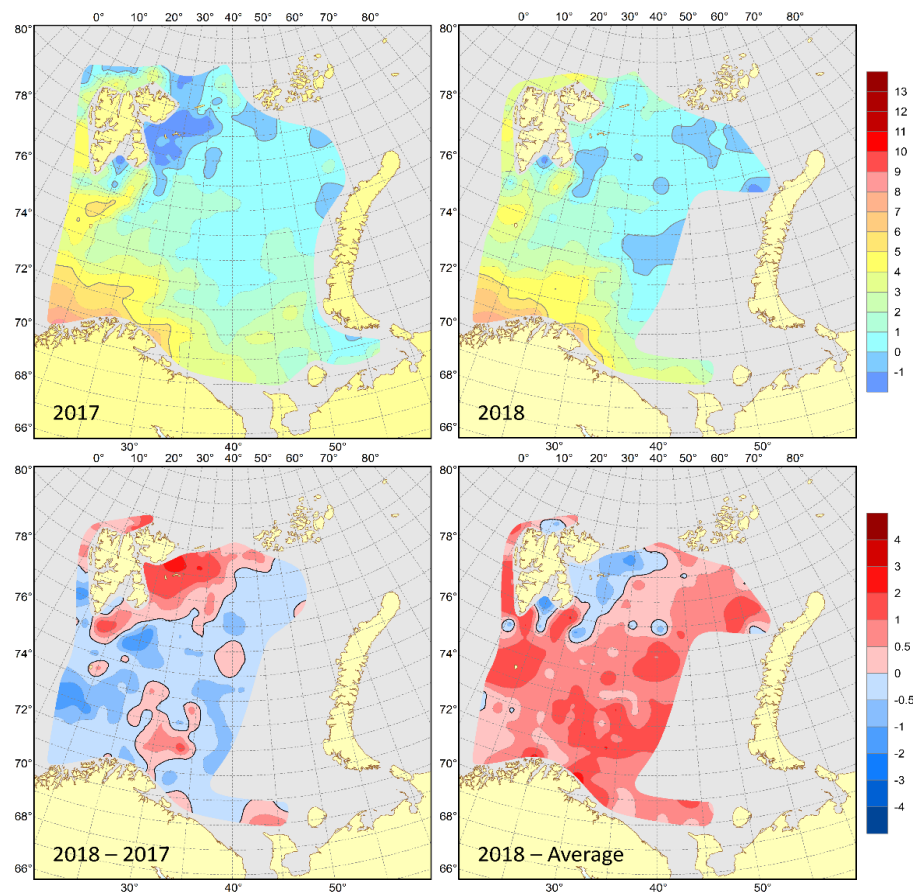
Figure 3.1.10. Surface temperatures (°C) in August–September 2017 (upper left) and 2018 (upper right), their differences between 2018 and 2017 (lower left, °C) and anomalies in August–September 2018 (lower right, °C).

Arctic waters were mainly found, as usual, in the 50–100 m layer north of 77°N. Temperatures at depths of 50 and 100 m were higher than the long-term (1931–2010) means (on average, by 1.1 and 0.7°C respectively) in most of the Barents Sea (Fig. 3.1.11). Small negative anomalies were mainly found at 100 m depth in some small areas in the northern part of the surveyed area. Compared to 2017, the 50 m temperature was on average 0.9°C higher in about two thirds of the surveyed area with the largest differences in the northernmost Barents Sea; negative temperature differences (on average –0.6°C) prevailed in the west of the sea. The 100 m temperature was on average 0.4°C lower than in 2017 in about half the surveyed area, especially in its western and eastern parts (Fig. 3.1.11). In the rest area, waters at 100 m were on average 0.4°C warmer compared to 2017 with the largest positive differences east of the Spitsbergen Archipelago.
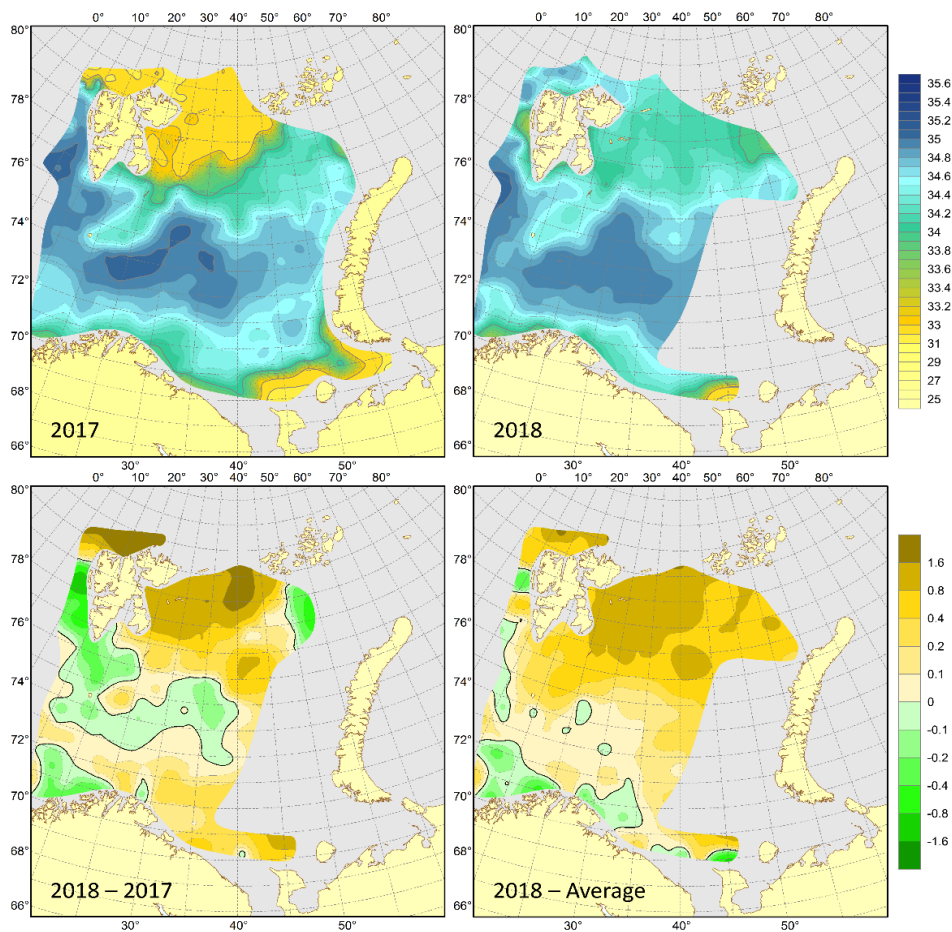
Figure 3.1.11. 100 m temperatures (°C) in August–September 2017 (upper left) and 2018 (upper right), their differences between 2018 and 2017 (lower left, °C) and anomalies in August–September 2018 (lower right, °C).

Bottom temperature was in general 0.8°C above average (1931–2010) in most of the Barents Sea (Fig. 3.1.12). Negative anomalies (–0.4°C on average) were only observed east of the Spitsbergen Archipelago. Compared to 2017, the bottom temperature was on average 0.4°C lower in two thirds of the surveyed area (Fig. 3.1.12). Bottom waters were warmer (on average, by 0.6°C) than in 2017 mainly in the northern sea, especially east of the Spitsbergen Archipelago.

Figure 3.1.12. Bottom temperatures (°C) in August–September 2017 (upper left) and 2018 (upper right), their differences between 2018 and 2017 (lower left, °C) and anomalies in August–September 2018 (lower right, °C).

Surface salinity was on average 0.5 higher than the long-term mean (1931–2010) in most of the Barents Sea with the largest positive anomalies (>0.8) in its northern part; at the same time the positive anomalies decreased southwards (Fig. 3.1.13). Negative anomalies (–0.1 on average) were mainly observed in the southernmost and southwestern parts of the Barents Sea. Compared to 2017, the surface waters were on average 0.5 saltier in two thirds of the surveyed area with the largest positive differences in the northern part of the sea and north of the Spitsbergen Archipelago (Fig. 3.1.13). Negative differences in salinity between 2018 and 2017 (–0.1 and more) were found in the central, northeastern, western and southwestern parts of the Barents Sea.
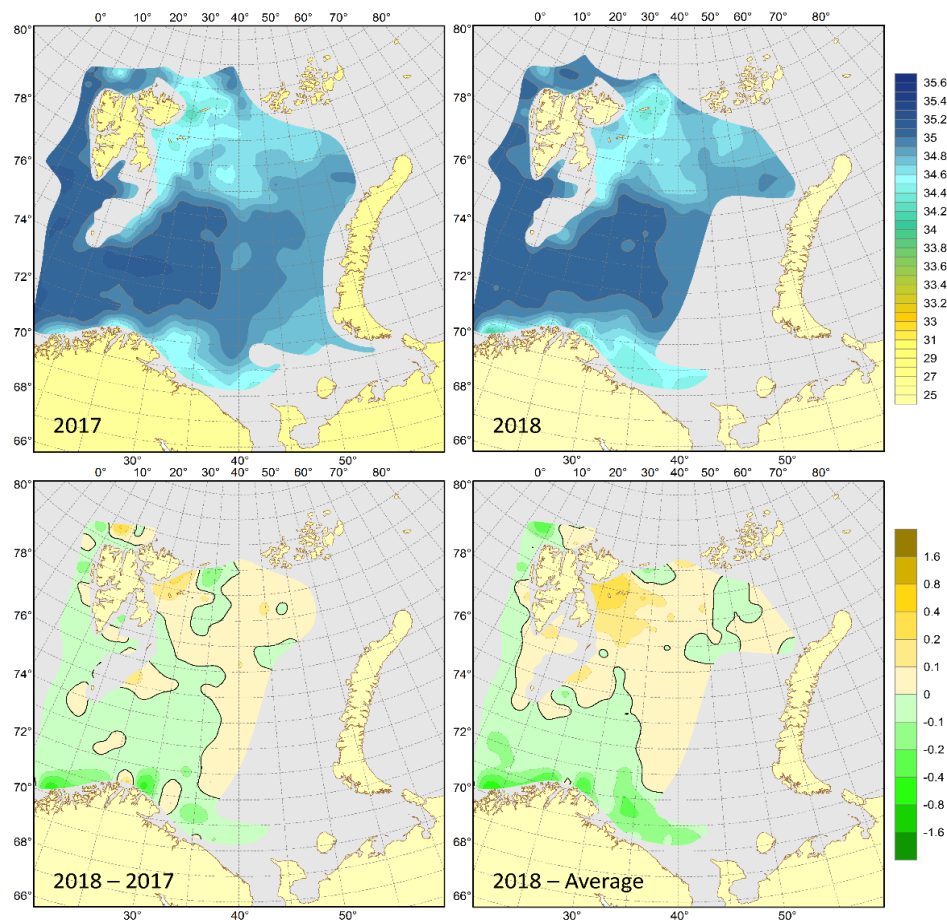
Figure 3.1.13. Surface salinities in August–September 2017 (upper left) and 2018 (upper right), their differences between 2018 and 2017 (lower left) and anomalies in August–September 2018 (lower right).

The 100 m salinity was, in general, close to both the average (1931–2010) and that in 2017 in most of the Barents Sea (Fig. 3.1.14). Significant negative anomalies and differences between 2018 and 2017 (–0.1 and more) were mainly observed in the coastal waters in the southwestern and southern parts of the Barents Sea, and significant positive anomalies and differences (>0.1) – in the northwest of the sea, especially east of the Spitsbergen Archipelago (Fig. 3.1.14).
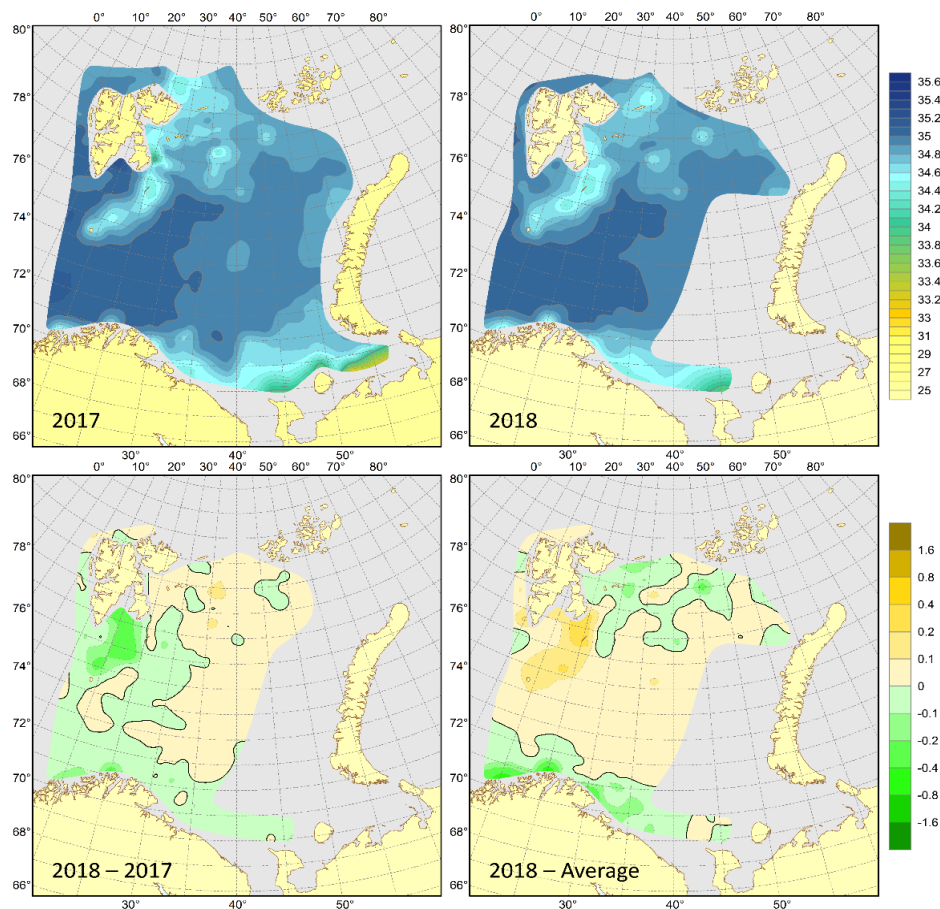
Figure 3.1.14. 100 m salinities in August–September 2017 (upper left) and 2018 (upper right), their differences between 2018 and 2017 (lower left) and anomalies in August–September 2018 (lower right).

Bottom salinity was close to both the average (1931–2010) and that in 2017 in most of the Barents Sea (Fig. 3.1.15). Positive salinity anomalies of higher than 0.1 took place in shallow waters over the Spitsbergen Bank, and significant negative anomalies were mainly found in the coastal waters in the southwestern and southern parts of the Barents Sea and in shallow waters east of the Spitsbergen Archipelago. Significant differences in bottom salinity between 2018 and 2017 were mainly found in the area between the Spitsbergen Archipelago and Bear Island, where the bottom waters in 2018 were fresher (by 0.1 and more) compared to 2017 (Fig. 3.1.15).

Figure 3.1.15. Bottom salinities in August–September 2017 (upper left) and 2018 (upper right), their differences between 2018 and 2017 (lower left) and anomalies in August–September 2018 (lower right).

Water masses and fronts

In August–September 2018, the area covered by warm water (above 4, 3 and 1°C at 50, 100 m and near the bottom respectively) was close to that in 2017 at 50 and 100 m, and 12% smaller at the bottom (Fig. 3.1.16). The area covered by cold water (below 0°C) was also close to that in 2017 at 50 m but 7 and 8% larger than in 2017 at 100 m and near the bottom respectively (Fig. 3.1.16). Since 2000, the area covered by cold bottom water was the largest in 2003 and rather small in 2007, 2008, 2012, 2016 and 2017; in 2016, it reached a record low value since 1965.

In the past decades, the area of Atlantic waters has increased in the Barents Sea, whereas the area of Arctic waters has decreased (Karsakov et al., 2018). In August–September 2018, the Atlantic waters (>3°C) covered a relatively large area that decreased compared to 2017; the Arctic waters (<0°C) still covered rather small area like they did in the previous year; and the area of Mixed waters (0°C<T<3°C) reached a record high value since 1965 (Fig. 3.1.17).
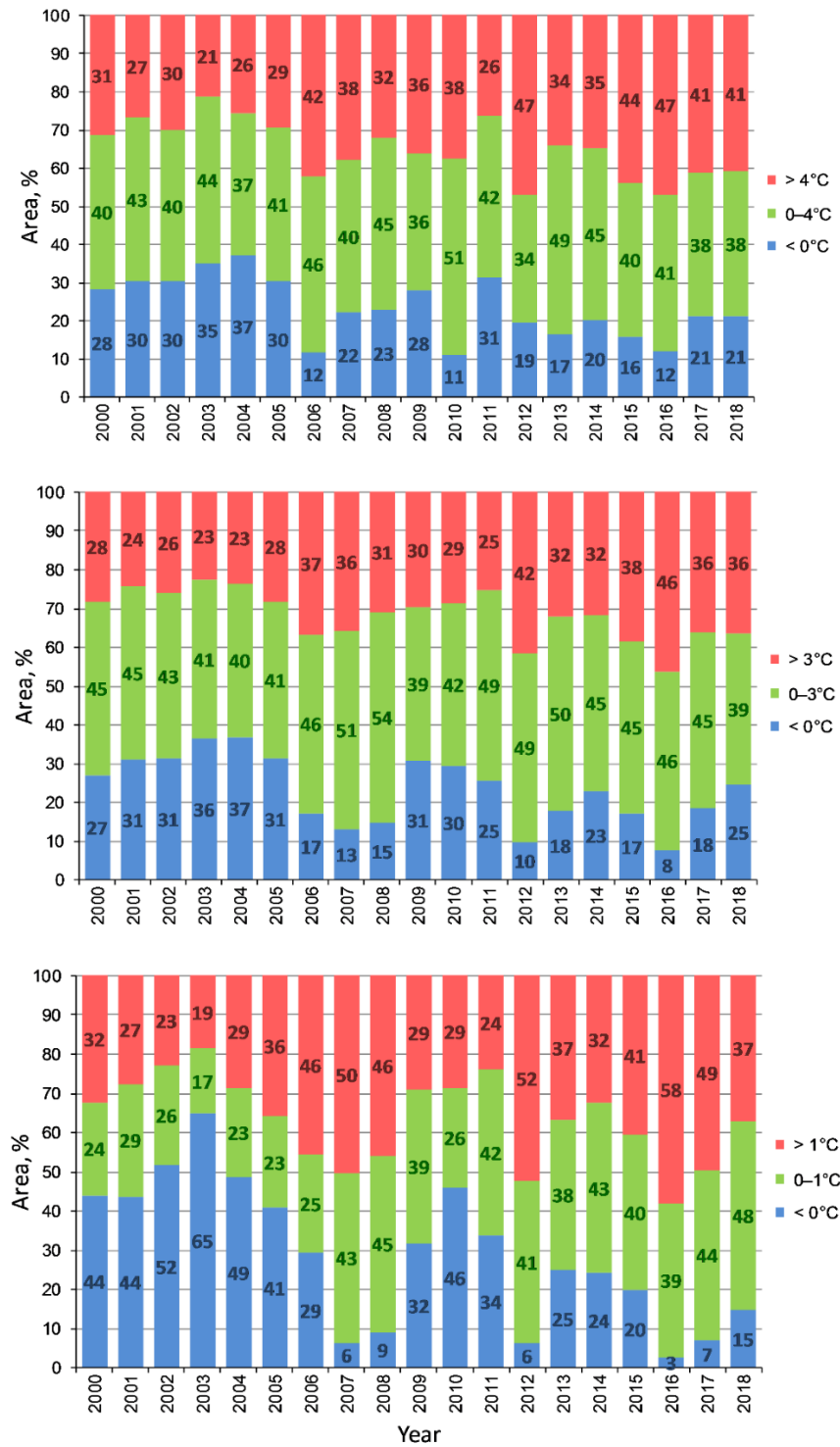
Figure 3.1.16. Areas covered by water with different temperatures at 50 m (upper panel), 100 m (middle panel) and near the bottom (lower panel) in the Barents Sea (71–79°N, 25–55°E) in August–September 2000–2018.
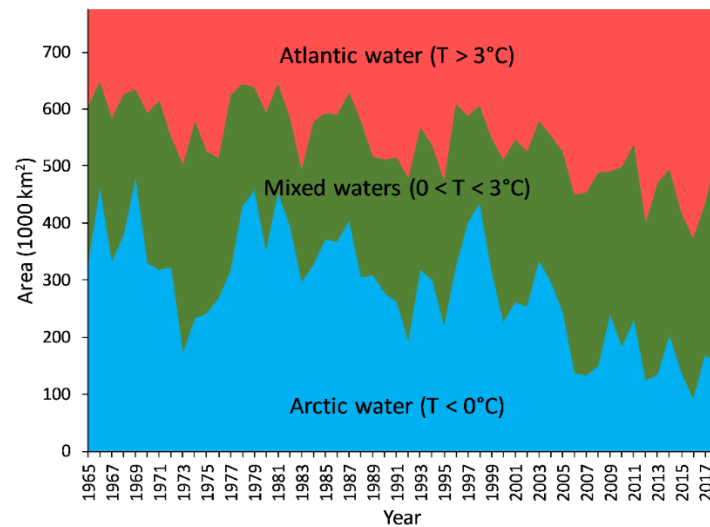
Figure 3.1.17. Area of water masses in the Barents Sea (71–79°N, 25–55°E) in August–September 1965–2018 (based on 50–100 m averaged temperature).

The transition zone between relatively warm and saline Atlantic Water and colder and less saline Arctic Water is commonly termed the Barents Sea Polar Front. Due to the steeper topography around the Spitsbergen Bank and Hopen Deep, the front is most pronounced in this area of the western Barents Sea. Using a grid of 30′ by 10′ in longitude and latitude, respectively, and defining the thermal frontal zone as the gradient in temperature exceeding 0.04 °C/km at 50 m depth during the August-September period, the extent index and center of gravity of the frontal zone around the Hopen Deep area are calculated. The extent index (defined as the number of grid nodes in which temperature gradients exceeded a threshold value of 0.04°C/km) ranged from 105 to 644 in 1960–2018, while the long-term (1960–2010) mean value is 393 (Figure 3.1.18). The index showed significant interannual variations in the 1960s and early 1970s. Then it was gradually increasing from the late 1980s and the early 2000s; thereafter it began to decrease to its minimum value in 2010. At the same time, the area of thermal frontal zones diminished five-fold between 2001 and 2010. After 2010, the index remained low, and only in 2011 and 2017 was it close to the average. Most notably, the center of gravity of the front has moved northeast, especially from the 1960s to the 1970s (by about 75 km), and again from the 2000s to the 2010s (Fig. 3.1.18). As a result, from the 1960s to the 2010s, the centroids of the Barents Sea thermal frontal zones shifted northeast by approximately 150 km. Moreover, the average temperature gradient in the frontal area has decreased since 2000 (not shown), from an average of 0.065 °C/km in the early 2000s to 0.055 °C/km in the 2010s.
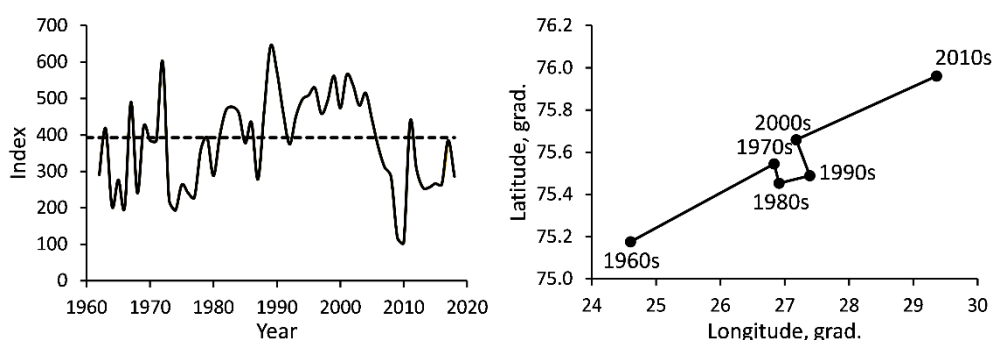
Figure 3.1.18. The extent index (left panel) and decadal mean centroids (right panel) of the thermal frontal zones in the Barents Sea (73–78°N, 15–43°E) at 50 m depth in August–September (*From Ivshin et al., 2018*). The dashed line shows the long-term (1960–2010) mean value.

References

ICES. 2018. Interim Report of the Working Group on the Integrated Assessments of the Barents Sea (WGIBAR). WGIBAR 2018 REPORT 9-12 March 2018. Tromsø, Norway. ICES CM 2018/IEASG:04. 210 pp.

Ivshin V, Trofimov A, Titov O. 2018. Variability in the frontal zones of the Barents Sea in 1960-2017. *In* Influence of Ecosystem Changes on Harvestable Resources at High Latitudes. The Proceedings of the 18th Russian-Norwegian Symposium, Murmansk, Russia, 5–7 June 2018, pp. 21-28. Ed. by E. Shamray, G. Huse, A. Trofimov, S. Sundby, A. Dolgov, H. R. Skjoldal, K. Sokolov, L. L. Jørgensen, A. Filin, T. Haug, and V. Zabavnikov. IMR/PINRO Joint Report Series, No. 1-2019. 217 pp.

3.2   Phytoplankton and primary production

The phytoplankton development in the Barents Sea is typical for a high latitude region with a pronounced maximum in biomass and productivity during spring. During winter and early spring (January-March) both phytoplankton biomass and productivity are quite low. The spring bloom is initiated during mid-April to mid-May and may vary strongly from one year to another. The bloom duration is typically about 3-4 weeks and it is followed by a reduction of phytoplankton biomass mainly due to the exhaustion of nutrients and grazing by zooplankton. Later in the fall when the increasing winds start to mix the upper layer and bring nutrients to the surface, a short autumn bloom can be observed. However, the time development of this general description can vary geographically. The spring bloom in the Atlantic water domain without sea-ice is thermocline-driven, whereas in the Arctic domain with seasonal sea-ice, stability from ice-melt determines the bloom (Skjoldal and Rey 1989, Hunt et al. 2012). Thus, the spring bloom at the ice edge in the Barents Sea can sometimes take place earlier than in the southern regions due to early stratification from ice melting.

Phytoplankton observation

By Stuart Larsen

In 2018, two sets of phytoplankton samples were collected in the Barents Sea by IMR. The samples were obtained from CTD mounted water bottles, and analysed using the Utermöhl sedimentation method for 50 ml water samples preserved in Lugol's solution.

The first set of samples was collected during spring, between the 22th and 25th of May along the Fugløya-Bear Island (FB) transect (Figure 3.2.1). The second set was collected during autumn, between the 4th of September and the 3rd of October in the Norwegian sector (Figure 3.2..2). During this time of year, solar elevation is too low at higher latitudes for the satellite to gather data and so complete satellite coverage for the Barents Sea was not possible. Sampling method and results of the phytoplankton analysis are provided in the BESS Report available at

https://www.hi.no/filarkiv/2018/03/5_1_phytopl_chloroph_nutrients_.pdf/nb-no. During 2018, the abundance of Cryptophyceae, Dinophyceae, and Dictyophyceae was comparable with that of 2017. However, averaged over all the samples taken at 10 m depth, the 2018 BESS found much higher numbers of unidentified flagellates: averaging approximately 300 000 l⁻¹ this year com-pared to 70 000 l-1 in 2017. In contrast, there were fewer diatoms: averaging approximately 53 000 l-1 in 2017 down to 5 700 l-1 in 2018 . The 2018 survey data also indicated increased numbers of coccolithophores, all identified as *Emiliania huxleyi*, with an average of approximately 11 300 l-1 in 2018 compared to 1 070 l-1 in 2017.

By Stuart Larsen

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The first set of samples was collected during spring, between the 22th and 25th of May along the Fugløya-Bear Island (FB) transect (Figure 3.2.1). The second set was collected during autumn, between the 4th of September and the 3rd of October in the Norwegian sector (Figure 3.2..2). During this time of year, solar elevation is too low at higher latitudes for the satellite to gather data and so complete satellite coverage for the Barents Sea was not possible. Sampling method and results of the phytoplankton analysis are provided in the BESS Report available at https://www.hi.no/filarkiv/2018/03/5_1_phytopl_chloroph_nutrients_.pdf/nb-no. During 2018, the abundance of Cryptophyceae, Dinophyceae, and Dictyophyceae was comparable with that of 2017. However, averaged over all the samples taken at 10 m depth, the 2018 BESS found much higher numbers of unidentified flagellates: averaging approximately 300 000 l⁻¹ this year com-pared to 70 000 l-1 in 2017. In contrast, there were fewer diatoms: averaging approximately 53 000 l-1 in 2017 down to 5 700 l-1 in 2018 . The 2018 survey data also indicated increased numbers of coccolithophores, all identified as *Emiliania huxleyi*, with an average of approximately 11 300 l-1 in 2018 compared to 1 070 l-1 in 2017.
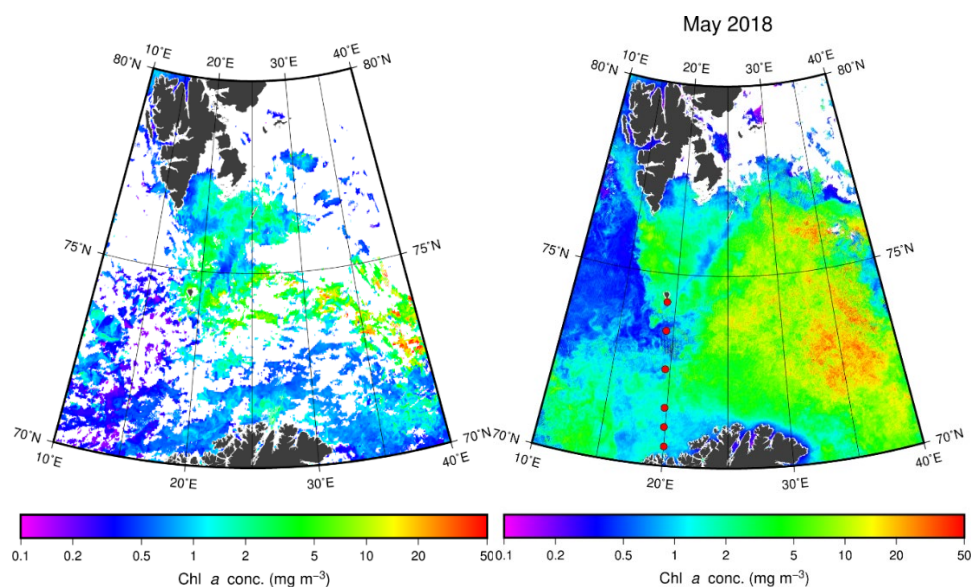

Figure 3.2.1. Left: Mean surface chlorophyll concentration from MODIS satellite imagery for 21-26 May 2018 with sam-ples taken along the Fugløya-Bjørnøya transect. Right: Mean surface chlorophyll concentration for the whole of May. Red dots show survey sampling locations along the transect, and white regions indicate missing satellite data.
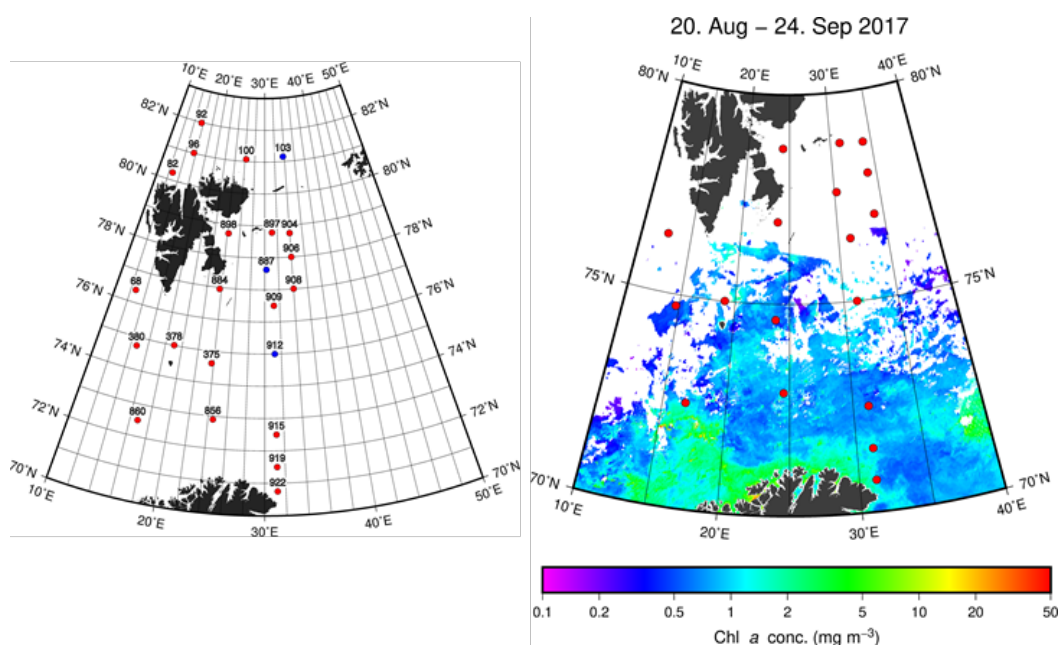
Figure 3.2.2. Left: Locations and station numbers for analysed phytoplankton samples obtained from the BESS between the 4th of September and the 3rd of October. Red dots indicate that only 10 m samples were analysed; blues dots indicate that both 10 m and 50 m samples were analysed, except for station 912 for which the 10 m sample was missing. **Right:** Mean surface chlorophyll concentration derived from daily MODIS satellite imagery for the September 4th to October 4th, 2018 period. Survey station locations are shown as red dots; white indicates regions of missing satellite data.

Satellite data

By Padmini Dalpadado

Remote sensing data having high spatial and temporal resolution were used in obtaining Chl a concentration (mg m-3), and mean daily NPP (g C m-2 day-1). Daily NPP and OWA were calculated from satellite data as described in detail in Arrigo and Van Dijken (2015). Satellite-derived surface Chl a (Sat Chl a, Level 3, 8 days binned) was based on SeaWiFS and MODIS/Aqua sensors. SeaWiFS was used in 1998-2002, and MODIS/Aqua in 2003-2017. Data were updated using NASA's latest reprocessing - version R2018.0. The values for the South-East and Pechora polygons were recalculated excluding the regions most influenced by river inflow (18% and 41% of the total area, respectively). The work done here is in collaboration with Professor Kevin Arrigo and Gert van Dijken from the Stanford University, USA.

Validation of satellite data

By Padmini Dalpadado

Validation of satellite Chl a using in situ data showed significant correlations between the two variables in the Barents Sea (Dalpadado et al. 2014, ICES/WGIBAR 2017, this study) and thus, the NPP model based on satellite data by Arrigo et al. (2015) gives reasonable results that compare well with sea ground truthing measurements. Also, estimates of new production from phytoplankton based on nitrogen consumption (seasonal draw-down of nitrate in the water column) for the Fugløya - Bear Island (FB) and Vardø-Nord (VN) sections, representing the western and central Barents Sea respectively, from March to June resulted in values comparable to satellite NPP estimates (Rey et al. in prep, pers. com.).

Spatial and temporal patterns of Chl a in spring

By Padmini Dalpadado

Remote sensing data, providing good spatial and temporal coverage, were used to explore the seasonal and interannual variability in Chl a distribution. Satellite data from the Barents Sea

during 2016-2018 showed large interannual variability with the highest Chl a concentrations generally observed in May (Figure 3.2.3). There was much less sea ice in 2016, and north- and eastward expansion of the Chl a distribution. Furthermore, earlier blooming and higher concentrations in the eastern regions in April and May were observed in this year. The year 2017 was a colder year with more ice especially compared to 2016. Chl a was much lower during April to July in 2017 compared to the previous year. The ice cover was larger in April 2017 and 2018, than in 2016. Though the Chl a in April in 2018 was lower compared to 2016, high concentration was observed in May for both years.
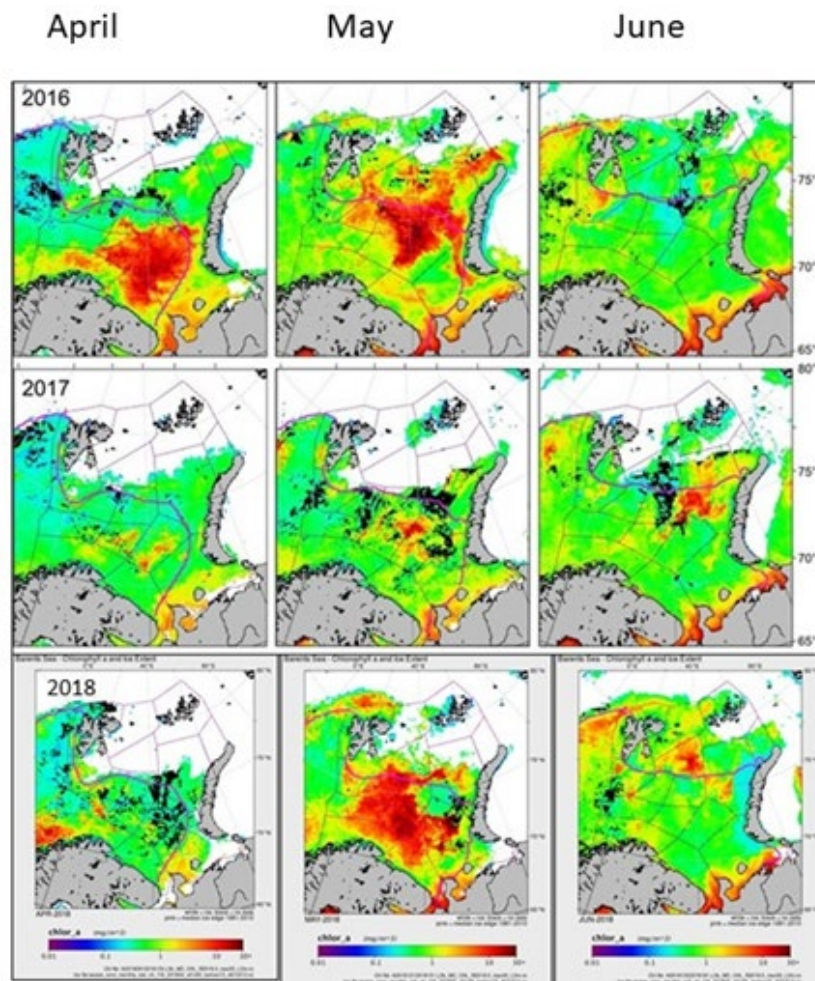
Figure 3.2.3. Spatial distributions of Chl a (mg m-3) in April, May and June for 2016, 2017 and 2018. White areas indicate ice-coverage. The pink lines show the climatological (average 1981-2010) position of the ice edge.

Net Primary Production (NPP)

By Padinini Dalpadado

NPP of the whole Barents Sea showed substantial interannual variability, but generally increased significantly during the period 1998-2018 (Figure 3.2.4, p = 0.001). The mean daily NPP (mg C m-2 day-1) for the whole Barents Sea (combining all polygons) has increased from 163 mg C m-2 day-1 for the years 1998-2009 to 189 mg C m-2 day-1 for 2010-2018. NPP in the eastern regions (North East and Pechora polygons) increased significantly during the study period (p < 0.01). The NPP in some of the northern polygons also showed an increasing trend over the years, but production values were low compared to the southern and eastern regions. The NPP in the South West polygon showed large interannual variability with no marked significant trend over time (p = 0.511).
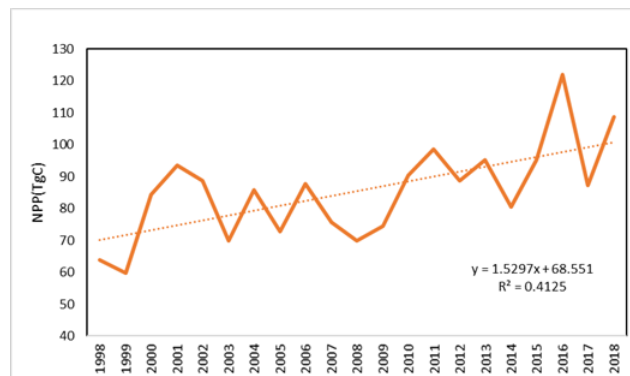
Figure 3.2.4. Annual net primary production (satellite based NPP) for the whole Barents Sea.

References

Arrigo K.R. and van Dijken G. (2015). Continued increases in Arctic Ocean primary production. Progress in Oceanography 136:60-70

Dalpadado P., Arrigo, A.R., Hjøllo, S., Rey, F. Ingvaldsen R.B., Sperfeld, E. Dijken G.L.V, Olsen, A., Ottersen, G. (2014). Productivity in the Barents Sea - response to recent climate variability. PLoS ONE 9(5):e95273 doi:10.1371/journal.pone.0095273

Hunt G.L., Blanchard A.L., Boveng P., Dalpadado P., Drinkwater K., Eisner L., Hopcroft R., Kovacs K.M., Norcross B.L., Renaud P., Reigstad M., Renner M., Skjoldal H.R, Whitehouse A., Woodgate R. A 2012. The Barents and Chukchi Seas: Comparison of two Arctic shelf ecosystems. Journal of Marine Systems: 43-68

Rey et al. (in prep). Interannual variability of new and net primary production in the Barents Sea.

Sakshaug E., Johnsen G., Kristiansen S. et al (2009). Phytoplankton and primary production. 2009. In Ecosystem Barents Sea. Eds. Sakshaug E, Johnsen G, Kovacs K. Tapir Academic Press, Norway. pp: 167-208

Skjoldal, H.R., Rey, F., 1989. pelagic production and variability of the Barents Sea ecosystem. In: Sherman, K., Alexander, L.M. (Eds.), Biomass yields and geography of large marine ecosystems, AAAS Selected Symposium, vol. 111. Westview Press, pp. 241–286.

3.3   Zooplankton

By Espen Bagøien, Andrey Dolgov, Irina Prokopchuk, and Hein Rune Skjoldal

Mesozooplankton biomass in the Norwegian part of the Barents Sea in 2018 was slightly above the long-term average for the last 20 years. The mesozooplankton biomass in "Atlantic" subareas of the Barents Sea in 2018 were at similar levels as in previous years, and has shown declining trends on the Central Bank and Great Bank subareas since the peak in 1995. Krill biomass has shown an increasing trend during the last decades. Jellyfish biomass in 2017 was at its third highest level since 1980 – but could not be estimated for 2018.

Mesozooplankton biomasses

Mesozooplankton play a key role in the Barents Sea ecosystem by transferring energy from primary producers to animals higher in the foodweb. Geographic distribution patterns for mesozooplankton biomass show similarities on a multiannual time-scale, although some interannual variability is apparent.

For logistical reasons, a large region in south-eastern and central-eastern parts of the Barents Sea was not sampled during the 2018 BESS (Figure 3.3.1). Differences in survey coverage between

years may impact biomass estimates for territorial waters and the Barents Sea as a whole; particularly as the ecosystem is characterized by large-scale heterogeneous distribution of biomass. One way to address this challenge, is to make interannual comparisons of estimated biomass within well-defined and consistent spatial subareas (polygons).

During August-October 2018, relatively high biomass (>10 g m^{-2}) was observed in and just south of Bear Island Trench, north and northeast of Svalbard/Spitsbergen, south of Franz Josef Land, and in basins of the south-eastern Barents Sea. Relatively low biomass (<3 g m^{-2}) was observed on Great Bank, Central Bank, and in areas further west in the central region bordering the Norwegian Sea. Low biomass was also observed near the coast in the south-eastern corner of the Barents Sea (Figure 3.3.1).

The pattern of large-scale horizontal distribution for plankton during autumn 2018 resembled that of 2017, not considering large areas in south-eastern and central-eastern regions of the Barents Sea which were not surveyed in 2018.
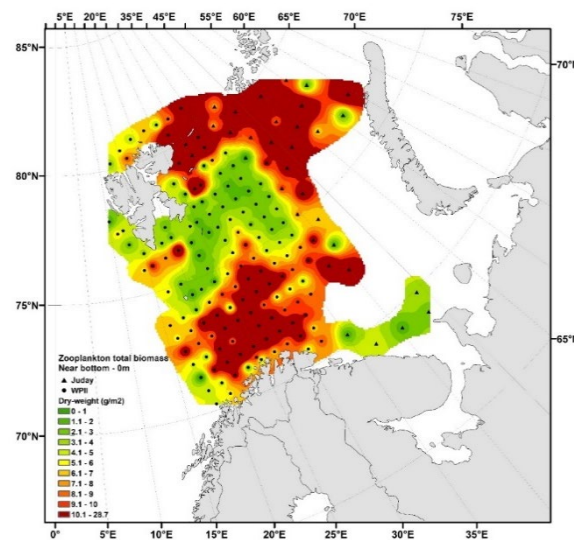
Figure 3.3.1. Distribution of total mesozooplankton biomass (dry weight, g m-2) from surface to seafloor. Data based on 173 samples obtained during the BESS during late August – mid-October 2018. A WP2 net was applied by IMR and a Juday net by PINRO; both nets with mesh-size 180 µm. Interpolation made in ArcGIS v.10.3, module Spatial Analyst, using inverse distance weighting (default settings).

In the Norwegian sector of the Barents Sea, mesozooplankton biomass was size-fractionated (180–1000 µm, 1000–2000 µm, and >2000 µm) before weighting . For the smallest- and middle size-fractions, estimated average biomass was slightly higher than the long-term (20-year) average (1998–2017) (Figure 3.3.2). For the largest size-fraction, average values have shown a decreasing trend during the ca. last 14 years; in 2018, biomass for the largest size-fraction was well below the long-term average. Based only on Norwegian data, which represent the longest time-series, average zooplankton biomass (summing all size-fractions) during August-October 2018 was 7.2 (SD 5.6) g dry-weight m-2 for the western part of the Barents Sea. This estimate is higher than in 2017 (6.4 g dry-weight m^{-2}), and just above the long-term average (7.0 g dry-weight m^{-2}) (Figure 3.3.2).

Combined Russian and Norwegian data (173 stations in total) (Figure 3.3.1), covering the entire area surveyed in the Barents Sea in 2018, provided an estimated average zooplankton biomass of 7.5 (SD 5.7) g dry-weight m^{-2}. This estimate is not directly comparable with the 2017 estimate (7.2 g m^{-2}), due to the above-mentioned lack of sampling in the south-eastern and south-central regions during 2018. In the Russian sector, average biomass for the area covered in 2018 was 9.1

(SD 6.1) g dry weight m⁻²; this value also is not directly comparable to the 2017 estimate (8.6 g dry-weight m⁻²) due to incomplete survey coverage in 2018.
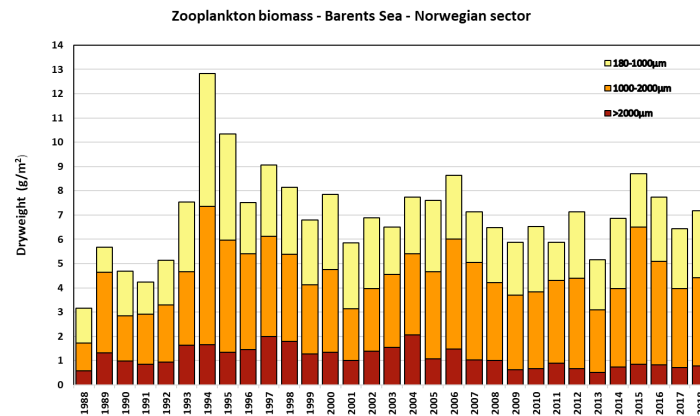

Figure 3.3.2. Time-series of average mesozooplankton biomass from surface to sea floor (dry-weight, g m-2) for western and central Barents Sea (Norwegian sector) during the autumn BESS (1988–2018). Data are shown for three size-fractions; 0.18–1 mm (yellow), 1–2 mm (orange), and >2 mm (red) based on wet-sieving.

Zooplankton biomass varies between years and is believed to be largely controlled by predation pressure, e.g. from capelin , however the annual impact of predation varies between regions . Capelin stock-size was relatively high during the 2008-2013 period and was expected to exert strong predation pressure on zooplankton. In 2014, capelin stock-size decreased; in 2015 and 2016 it declined further to very low levels, likely easing the pressure on their zooplankton prey. The 2017 estimate suggested a marked increase in capelin stock-size. The 2018 estimate again showed decrease, but was higher than the lows estimated for 2015 and 2016. Estimated stock size for capelin in 2018 (TSB ~ 1 600 thousand tonnes) was below the long-term average for the 1988-2017 period (TSB ~ 2 330 thousand tonnes), and likely exerted moderate predation pressure on the zooplankton community. Predation from other planktivorous pelagic fish (herring, polar cod, and blue whiting) and pelagic juvenile demersal fish species (cod, haddock, saithe, and red-fish), and larger plankton forms (e.g. chaetognaths, krill, and amphipods) can also impact mesozooplankton in the Barents Sea. In addition, processes such as advective transport of plankton from the Norwegian Sea into the Barents Sea, primary production, and local production of zooplankton are likely to contribute to the variability of zooplankton biomass. As mentioned above, methodological factors such as differing spatial survey coverage also contribute to the variability of biomass estimates between years. For a more direct comparison of interannual trends, that is less influenced by variable spatial coverages, time-series of biomass estimates for specific subareas of the Barents Sea are provided in the following section).

Mesozooplankton biomass in subareas of the Barents Sea

By Hein Rune Skjoldal and Padmini Dalpadado

IMR estimates of 2018 zooplankton biomass have been calculated as average values for each of 9 subareas. Time-series of biomass estimates for these subareas for the 1989-2016 period were described in a background document (2018 WGIBAR Report, Annex 4). Time-series estimates for four Atlantic water subareas (Bear Island Trench, South-West, Thor Iversen Bank, and Hopen Deep), and for Central Bank and Great Bank are shown in Figure 3.3.3.
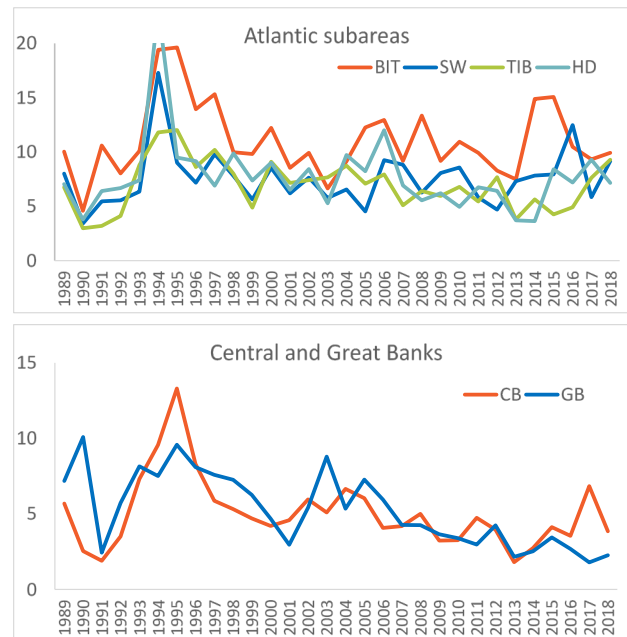
Figure 3.3.3. Time-series estimates of mean zooplankton biomass (g dw m^{-2}) for stations within subareas of the Barents Sea (see WGIBAR 2018 Report, Annex 4) based on autumn survey data for the 1989-2018 period. Upper panel – four subareas in the southwestern Barents Sea covered mainly with Atlantic water: Bear Island Trench (BIT); South-West (SW); Hopen Deep (HD); and Thor Iversen Bank (TIB). Lower panel – two subareas in the central Barents Sea with colder and partly Arctic water conditions: Central Bank (CB) and Great Bank (GB). Results presented represent the total biomass collected with WP2.

Biomass estimates in the 'Atlantic' subareas have fluctuated between 5 to 10 g dw m^{-2} since about year 2000, with generally higher values for the Bear Island Trench (up to 15 g dw m^{-2}). The values for 2018 are at the same level as in the previous years. It should be noted that sampling variance is high, with coefficient of variation (CV = SD/mean) of about 0.5 for mean values per subarea (see WGIBAR 2018 report, Annex 4). This translates into confidence intervals (95%) of ±20-25% around the mean for *n* observations of 16–25 (which is a typical number of stations within a subarea).

Biomass estimates at Central Bank and Great Bank have shown declining trends since the 1990s to the minim in 2013 (Figure 3.3.3 - Lower). Biomass at Central Bank has subsequently increased after this, although the 2018 estimate was relatively low (about 4 g dw m^{-2}). In contrast, biomass at the Great Bank has remained at a very low level also in 2018 (about 2 g dw m^{-2}).
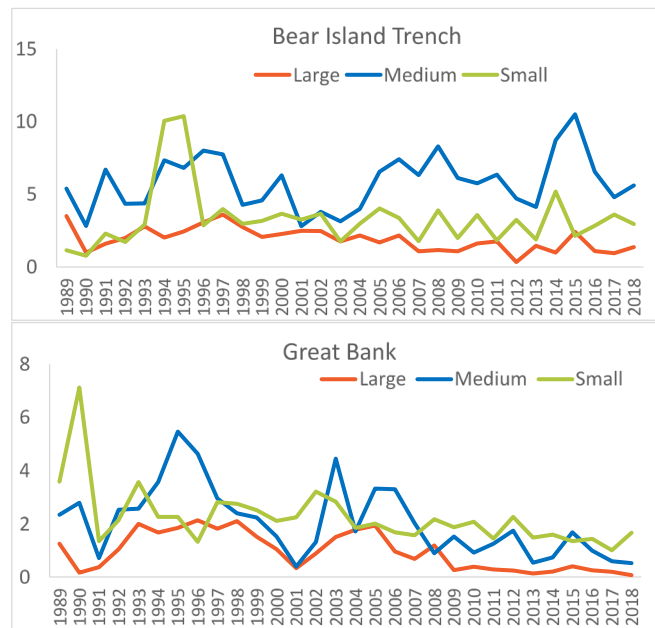
Figure 3.3.4. Zooplankton biomass (g dry-weight m-2) in three size fractions (small <1 mm, medium 1-2 mm, and large >2 mm) for Bear Island Trough (upper panel) and Great Bank (lower panel) subareas for the 1989-2018 period. Note: Size fractions are based on screen mesh size, not size of individual zooplankton.

Size composition of mesozooplankton is shown in Figure 3.3.4 for two subareas: Bear Island Trench - a region of Atlantic water inflow; and Great Bank. These two subareas have had different temporal development. Bear Island Trench has had a more consistent pattern, with relatively high biomass of the medium size fraction since 2005. This fraction contains older stages of Calanus spp. which dominate mesozooplankton biomass in the Barents Sea (Aarflot et al. 2017). The recent situation likely reflects high influx of Calanus finmarchicus with Atlantic inflow to the Barents Sea, possibly related to a second generation within a single spawning season under warmer climate conditions (Skjoldal et al., unpublished manuscript).

Decline in biomass for Great Bank has been associated with a shift in dominance from the medium size fraction to the small fraction over the last decade. During this same period, the large size fraction declined to a very low level. The decline and shift from large to small zooplankton could reflect a combination of warming and predation from capelin (Dalpadado et al., unpublished manuscript). Great Bank used to be the domain for the dominant Arctic species *Calanus glacialis* (Melle and Skjoldal, 1998); This area traditionally has been a core feeding area for capelin; decreased biomass of *C. glacialis* in this area may negatively impact the capelin stock.

Figure 3.3.5 shows a comparison of long-term average estimates of zooplankton biomass (1989–2016) for each subarea together with estimates for 2018. In most subareas, biomass estimates for 2018 are close to the long-term average. Note that due to lack of coverage in the eastern Barents Sea during 2018, number of observations (stations) in the South-East, South-East Basin, and Pechora was low (2-3 stations).
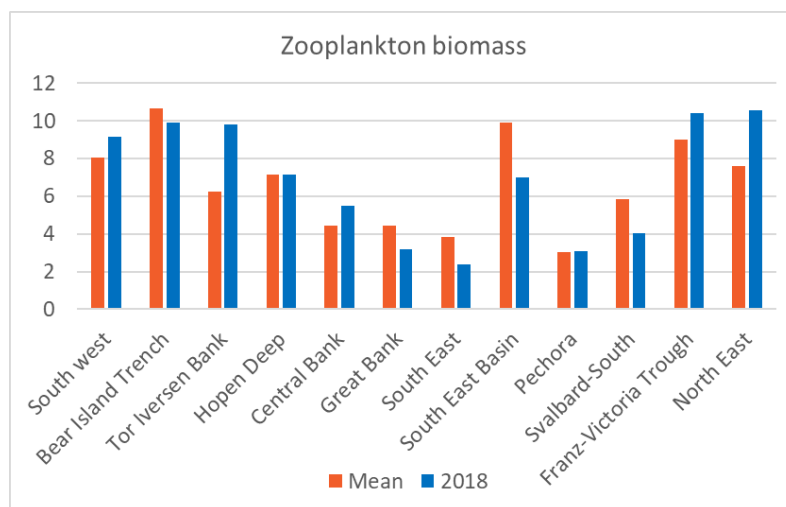
Figure 3.3.5. Average zooplankton biomass (g dry-weight m-2) for twelve subareas of the Barents Sea, comparing long-term averages for the 1989–2016 period with average values for sampled in 2018.

Mesoplankton species-composition in the eastern Barents Sea

By Irina Prokopchuk

Russian (PINRO) investigations along the Kola section in June 2018 showed copepods as the dominant group of zooplankton at that time, comprising on average 64% in abundance and 85% in biomass, and *Calanus finmarchicus* as the dominant species. Average abundance of *C. finmarchicus* in 2018 was 308 309 ind. m-2, almost twice the 2017 value, but lower than for 2016 and long-term average (Figure 3.3.6). Highest abundance of *C. finmarchicus* was observed at the most southerly station of the section at 69°30′N and further north at 72°30′N, while its lowest abundance was observed at 70°00′N. In the *C. finmarchicus* population, individuals at all life stages were present: CIII-CIV stages dominated at the southern stations; and CI-CIV individuals were represented at the northern stations.
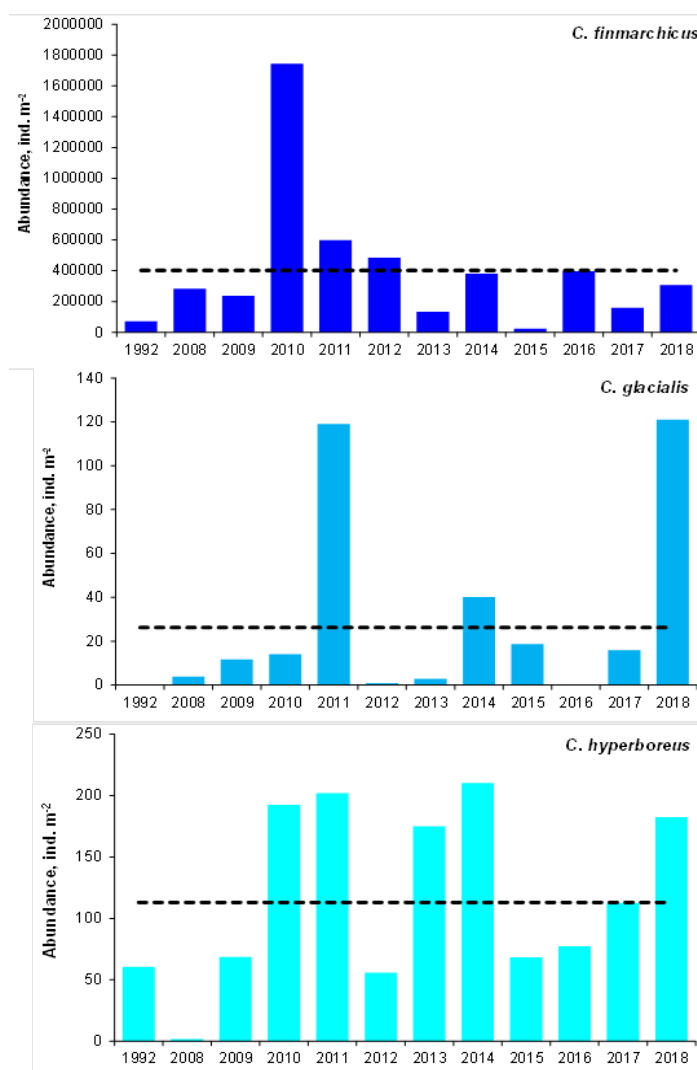
Figure 3.3.6. Abundance (ind. m⁻²) of *C. finmarchicus, C. glacialis,* and *C. hyperboreus* along the Kola section during May-June 1992 and the 2008-2018 period. Dashed line shows long-term average values. Note the gap in years between 1992 and 2008 to the left part of the figure.

Average abundance of the arctic species C. glacialis in 2018 was 121 ind. m-2, which is 7.6 times higher than the 2017 estimate, and 4.2 times higher than the long-term average (Figure 3.3.6). *C. glacialis* mainly occurred from 73º00' N and northwards; only copepodites CV were observed for this species.

Average abundance of the arctic species *C. hyperboreus*, the largest Calanus species in the Barents Sea, was higher in 2018 than in 2017 (182 and 113 ind. m-2, respectively) and exceeded the long-term average (117 ind. m-2) (Figure 3.3.6). A gradual increase in *C. hyperboreus* abundance has been observed since 2015. Highest abundance of this species was observed northwards from 73º00' N. The *C. hyperboreus* population was represented by copepodites CIV-CV.

Russian (PINRO) regional scale investigations of mesozooplankton conducted by the BESS during August-September of 2017 showed that copepods dominated both in terms of abundance (89.8%) and biomass (68.8%) (Figures 3.3.7 and 3.3.8). Total zooplankton abundance in the southern (south of ca. 75°N) and northern (north of ca. 75°N) Barents Sea was almost equal (1 477 and 1 458 ind. m-3, respectively); total zooplankton biomass was higher in the northern than the southern Barents Sea (192.3 and 145.8 mg m-3, respectively).

In the southern Barents Sea, copepods dominated both abundance and biomass (87.6 and 79.5%, respectively). Among other groups, chaetognaths comprised 9.9% of total zooplankton biomass.

In 2017, total zooplankton abundance decreased by a factor of 1.4 compared to 2016; total zooplankton biomass decreased similarly. Considering species composition of copepods, the small *Oithona similis* and *Pseudocalanus* sp. and the larger *Calanus finmarchicus* were most abundant (~55.1 and 20 % of total copepod abundance, respectively), and the large *Metridia longa* comprised 4.9 % (Figure 3.3.7). However, in terms of copepod biomass, *C. finmarchicus* (59.9%), *M. longa* (14.3%), and *Pseudocalanus* sp. (9.8%) were the most important species; while *O. similis* comprised 5.6% of the total (Figure 3.3.8). In 2017, abundance and biomass of *O. similis* and P*seudocalanus* sp. decreased compared to 2016. At the same time, both abundance and biomass of *M. longa* increased between 2016 and 2017 by a factor of 2, while these same parameters for *C. finmarchicus* remained at the 2016 level.

In the northern Barents Sea, copepods were the most abundant (91.5%) zooplankton group. Regarding total zooplankton biomass, copepods also represented the most important group (60.4%) during 2017, while chaetognaths and pteropods comprised 16.3 and 6.5%, respectively. In comparison to 2016, increases in total zooplankton abundance and biomass occurred primarily due to increased abundance of copepods and chaetognaths. In the northern Barents Sea, the small copepods *O. similis* and *Pseudocalanus* sp. contributed 33.3 and 33.2%, respectively; while larger species M. longa, C. finmarchicus, and C. glacialis contributed 11.6, 9.2 and 5.2% to total copepod numbers, respectively (Figure 3.3.7). Total copepod biomass consisted mainly of *C. glacialis* (28.0%), *C. finmarchicus* (24.5%), *M. longa* (20.7%), *Pseudocalanus* sp. (16.4%), and *C. hyperboreus* (6.2%). Compared to 2016, abundance of *C. finmarchicus, C. glacialis*, and *Pseudocalanus* sp. increased, while that of *O. similis* decreased in 2017. The same trends were observed in biomass of these copepod species. The most prominent increases in both abundance and biomass were observed for *M. longa*.
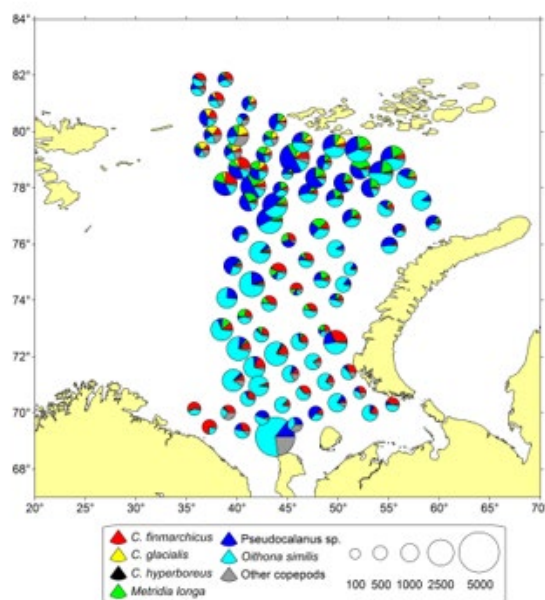

Figure 3.3.7. Abundance (ind. m⁻³) of the most numerous copepod species (surface to sea floor) in the Barents Sea (based on the PINRO samples from the BESS during August-September of 2017).

Mesozooplankton species-composition in the western Barents Sea

Espen Bagøien and Padmini Dalpadado

The Fugløya-Bear Island (FB) transect, spanning the western entrance to the Barents Sea, is generally monitored by IMR 5-6 timer per year, covering the different seasons. Up to eight stations with fixed positions are sampled during each coverage, although the number may vary depend-

ing on weather conditions. Zooplankton samples collected each year during the 1995–2018 period from four fixed locations at different latitudes (70.30°N, 72.00°N, 73.30°N, and 74.00°N) representing different water masses (Coastal, Atlantic, and mixed Atlantic/Arctic) have been analysed taxonomically. Average abundance is estimated annually, by pooling the four stations and summing copepodite stages I-VI of *C. finmarchicus, C. glacialis,* and *C. hyperboreus* (Figure 3.3.9). *C. finmarchicus* is, by far, the most common of these three species, and displays high interannual variation in abundance*. C. finmarchicus* tends to be most abundant at the three southernmost stations. Particularly high abundance was recorded during 2010 along most of the transect, except at the northernmost station (74.00°N). After registering very low abundances at all stations in 2013, *C. finmarchicus* has generally been abundant along most of the transect during the last 4 years (2014–2018).
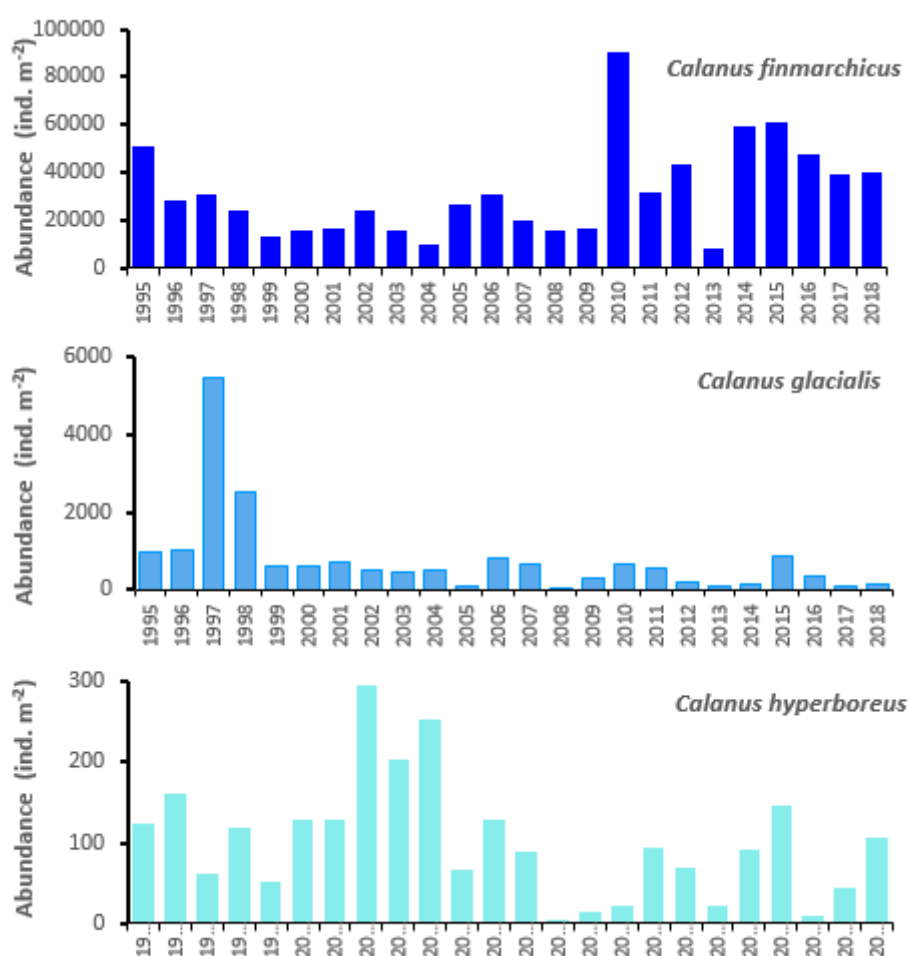
Figure 3.3.9. Abundance (ind. m⁻²) of *Calanus finmarchicus, C. glacialis,* and *C. hyperboreus* along the Fugløya-Bjørnøya transect during the 1995–2018 period. Each bar represents the annual average for 4 stations and 5–6 coverages per year (except for 4 and 3 station coverages in 2012 and 2013, respectively).

C. glacialis has typically been most abundant at the two northern-most stations where Atlantic and Arctic waters mix. This species also shows large interannual variations in abundance (Figure 3.3.9). Abundance of *C. glacialis* along the FB transect has decreased since initial years of this time-series (1995–1998), with very low abundance recorded in 2005, 2008, and during the 2012-2014 and 2017-2018 periods. Abundance of the largest species, *C. hyperboreus*, along the FB transect has been low relative to the abundance of *C. finmarchicus*, but also compared to *C. glacialis* in general throughout the study period. Few individuals of this species were observed during 2008-

2010, 2013, and 2016. (Figure 3.3.9). The FB time-series of *C. hyperboreus* abundance shows strong interannual variability.

Calanus helgolandicus, a more southern species, has been observed regularly at Fugløya-Bear Island transect, particularly during the December-February period (Dalpadado *et al.,* 2012). In recent years, it has been observed more frequently in the North Sea and in southern regions of the Norwegian Sea (Svinøy transect). *C. helgolandicus* is similar in appearance to *C. finmarchicus* and taxonomic separation of these two species is time-consuming. Hence, the routine is to examine a limited number of *C. helgolandicus* individuals belonging to the later stages – up to 20 copepodites of stage V and up to 20 adult females – to establish the species-proportions in each FB sample. During winter, the ratio of *C. helgolandicus* to *C. finmarchicus* along the Fugløya–Bear Island transect has been observed to increase and *C. finmarchicus* is normally overwintering in deeper waters. Our FB time-series provides no evidence of an increase over the years in either the proportion or absolute abundance of *C. helgolandicus* at the entrance to the Barents Sea.

Macroplankton biomasses and distributions

Krill

Krill (euphausiids) represent the most important group of macrozooplankton in the Barents Sea, followed by hyperiid amphipods. Krill play a significant role in the Barents Sea ecosystem, facilitating transport of energy between different trophic levels. There are mainly four species of krill in the Barents Sea; *Thysanoessa inermis* associated with Atlantic water in the western and central Barents Sea, *Meganytiphanes norvegica* and *Thysanoessa longicaudata* associated with the inflowing Atlantic water, particularly during warm periods, and *Thysanoessa raschii* found mainly in shallow waters in the southeastern Barents Sea. *M. norvegica* is the largest species reaching a maximum length of about 4.5 cm, while *T. inermis* and *T. raschii* reach lengths of about 3 cm. *T. longicaudata* is the smallest species – not exceeding 1.8 cm.

Winter distribution and biomass

By *Anna Mikhina, Valentina Nesterova, Andrey Dolgov*

Euphausiids were collected in the Barents Sea during the PINRO winter survey (November-December 2017) with the trawl-attached plankton net. Note: The PINRO long- term data series on euphausiids was initiated in 1959 and stopped in 2016 (Figure 3.3.12). In 2017, only a part of this survey was conducted; results from only one cruise are presented, covering the southern part of the Barents Sea (Figure 3.3.10). These data are not comparable with the previous years.

Results indicate that in 2017, the trend of increasing euphausiid abundance continued in the southern Barents Sea. Compared to 2015 (no sampling in 2016), average euphausiid abundance in the southern Barents Sea in 2017 increased. This increase was mainly observed in central and coastal areas. Euphausiid abundance in eastern and western areas decreased in 2017 relative to 2015. Euphausiid concentrations were formed mainly by local species (*T. inermis and T. raschii*) and Atlantic species (*M. norvegica and T. longicaudata*). The proportion of Atlantic species decreased in 2017 relative to 2015 but remained at a quite high level. At the same time, euphausiid abundance decreased in the northwestern Barents Sea. The overall average abundance of euphausiids in the Barents Sea decreased in 2017 relative to 2015.
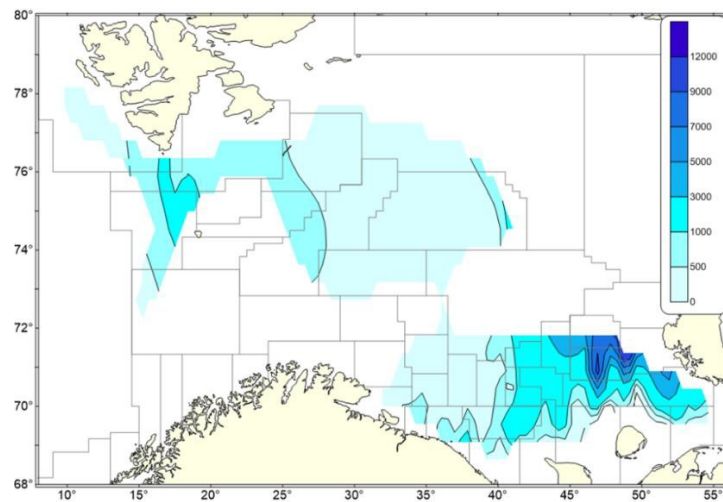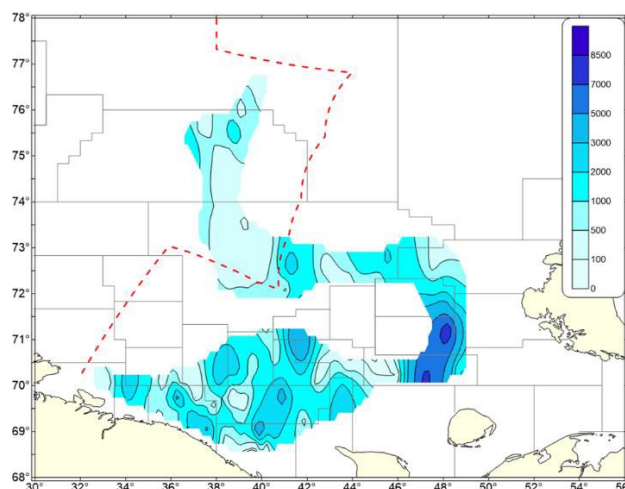
Figure 3.3.10. Distribution of euphausiids (ind. 1000 m⁻³) in the near-bottom layer of the Barents Sea based on data from the Russian winter survey during November-December 2017.

Euphausiids were also collected in the southern Barents Sea during the Russian-Nor- wegian winter survey (February 2018) with the trawl-attached plankton net. Euphau- siid sampling in this survey was initiated in 2015 onboard a Russian research vessel (no sampling occurred in 2017), but different areas were covered in different years. These results are very preliminary, and comparison with previous years requires cau- tion. Results indicate that in 2018, euphausiid abundance was high in the southern Bar- ents Sea in comparison to November-December 2017. Average abundance of euphau- siids in all areas was much higher in 2018 than in 2016. However, in 2018 the average abundance of euphausiids in western and coastal areas decreased compared to 2015 but increased considerably in the central and eastern areas. As during November-De- cember 2017, euphausiid concentrations were formed mainly by local species (*T. in- ermis* and *T. raschii*) and Atlantic species (*M. norvegica* and *T. longicaudata*).

Figure 3.3.11. Distribution of euphausiids (ind. 1000 m⁻³) in the near-bottom layer of the Barents Sea based on data from the Russian Norwegian winter survey during February 2018.
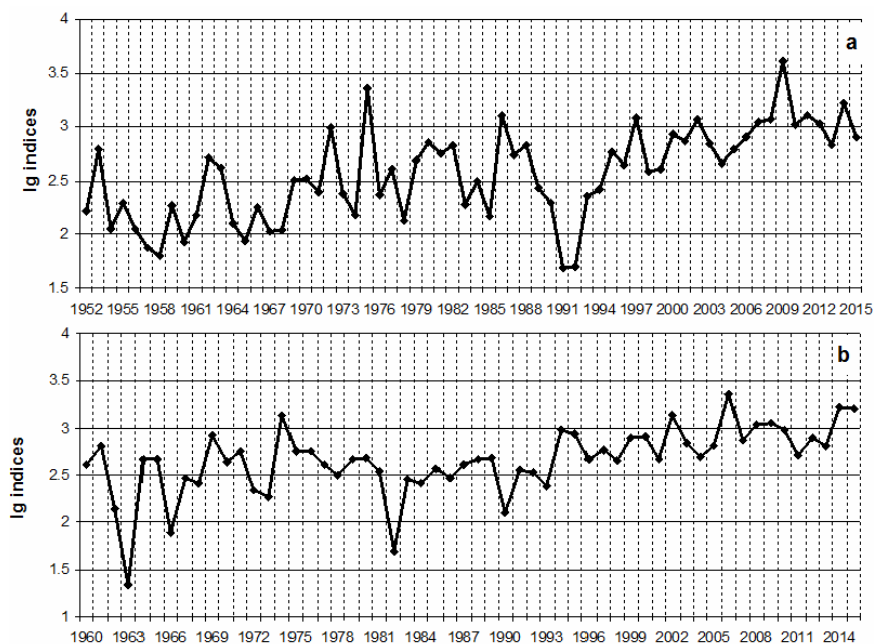
Figure 3.3.12. Abundance-indices of euphausiids (log10 of number of individuals per 1000 m-3) in the near–bottom layer of the Barents Sea based on data from the Russian winter survey during October-December for the 1959-2015 period. Based on trawl-net catches from the bottom layer in: a) Southern Barents Sea; and b) Northwestern Barents Sea. Note: this data-series was stopped in 2016, but is presented here to show general trends since the early 1950s and 1960s.

Summer-autumn distribution and biomass

By Espen Bagøien, Elena Eriksen, Tatiana Prokhorova and Andrey Dolgov

The following results are based on autumn 2018 BESS data; krill catches were made using standard pelagic trawls. Estimation of krill biomass for the entire Barents Sea was not possible in 2018 due to a lack of spatial coverage. As result, only krill distribution is presented.

During 2018, krill were widely distributed in the western Barents Sea (Figure 3.3.13). Biomass estimates in the upper 60 m are presented as grams of wet weight per square meter (g m⁻²). Night catches in the west averaged 5.8 g m⁻² in 2018 and were lower than the 1980-2017 long-term average for the entire Barents Sea (7.7 g m⁻², Figure 3.3.14).
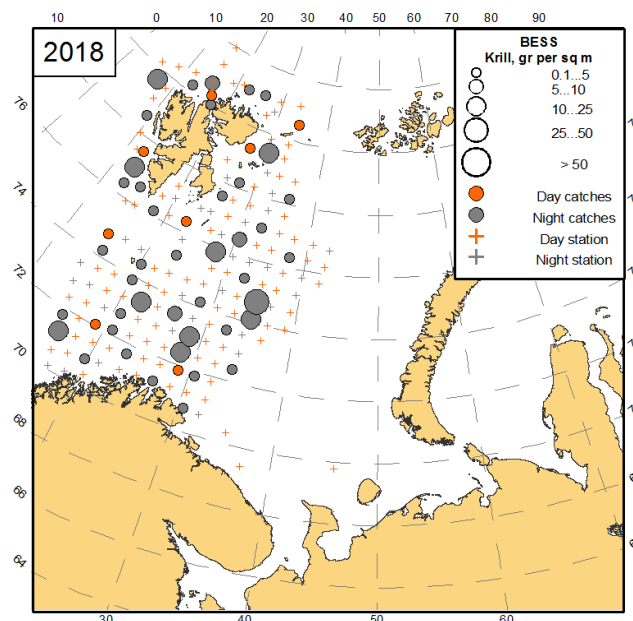
Figure 3.3.13. Krill distribution, based on pelagic trawl stations covering upper layers of the water column (0-60 m) in the Barents Sea during August-October 2018.

The number of the night stations in 2018 was 74, while there were 104 day stations. During night, most krill migrate to upper water layers to feed and are therefore more accessible to the trawl. Larger catches (more than 50 g m^{-2}) were observed in the central area of the sea.
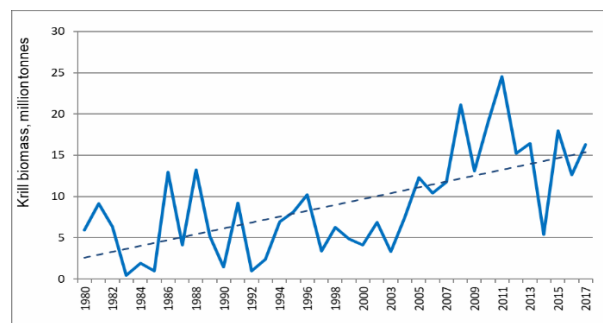

Figure 3.3.14. Average krill biomass (g wet-weight m^{-2}) sampled during BESS autumn night catches with pelagic 0-group fish-trawls within the 0-60m layer during the 1991-2016 period.

Amphipods

Information on amphipods (mainly hyperiids) presented here is based on catches with standard pelagic trawl in the 0-60 m layer during the BESS in autumn. Estimation of amphipod biomass in 2018 for the entire Barents Sea was not possible due to lack of survey coverage. Therefore, only amphipod distribution is presented here.

During 2018, amphipods were caught east of Svalbard/Spitsbergen Archipelago (Fig- ure 3.3.15). During 2012 and 2013, amphipods were absent from pelagic trawl catches, while in 2014 some limited catches were taken north of Svalbard/Spitsbergen. Several large catches were made east and north of Svalbard/Spitsbergen during 2015-2017.
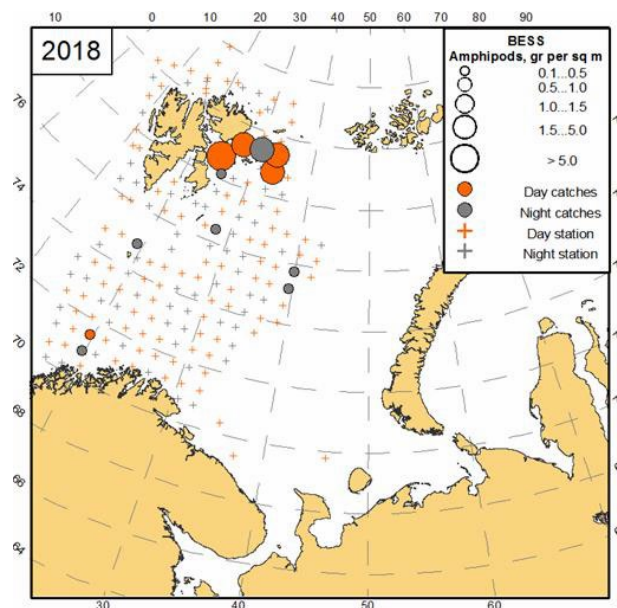
Figure 3.3.15. Amphipod distribution, based on trawl stations covering the upper 60 m in the Bar- ents Sea during August-October 2018.

Jellyfish

Geographic distribution and estimated biomass of gelatinous zooplankton here pre- sented are based on the BESS during autumn and using a standard pelagic trawl for 0– 60 m depth. Estima- tion of the biomass of gelatinous zooplankton for the entire Barents Sea was not possible in 2018 due to lack of coverage. Therefore, only the geographic distribution of jellyfish is presented for 2018.

During August-October 2018, lion's mane (*Cyanea capillata*; Scyphozoa) was the most common jellyfish species, with respect to both weight and abundance (average catch of 39 kg, correspond- ing to 5.1 tonnes per sq nmi), and was widely distributed over the covered area (Figure 3.3.16). Large catches (> 10 tonnes per sq nmi) were made in the northcentral Barents Sea.

Individual blue stinging jellyfish (*Cyanea lamarckii*) were observed at three stations close to the northern Norwegian coast (Figure 3.3.17). *C. lamarckii* has been observed regularly in the Barents Sea in recent years and the presence of this warm-temperate species may be linked to the inflow of Atlantic water masses.

Individual helmet jellyfish (*Periphylla periphylla*) were observed at two stations only (Figure 3.3.17). *P. periphylla* were caught in seven pelagic trawl (27 specimens) and one bottom trawl (2 specimens) station during 2014, and in six pelagic trawl- (9 specimens) and six bottom trawl (6 specimens) stations during 2016. The presence of this deep- water species may be linked to pe- lagic feeding during the night.
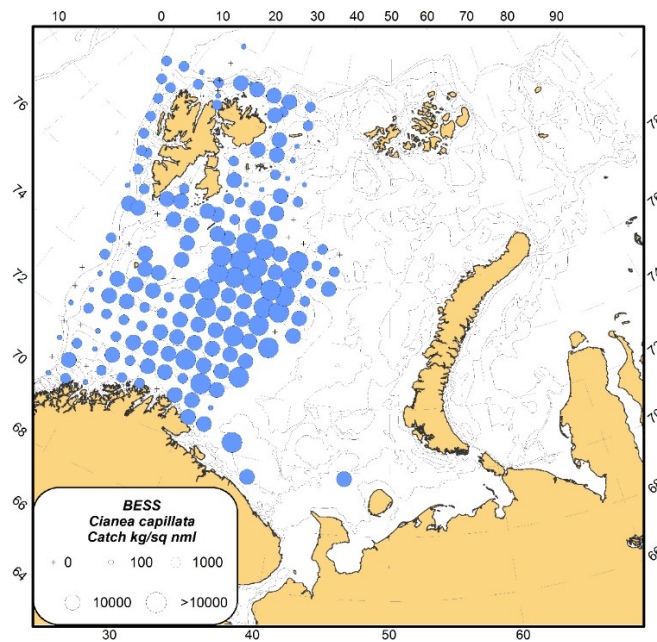
Figure 3.3.16. Distribution of jellyfish, mainly *Cyanea capillata,* catches (wet weight; kg per sq nmi) in the Barents Sea, during August-October 2017. Catches presented for both day and night from standard pelagic trawl stations at 0–60 m depth.
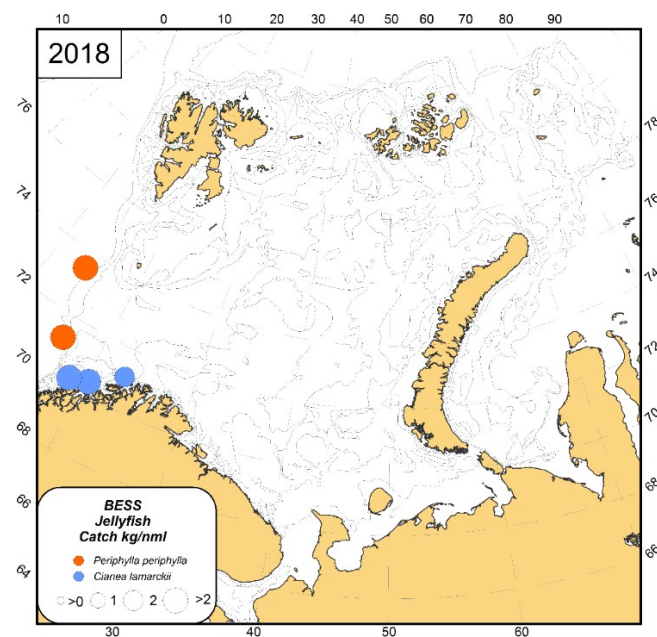

Figure 3.3.17. Jellyfish catches (wet weight; kg per sq nmi) of *Cyanea lamarckii* and *Periphylla pe- riphylla* in the Barents Sea during August-October 2018. Catches are presented for both day and night from standard pelagic trawl stations in the upper 0–60 m layer.

Long-term trends

Total biomass of jellyfish, mainly *C. capillata,* in upper 60 m for the entire Barents Sea during autumn 2018 could not be estimated due to incomplete coverage, but is shown for the years 1980-2017 (Figure 3.3.18). The estimated long-term average is 1.3 million tonnes. Interannual variation is considerable.
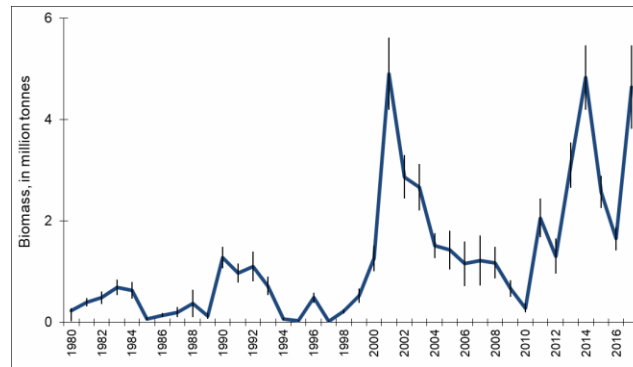
Figure 3.3.18. Estimated total biomass of the jellyfish, mainly *Cyanea capillata,* in the BESS sam- pling area during August-October for the 1980-2017 period. Based on catches by Harstad trawl in the upper 0-60 m layer - 95% confidence interval indicated by grey lines.

3.4 Benthos and shellfish

3.4.1 Benthos

L.L. Jorgensen (IMR), N.A. Strelkova (PINRO)

Benthos is an essential component of the marine ecosystems. It can be stable in time, character-izing the local situation, and is useful to explain ecosystem dynamics in ret- rospect. It is also dynamic and shows pulses of new species distribution, such as the snow crab and the king crab, and changes in migrating benthic species (predatory and scavenger species such as sea stars, am-phipods and snails with or without sea anemo- nes). The changes in community structure and composition reflect natural and anthro- pogenic factors. There are more than 3000 species of ben-thic invertebrates registered in the Barents Sea (Sirenko, 2001), but here we only present the meg-afaunal component of the benthos collected by trawl and registered (species, abundance and bio-mass) dur- ing the Barents Sea Ecosystem Survey (BESS). This includes mainly large bodied ani-mals with long lifespans. This investigation was initiated in 2005 only – a short timeline relative to investigations related to plankton and fish. Accordingly, interpretation of long-term trends for megabenthic data must be pursued with caution.

Benthos collection. Benthos, collected with the standard demersal trawl gear during the BESS, have been registered annually by benthic taxonomic specialists since 2005 onboard Russian ves-sels; annual surveys have been conducted during 2007–2013 and 2015–2016 onboard Norwegian vessels. Species identification has been to the lowest possible taxonomic level. In cases where there no specialist was available onboard (2007–2008 in northern Barents Sea in the Norwegian sector), the benthos has only been identified to major benthic group. Work is ongoing between IMR and PINRO special- ists to standardize and improve species identification, as well as the catchability of ben- thos between different trawls and vessels. Several articles have been published based on the resulting high-resolution taxonomic data (Anisimova *et al.,* 2011; Ljubin *et al.,* 2011, Jørgensen *et al.,* 2015a; Jørgensen *et al.,* 2015b, Jørgensen *et al.,* 2019).

Megafauna description. The distribution of large benthos groups shows that Porifera (mainly the *Geodia* group) dominate biomass in the west, while Echinodermata (mainly brittle stars) dom-inate in the east. In the Northeast, Cnidaria (soft corals, such as the sea pen *Umbellula encrinus,* and sea anemones) dominates along with Echinodermata, while Crustacea dominates along with the Echinodermata in the Southeast (Figure 3.4.1.1).
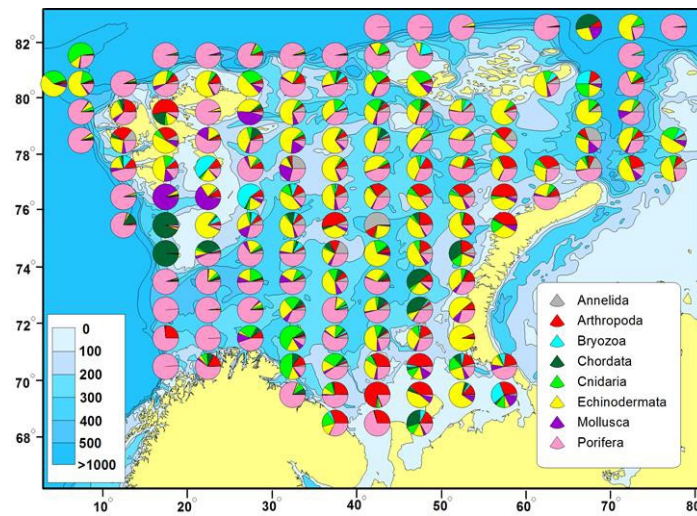
Figure 3.4.1.1 The main benthos group distribution (in biomass). The data are the integrated mean for the period 2012-2017.

Statistical analyses of monitoring data show that there are four distinct zones of ben- thos in the Barents Sea (Jørgensen *et al.*, 2015a, fig. 3.4.1.2). These four zones are char- acterized with temperate species in the southwestern zone, cold-water species in the eastern zone, arctic species in the northern and north-eastern zone, and an area in the eastern Barents Sea where the snow crab, a new non-indigenous large benthic species, are expanding. The period with warmer water entering the Barents Sea has led to mi- gration eastwards and northwards of temperate species and groups (Jørgensen *et al.*, 2015a). The retreating ice front opens for new areas for human impact as well as im- posing changes in the planktonic production and annual cycles, with possible impact on the benthic zones.
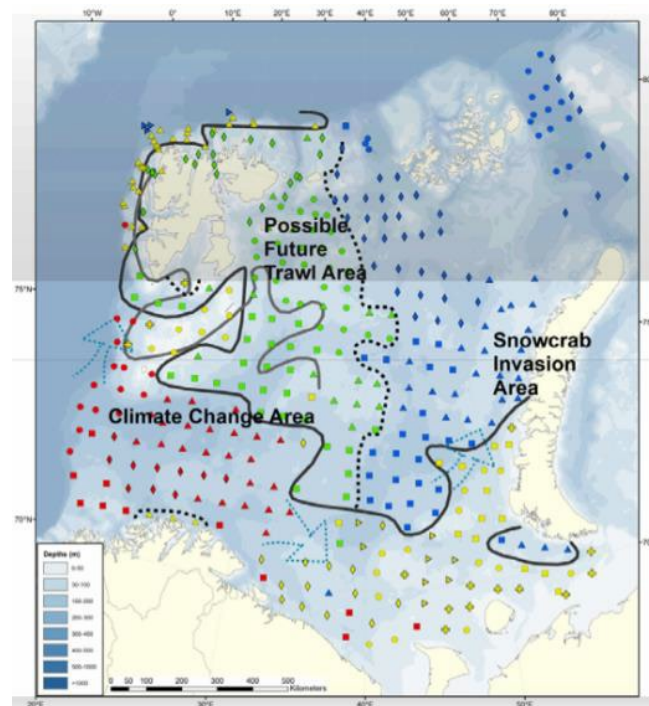
Figure 3.4.1.2 The baseline map of the Barents Sea mega-benthic zones in 2011, based on fauna similarity (see Jørgensen et al., 2015a for methodology, results and discussion) with the northern (green and blue) and southern (yellow and red) region where the black full line is illustrating the "benthic polar front" in 2011. The grey full line is the approximately oceanographic Polar Front. Dotted line: Is partly illustrating a west-east division. Red: South West subregion (SW) Yellow:

Southeast, banks and Svalbard coast (SEW). Green: North West and Svalbard fjords (NW). Blue: North East (NE). Source: IMR.

Jørgensen *et al.* (2019) show a recent increase in community mean temperature ranks (*P*=0.0011), indicating an increased importance of species with affinity for warmer waters and a reduced importance of cold water species. Commercial fish stocks and snow crab are expanding into the western part of the Barents Sea, thereby simultane- ously increasing the exposure of both large immobile species to trawling and of small prey species to crab predation. Overall, we have found a high-level of vulnerability to the three investigated exposures in the northwestern Barents Sea, which may lead to alterations in community structure and diversity.

The status of megabenthos inn 2018

The Barents Sea was only partly covered in 2018, and ten Russian and Norwegian ex- perts were involved in the megabenthos by-catch processing across the four BESS ves- sels. The main results from this work are given in table 3.4.1.1 while the megabenthos distribution are given in figure 3.4.1.3.

Table 3.4.1.1 The main characteristics of the megabenthic by-catches during BESS 2018.

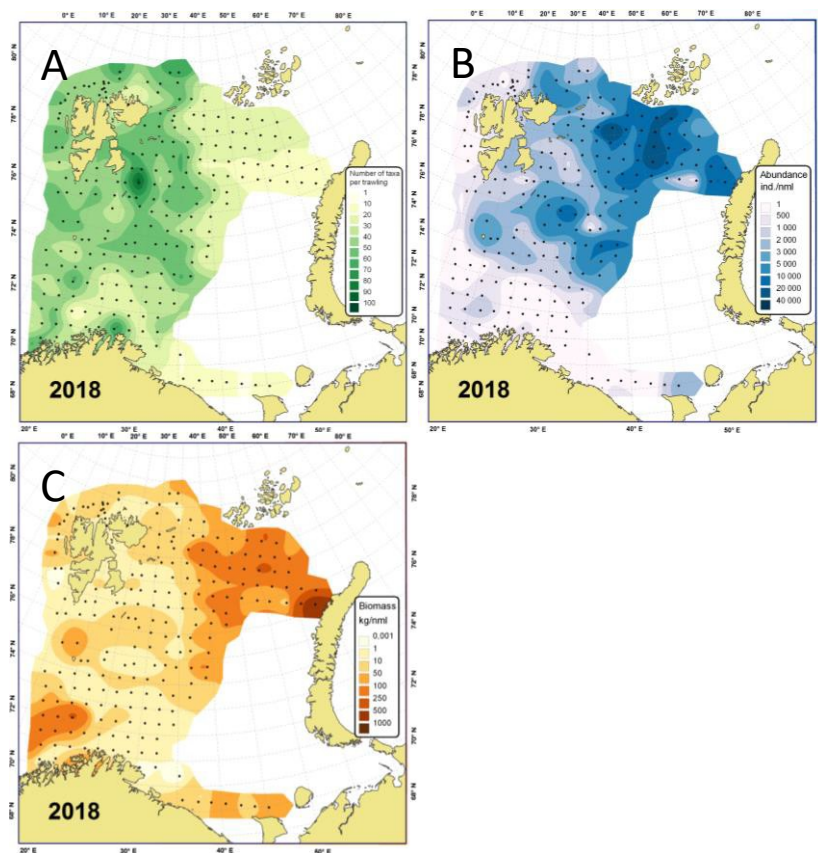| Characteristics	Values
Number of stations	217
Total number of taxa / species	574 / 404
Number of taxa per station; min-max / average ± standard error	5-95 / 39.0±1.1
Number of individual per station; min-max / average ± standard error	11-50221 / 3966±485
Biomass per station (kg); min-max / average ± standard error	0.055-6897 / 91.08±36.40

Figure 3.4.1.3 The A) number of taxa, B) number of individuals and, C) biomass per nautical mile (nml) according to BESS 2018.

The results showed a high number of taxa (fig. 3.4.1.3 A) in the northwest and low number in the east, and the southern areas, except for some few places with elevated taxa-richness. The abundance (fig. 3.4.1.3 B) showed high numbers of individuals in the north east and east of Svalbard, including the Spitsbergen Bank. Individuals were few in the south and along the slope in the west. The biomass (fig. 3.4.1.3 C) were high in the northeast, in the southwest, on the Spitsbergen Bank and locations west of Svalbard.

Long-term trends in distribution of the megabenthic biomass

Spatial distribution. The relatively short monitoring time-series for distribution of megabenthos biomass (g/nml trawling) shows relative stable large-scale patterns, with high biomass particularly in the southwest; biomass is also stable in the Northeast, but more variable. In central Barents Sea, biomass has a high level of spatial and temporal variability which is difficult to characterize due to the relatively short data time-series (fig. 3.4.1.4).
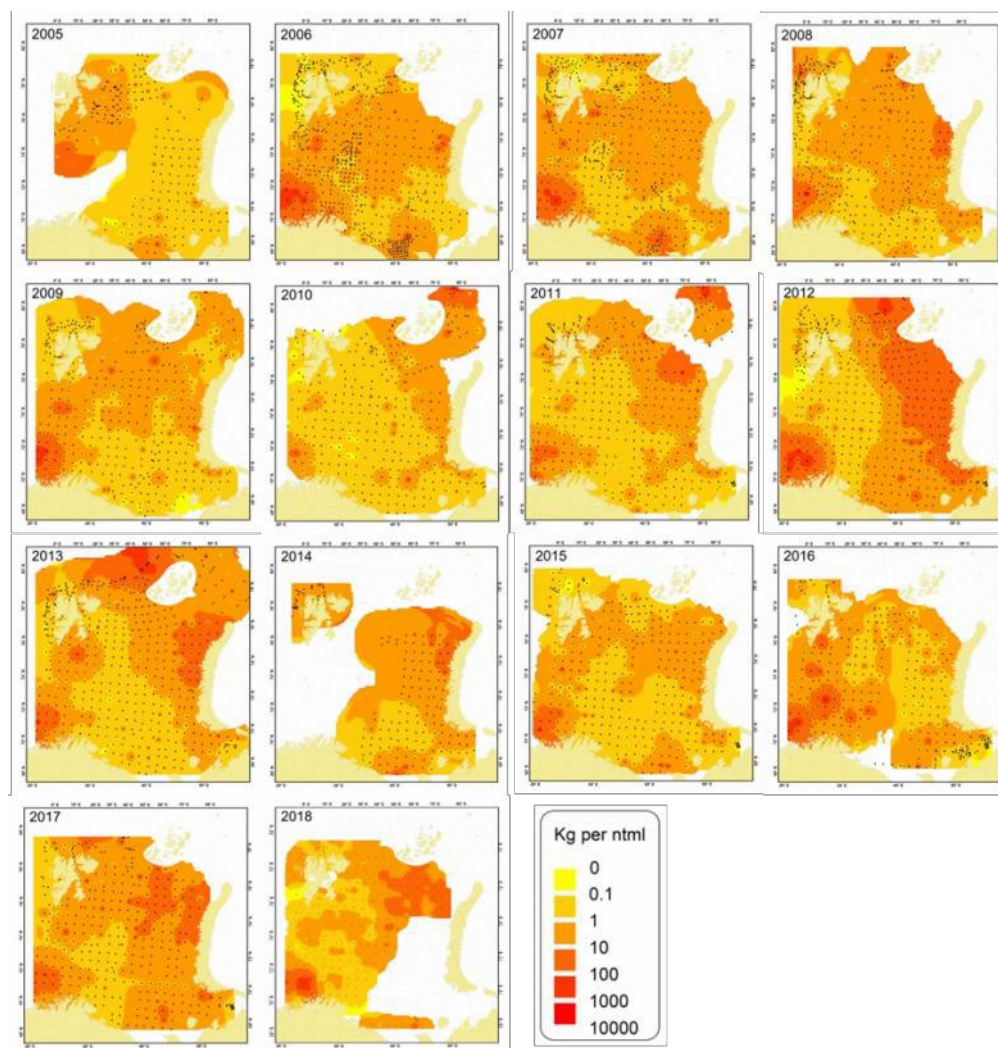
Figure 3.4.1.4 Distribution of the megabenthos biomass (excluding *Pandalus borealis*) in the Bar- ents Sea from 2005 to 2018.

Figure 3.4.1.4. show that in the years 2005, 2014 and 2018 there were a lack of station coverage in the Norwegian or Russian areas. In 2014, 2015, and 2016 the Loop Hole area was not sampled because a commercial snow crab fishery. In 2012 and probably 2017 the biomass was overesti- mated in the Russian zone due to technical issues with the trawl tuning. Such lack of coverage and non-standardised processing makes it dif- ficult to calculate benthic long term monitoring.

Inter-annual fluctuation of the mean megabenthos biomass. To estimate long-term dynamics of the megabenthos, inter-annual changes of the mean biomass were calcu- lated for the total Barents Sea and separated for the four sectors – northeast, northwest, southeast and southwest part of the sea (fig. 3.4.1.5 A, B) (ICES WGIBAR Report 2017, 2018). Despite fluctuations, the min- imum mean benthos biomass was recorded in 2010 both for the Barents Sea totally and for it separates sections. This allows us to assume that this could be a "negative reaction" of the mega- benthos to the cold year of 2003 (fig. 3.4.1.5 C) approximately seven years earlier. This hypothesis is supported by previous investigations documenting response of the Barents Sea macrobenthos to changes of environmental conditions with a delay in approximately four years (Lubina *et al.*, 2011, 2016; Denisenko, 2013). Difference in duration of the delay may be caused by different mean size and longevity of the lifespan of macro and mega benthic organisms.
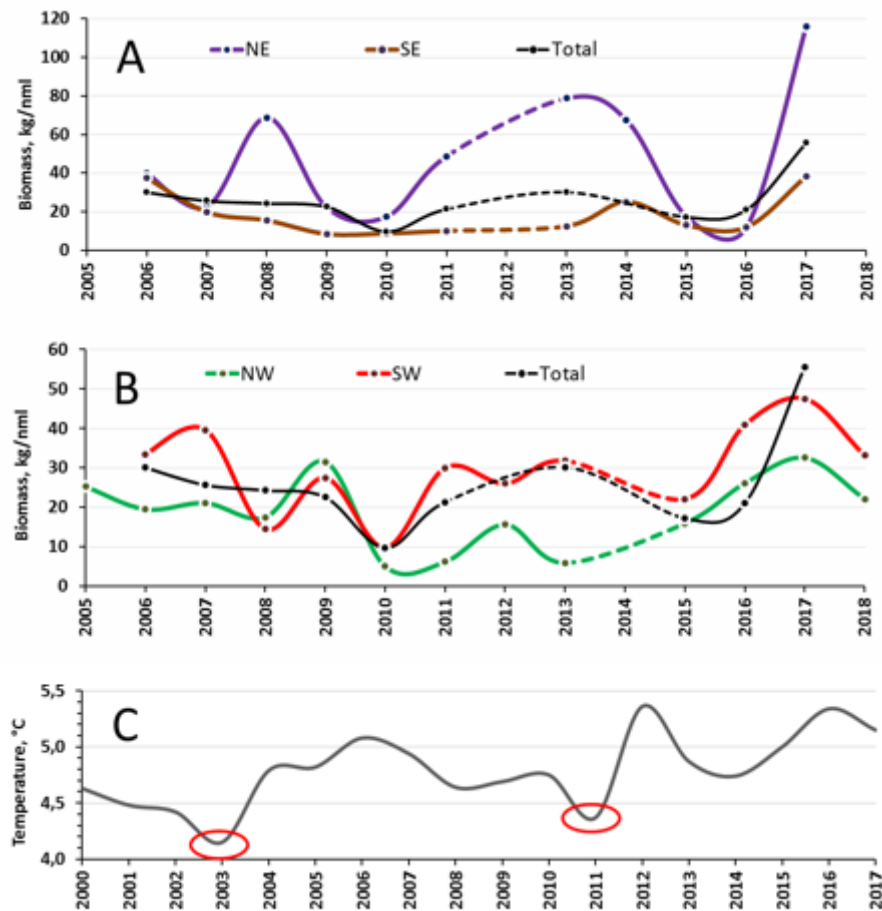
Figure 3.4.1.5 The inter-annual fluctuation of the mean megabenthos biomass in total Barents Sea and in it eastern (A) and western (B) sections and variations of the mean temperature in the water layer 0-200 m in the 3-7 stations of the Kola Section (http://www.pinro.ru) (C). "Total" – Barents Sea within 68-80° N, 15-62° E, "NE" – north-eastern sector (74-80° N, 40-62° E), "NW" – north-western sector (74-80° N, 15-40° E), "SE" – south-eastern sector (68-74° N, 40-62° E), "SW" – south-western sector (68-74° N, 15-40° E). Biomass of Pandalus borealis and all catches more than 1t are excluded. Red circles show cold years which could cause decrease of the biomass in 2010 and probably in 2018.

Due to lack of station coverage in 2018, only the south-western and the north-western sectors of the Barents Sea could get an added mean megabenthic biomass to the time series. In both these sectors a decrease in the mean biomass value was recorded (fig. 3.4.1.5 B.)

This drop in the mean biomass is 7-year after the cold year in 2011. This agrees with the hypothesis above, but due to the short time-series and high uncertainty of mega- benthos quantification, such an assumption can only be taken as a working hypothesis.

TIBIA-polygon mapping and monitoring of the main benthos parameter. Due to high variation of the inter-annual data and an annual lack of coverage, we averaged three year periods 2004-2009, 2010-2013, and 2014-2017 of station data to each of the TIBIA polygons. The results of this averaging are presented in the figure 3.4.1.6.
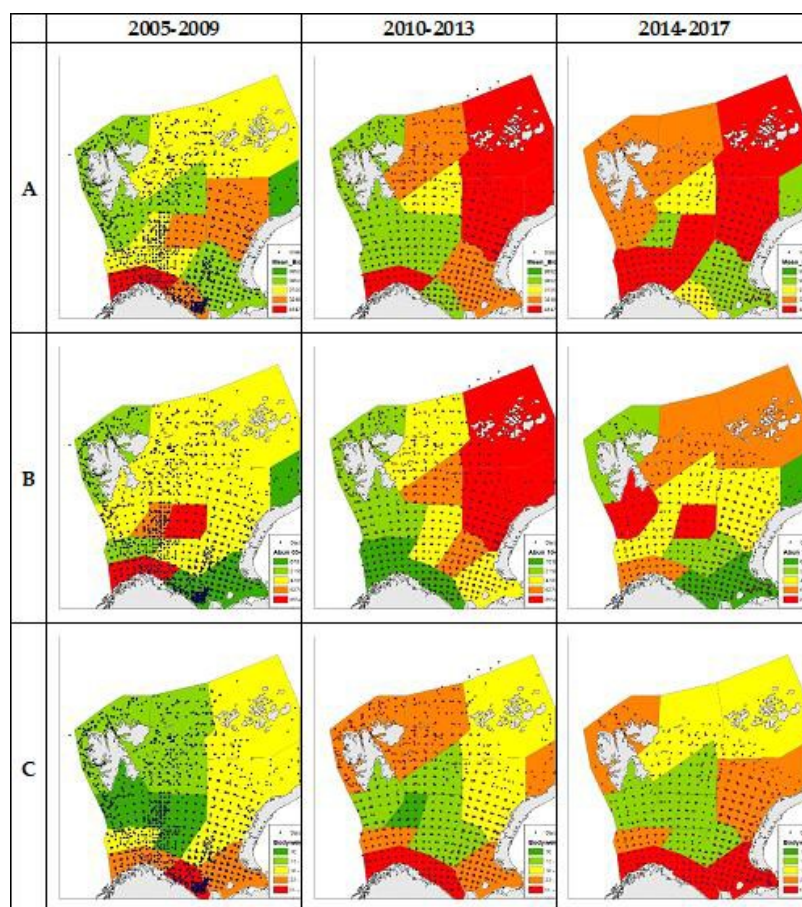
Figure 3.4.1.6 Mean megabenthic A) biomass (g/nm), B) abundance (number of individuals per nm), C) body weight (g) per TIBIA polygons for periods 2005-2009, 2010-2013 and 2014-2017.

The mean biomass increased in the central area, the NE area and around Svalbard from 2005 to 2017 (fig. 3.4.1.6 A). A reduction of mean biomass was observed in the Bear Island trench, the Hopen Deep and partly in the SE.

The mean abundance values demonstrated the same tendency, but not so strongly ex- pressed, as the biomass. High numbers of individuals are always recorded in north (east) while always low west and north of Svalbard and partly (NB-due to large *Geodia* catches) in the south (fig. 3.4.1.6 B).

The mean body weight of megabenthic organisms are always large in south and in north (east), while always low in central/west Barents Sea (fig. 3.4.1.6 C). The body weight has increased west, north and east of Svalbard from 2005 to 2017.

3.4.2 State of selected benthic species

D.V. Zakharov (PINRO)

Snow crab

The snow crab (*Chionoecetes opilio*) is a non-indigenous species in the Barents Sea and was first recorded in 1996 on the Goose Bank area (Strelkova, 2016). Several theories about the cause of the arrival exist, and the introduction via ballast water is one of them. The introduction of the snow crab to the Barents Sea is believed to have occurred during 1996–1993.

Regular annual monitoring of the snow crab population began with BESS in 2004. This survey is, currently, the most important source of information on snow crab population status.

Assessments of snow crab dynamics based on BESS data (Table 3.4.2.1 and figures 3.4.2.1 and 3.4.2.2) indicate that in the Barents Sea the snow crab population is still developing (spreading, population increase).

Table 3.4.2.1 Characteristics of the snow crab catches during BESS 2005-2017.

Year	Total number of sta- tion	Number of sta- tion with snow crab	Total num- bers, ind.	Total bio- mass, kg	Mean abun- dance, ind./nm	Mean biomass, kg/nm
2005	649	10	14	2.5	1	0.3
2006	550	28	68	11	3	0.5
2007	608	55	133	18	3	0.4
2008	452	76	668	69	11	1.2
2009	387	61	276	36	6	0.8
2010	331	56	437	22	10	0.5
2011	401	78	6 219	154	99	2.4
2012	455	116	37 072	1 169	395	12.6
2013	493	131	20 357	1 205	210	12.7
2014	304	78	12 871	658	206	10.5
2015	335	89	4 245	378	57	5.2
2016	317	84	2 156	137	26	1.9
2017	376	159	25 878	1422	147	10.0
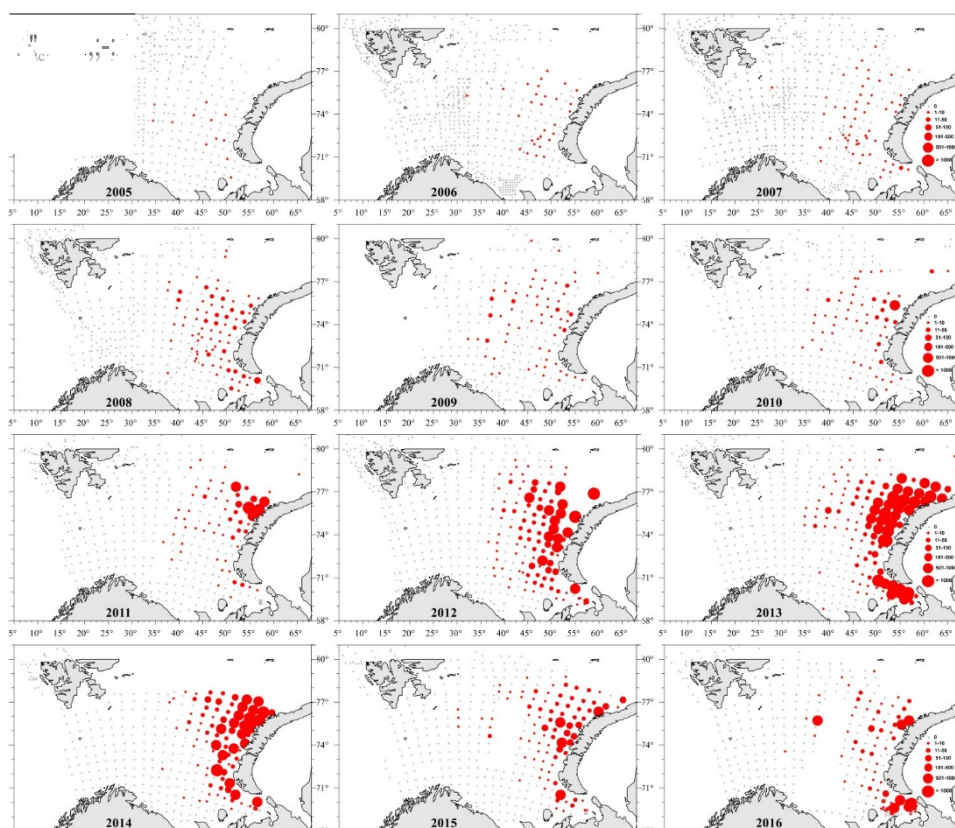
Figure 3.4.2.1. The temporal distribution of the snow crab population in the Barents Sea (number of individuals/nm) according to BESS 2005-2016.
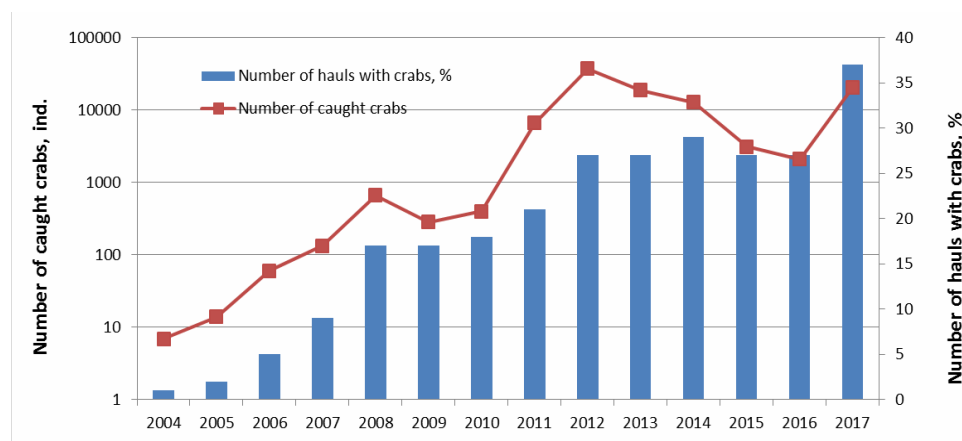
Figure 3.4.2.2. The dynamic of the snow crab population in the Barents Sea given as the total num- ber of crabs (blue bars) and the number of trawl hauls with crabs (red line) during the BESS 2004– 2017.

In 2017, as in previous years, the densest aggregations of snow crabs (more than 1000 ind/nml) were concentrated in the central part of the Barents Sea in the Loop Hole area and near Novaya Zemlya archipelago within the Russian Economic Zone. Since 2017, the snow crab was for the first time recorded at Svalbard. One record was made in Stor-fjord at 162 m depth (two immature males with 47 mm and 48 mm carapace widths); the other was northwest of Svalbard archipelago at 506 m depth (one juvenile male with a 14 mm carapace width) (fig. 3.4.2.3).
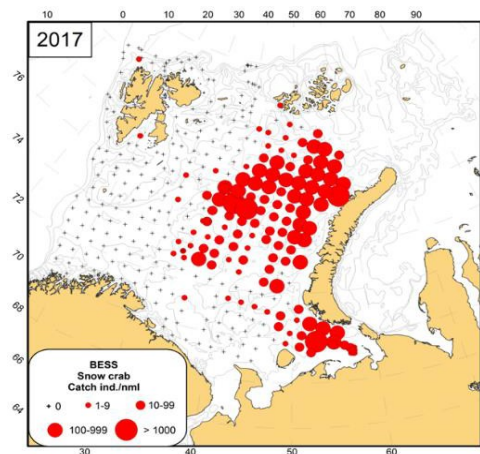
Figure 3.4.2.3 Distribution of the snow crab (Chionoecetes opilio) in the Barents Sea in August-Oc- tober 2017 (according to BESS data).

Studies of snow crab population size structure indicate that abundant generations ap- pear peri- odically, and that this affects the overall population dynamics in the Barents Sea. During the ecosystem survey period, abundant generations were recorded with 3 years' interval - in 2009, 2012, and 2015–2016 (fig. 3.4.2.4) (Bakanev & Pavlov 2016).
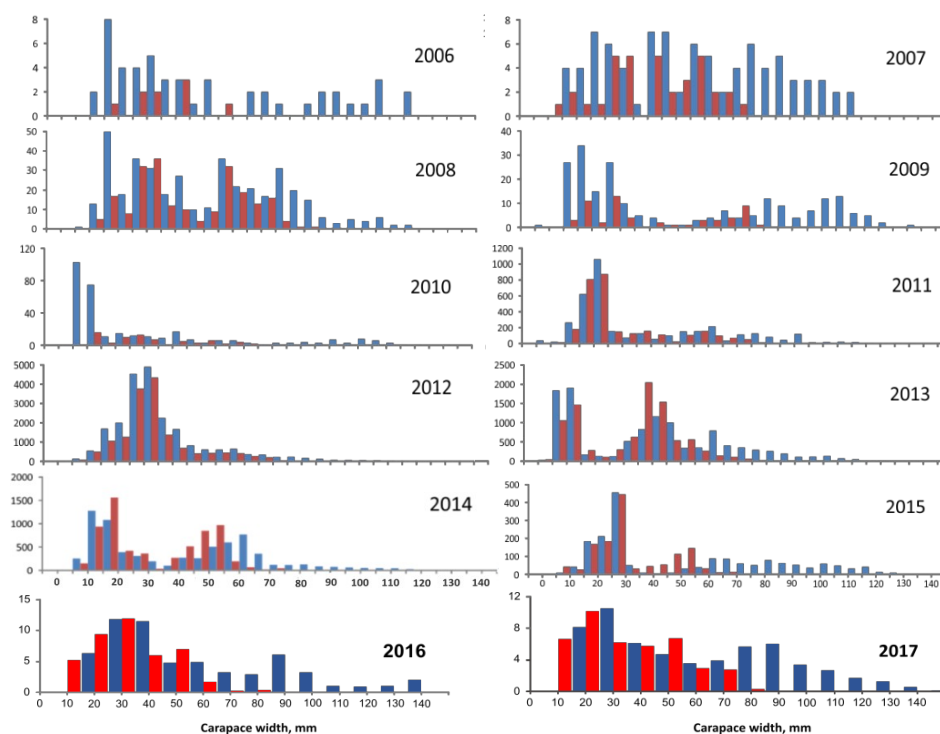

Figure 3.4.2.4 The sex and size structure of the snow crab population from 2006–2017 (Bakanev & Pavlov 2016, with editions). On vertical axes: 2006–2015 – number of individuals; 2016–2017 – abun- dance, %.

Since 2003, snow crabs in the eastern part of the Barents Sea, have been recorded in stomachs of bottom fish species (cod, haddock, catfish, American dub, and starry ray).

In recent years, snow crabs have become one of the most important prey species for cod. In 2011–2012 it made up about 2% of the cod stomachs examined, in 2013–2014 it made up 4–7%, and in 2015–2016 it made up 5–6%. All size categories of snow crab (up to 120 mm carapace width) are eaten by cod. Cod feeding on snow crabs was most intensive (up to a quarter of total stomach content) during autumn at Novaya Zemlya, Great Bank, Central Banks.

Northern shrimp

Northern shrimp (*Pandalus borealis*) is common and widely distributed in the Barents Sea above the deep (250-350 m) muddy flats of the Barents Sea and in temperatures between 2 - 3°C. During the 2017 BESS survey, it was recorded at 281 of the 376 trawl stations with a biomass that varied from a few grams to 439.8 kg per nautical mile, with an average catch of 13.8±1.7 kg/nml across 281 station. The densest concentrations of shrimp were registered in central Barents Sea, around Spitsbergen, and in Franz Victo- ria Trough (fig. 3.4.2.5). In 2017, the northern shrimp biomass index (method of squares) was 314.2 thousand tons; 1.5% higher than in 2016, and 8% lower than the average index value.

Figure 3.4.2.5 Distribution of the Northern shrimp (Pandalus borealis) in the Barents Sea, August– October 2004–2017.

During the BESS 2006-2017 average catches of the shrimp varied from 4 to 11 kg (Figure 3.4.2.6), all stayed stable around the average level. The increase of biomass in 2017 may be connected with the investigations in Franz Victoria Trough were large biomasses of shrimp were recorded.
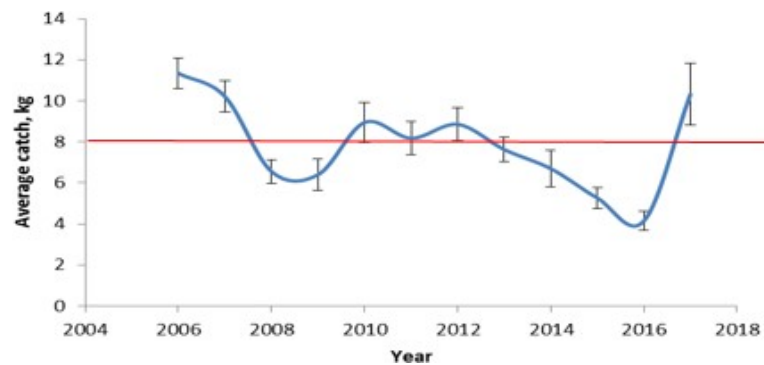
Figure 3.4.2.6. Average catches of the Northern shrimp (Pandalus borealis) in the Barents Sea during the BESS 2006-2017. The red line shows mean value over the all years.

Biological analyses of the northern shrimp population in the eastern part of the BESS were conducted in 2017 by Russian scientists. Similar to 2016, the bulk of the popula- tion consisted of younger individuals: males of 12–27 mm carapace length; and females of 17–30 mm carapace length (fig. 3.4.2.7).
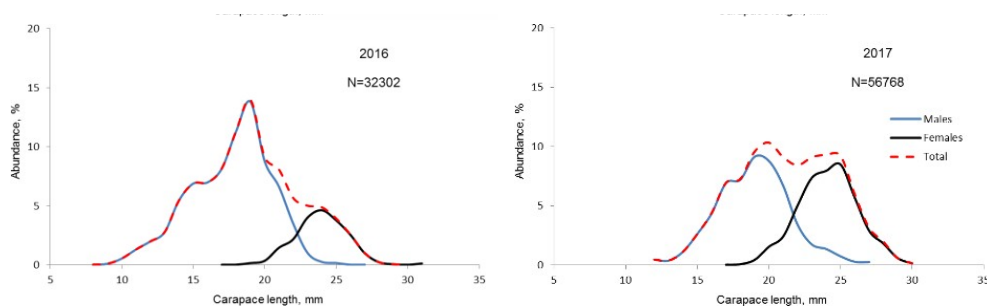

Figure 3.4.2.7 Size and sex structure of catches of the Northern shrimp (Pandalus borealis) in the eastern Barents Sea, August–October 2006–2017.

In the western survey area, as in the eastern part of the Barents Sea, smaller shrimp (males 11–23 mm carapace length, and females 18-28 mm carapace length) were most abundant; comprising up 64% of catches (fig. 3.4.2.8).
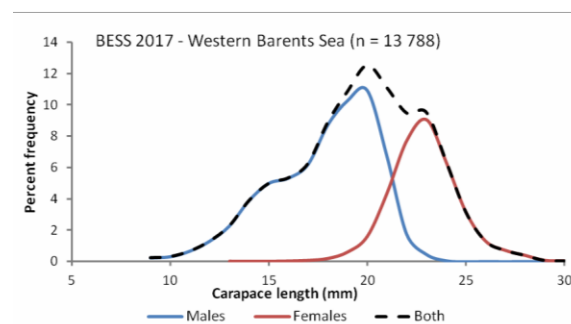
Figure 3.4.2.8. Size and sex structure of catches of the Northern shrimp (Pandalus borealis) in the western Barents Sea, August–October 2017.

References

Anisimova, N.A., Jørgensen, L.L., Ljubin, P., Manushin, I. 2011. Benthos. In The Barents Sea Ecosystem Resources and Management. Half a century of Russian-Norwegian Coop- eration. Pp 121-159. Ed by T. Jakobsen, V. Ozhigin. Tapir Academic Press, Trondheim Norway.

Lyubin, P. A., Anisimova, A. A., and Manushin, I. E. 2011. Long-term effects on benthos of the use of bottom fishing gears. In The Barents Sea: Ecosystem, Resources and Manage- ment: Half a Century of Russian-Norwegian Cooperation, pp. 768–775. Ed. By T. Jak- obsen, and V. K. Ozhigin. Fagbokforlaget, Bergen, Norway. 832 pp.

Sirenko BI (2001) Introduction. In List of species of free-living invertebrates of Eurasian Arctic Seas and adjacent waters. pp. 3-8. Ed by Sirenko B.I. Explorations of the fauna of the seas, 51. Zoological Institute of the Rus.Ac. of Sci.: Saint Petersburg.

3.5   Pelagic fish

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Total biomass

Zero-group fish are important consumers of plankton and are prey for other predators, and, therefore, are important for transfer of energy between trophic levels in the eco- system. Esti- mated total biomass of 0-group fish species (cod, haddock, herring, capelin, polar cod, and red- fish) varied from a low of 165 thousand tonnes in 2001 to a peak of 3.4 million tonnes in 2004 with a long-term average of 1.7 million tonnes (1993-2017) (Figure 3.5.1). Biomass was dominated by cod and haddock, and mostly distributed in central and northern-central parts of the Barents Sea.

In 2018, the biomass of 0-group fish was not estimated due to lack of spatial coverage.
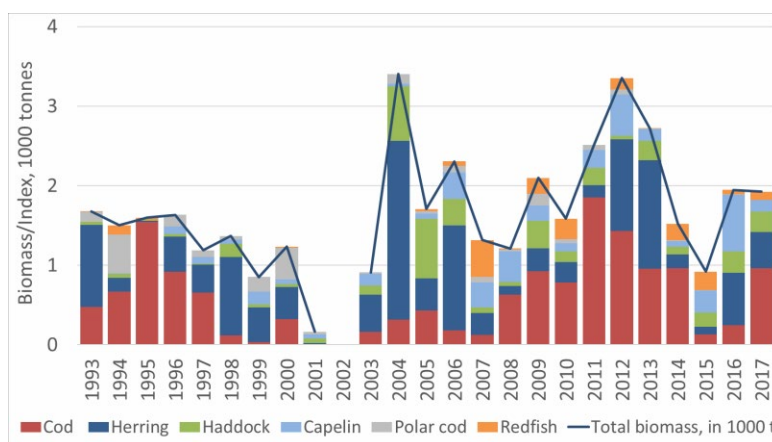

Figure 3.5.1. Biomass of 0-group fish species in the Barents Sea, August–October 1993–2017.

Capelin, young herring, and polar cod constitute the bulk of pelagic fish biomass in the Barents Sea. During some years (e.g., 2004–2007 and 2015–2016), blue whiting (*Mi- cromesistius poutassou*) also had relatively high biomass in the western Barents Sea (east of the continental slope). Total biomass of the main pelagic species during 1986–2017 fluctuated between 0.5 and 9 million tonnes; largely driven by fluctuations in the cap- elin stock. During 2017-2018, the cumulative biomass of capelin, herring, polar cod, and blue whiting was close to the long-term average (Fig- ure 3.5.2). Data on blue whit- ing for 2018 are still being processed.
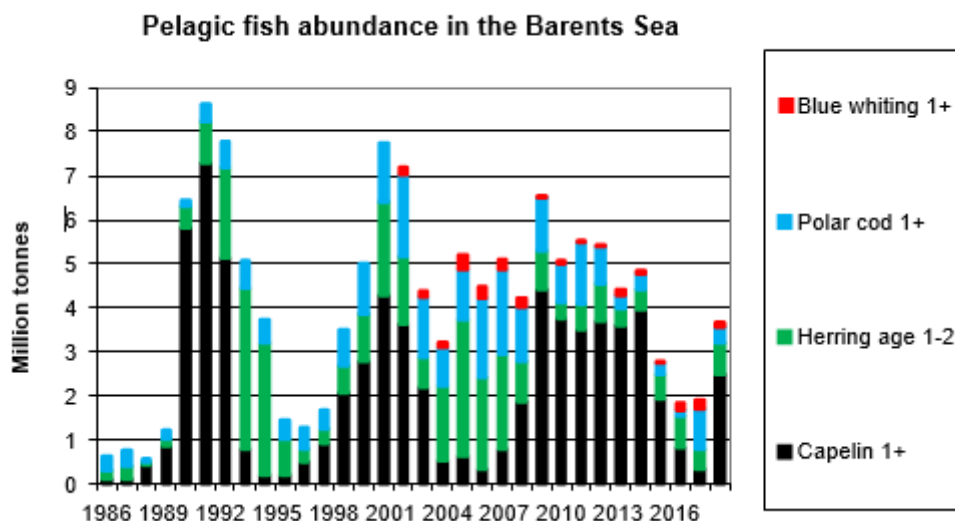
Figure 3.5.2 Biomass of main pelagic fish species (excluding 0-group fish) in the Barents Sea, Au- gust-October 1986–2017.

Capelin

Young-of-the-year

Estimated abundance of 0-group capelin varied from 952 million individuals in 1993 to 995,101 million individuals in 2008 with an average of 314,184 million individuals during the 1980-2017 period (Figure 3.5.3). In 2018, the total abundance index for 0- group capelin was not estimated due to lack of coverage.
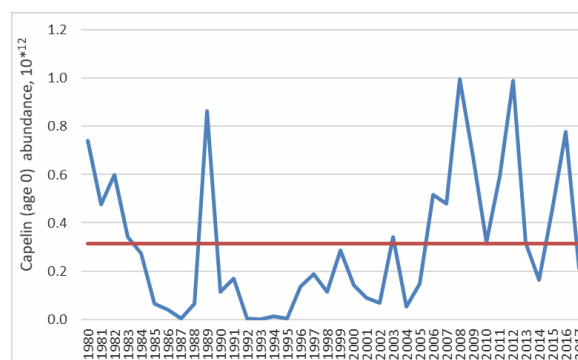

Figure 3.5.3. 0-group capelin abundance (corrected for trawl efficiency) in the Barents Sea. Red line shows long-term mean for the 1980–2017 period; blue line indicates 0-group abundance fluctuation.

In 2018, the western Barents Sea (west of the Norwegian-Russian border) was sampled and spatial indices were estimated for eight regions (South West, Bear Island Trench, Thor Iversen Bank, Hopen Deep, Svalbard South, Svalbard North, Central Bank, and Great Bank (ICES WGIBAR 2018 Annex 4). 0-group capelin were distributed mainly in central and northcentral regions (Thor Iversen Bank, Hopen Deep, and Central Bank) (Figure 3.5.4). In these eight regions, highest abundance was observed when strong year classes occurred in 1989, 2008, 2012 – 2013, and 2016. Intermediate abundance of 0-group capelin was observed in western and central regions indicating an average year class in 2018. However, capelin usually occur in southern and eastern areas also; therefore, 0-group abundance was likely underestimated in these regions.
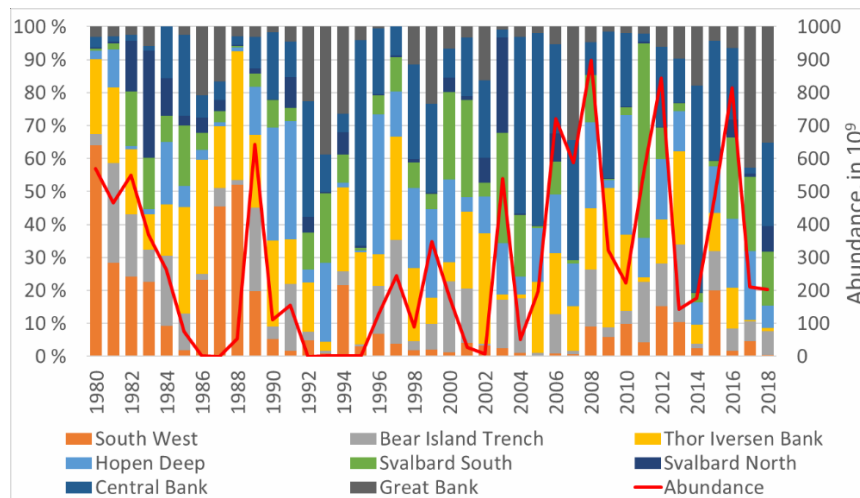
Figure 3.5.4. Percentage of 0-group capelin abundance in western, central, and northern regions of the Barents Sea (1980–2018). Red line shows total abundance for these eight regions.

Distribution of 0-group capelin has varied during the last four decades. The total area of distribution was smallest during the 1990s, has been largest during the current decade, and associated with the occurrence or non-occurrence of strong year classes (Figure 3.5.5) Capelin have expanded distribution in the southeastern and northeastern direction (Eriksen et al. 2017).
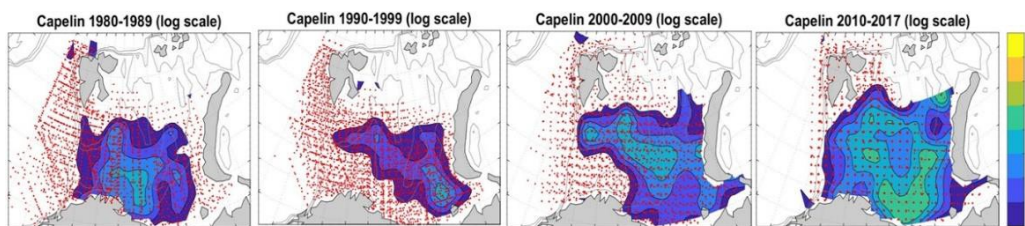
Figure 3.5.5. Distribution of 0-group capelin abundance in the Barents Sea during the 1980s, 1990s, 2000s, and 2010s. Abundance was log-transformed (natural logarithms) before mapping. Fish den- sity varied from low (blue) to high (yellow). Red dots indicated sampling locations. The map is from Eriksen et al. (Progress in Oceanography, under revision).

Adult capelin

Sampling the main area of capelin distribution during 2018 was timely and well covered; but some areas where young capelin might occur were not surveyed. This in- creases the uncertainty in estimating recruitment. It is believed, however, that the stock assessment was sound, and re- sults are comparable to last year.

The geographic distribution of capelin density is shown in Figure 3.5.6. Capelin distribution in 2018 was spatially comparable to 2017, but abundance decreased in northern and northeastern regions of the Barents Sea. The main capelin schools were observed along the western edges of the Great Bank, while fewer were observed in eastern and northern regions.

Average length of capelin in 2018 was 12.7 cm; average weight was 11.4 g, approxi- mately the same as in 2017. For age 1 capelin, increasing trends in length and weight were observed (Figure 3.5.7). For age 2 capelin, average fish weight and length were both almost the same as in 2017. For age 3 capelin, both average length and weight decreased slightly but remained above the longterm average. In general, all biological characteristics of capelin were at the average long-term level. This is most clearly ob- served in age 2 fish (Figure 3.5.7). Usually this age group forms a large component of total stock and reflects general trends in condition of the capelin stock.

Dynamics of changing average weight-at-age reflect capelin feeding conditions during the summer-autumn period. These conditions are determined not only by the stock size, but also by the state of the plankton community in the Barents Sea. It is evident that in 2018 the capelin food base (zooplankton abundance and species composition) was favourable.
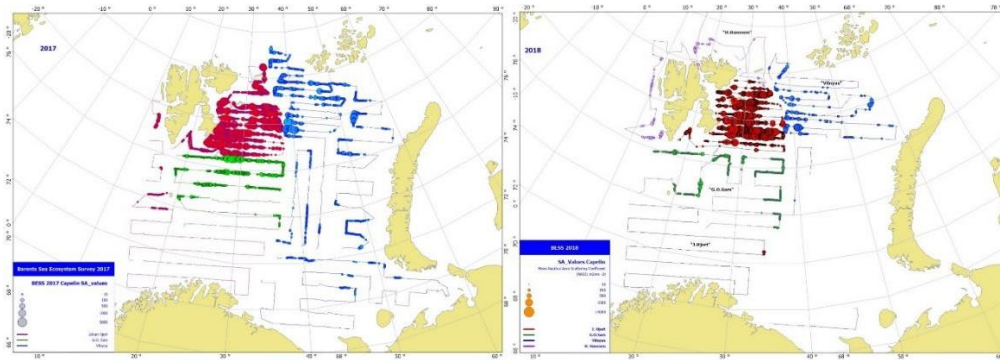

Figure 3.5.6 Geographic distribution of capelin in 2017 (left) and 2018 (right). Circle size corre- sponds to SA (area back-scattering coefficient) values per nautical mile.
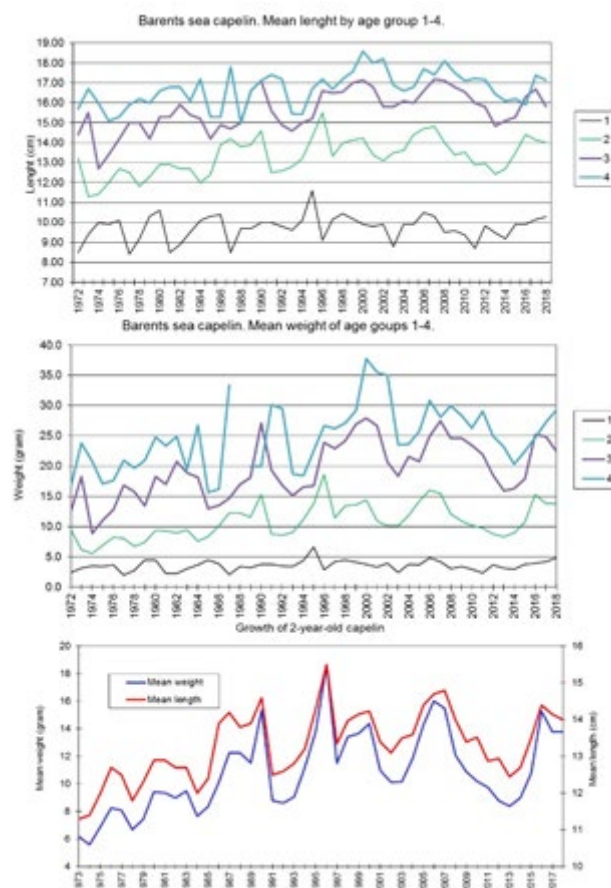
Figure 3.5.7 Biological characteristics of capelin during August-September (1973-2018).

The total adult capelin stock was estimated to be approximately 1.6 million tonnes in 2018, which is below the long-term average (2.9 million tonnes) and represents a 36% decrease from 2017. About 66% (1.06 million tonnes) of the 2018 stock was above 14 cm in length and considered to be maturing (Figure 3.5.8).

Age 2 capelin (2016 year class) dominated the stock composition (≈43%); the 2015 year class (age 3) made up 15.3% of the stock. The recruiting age 1 (2017) year class) was estimated at 58.6 billion

individuals, which is below the long-term average value. How- ever, as noted above, there is some uncertainty in the estimation of age 1+ individuals. It is likely that the actual number of age-group 1+ individuals is larger. The estimated number of older (age 4+) individuals (0.32 bil-lion) was relatively low (Figure 3.5.9).
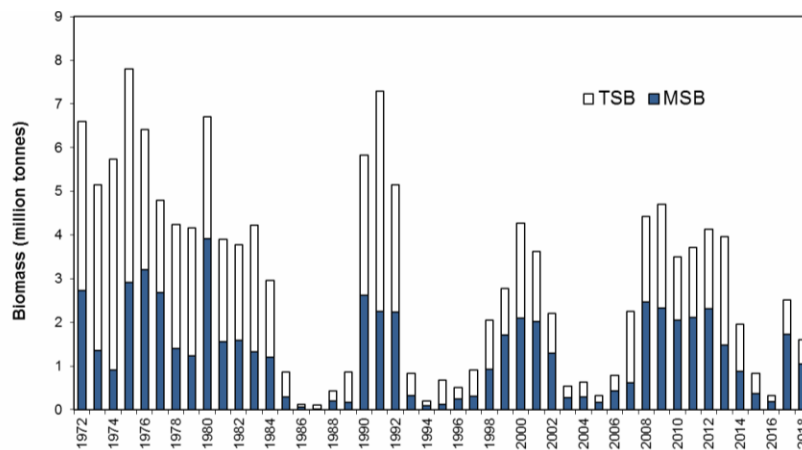

Figure 3.5.8. Capelin biomass based on 1972–2018 acoustic survey data: maturing stock biomass (MSB) and total stock biomass (TSB).
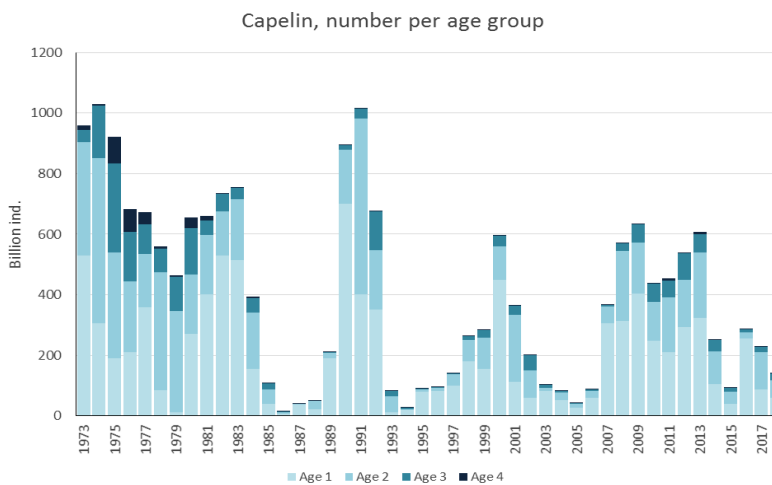

Figure 3.5.9. Capelin stock age composition (age 1-4) during 1972–2018. (Note: age 5 and older was removed due to negligible numbers in the total stock).

Due to significant spawning mortality, the natural mortality of capelin can be esti- mated indi-rectly only. Figure 3.5.10 shown total mortality (Z) calculated as the decrease from age 1 to age 2 in the autumn survey. Negative mortality values are most likely the consequence of underesti-mation of age 1 fish in the survey. Capelin natural mor- tality varies significantly between years.

Figure 3.5.10. Capelin natural mortality from age 1 to age 2, estimates based on acoustic survey data. X axis shows cohorts.

Spatial distribution of capelin in the Barents Sea depends on environmental and stock conditions, primarily: position of the ice edge; distribution of zooplankton; and capelin stock size and structure. In years with a large stock, capelin is distributed widely. Juvenile capelin are distributed further south than adults. During the 1972-1979 period, the capelin stock was large and widely distributed. During 1980-1989, the stock de- creased and distribution was more southward. Since the 2000s, capelin began movement north- and eastwards. During 2010-2017, the stock was in good condition and moved significantly northward into ice-free waters (Figure 3.5.11). This represented a shift northward an average of 60-80 nautical miles further than observed in the 1970s. During more recent years, capelin stock size has decreased; the area of distribution has decreased as well. In general, during periods of warming in the Barents Sea, capelin move further north and north-eastward to find feeding grounds with high plankton biomass. However, at low stock levels, capelin have adequate food availability, and temperature does not appear to be a key factor driving northward expansion.
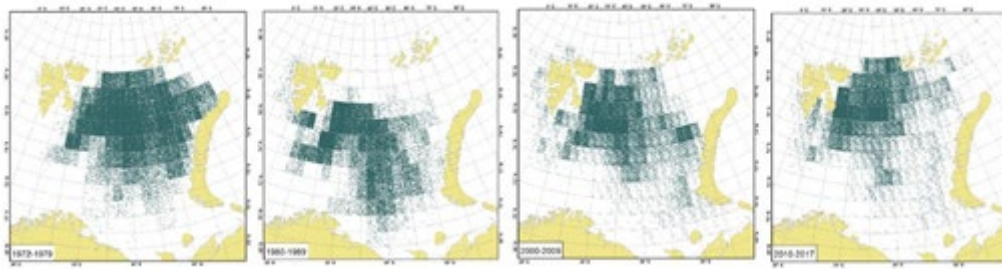
Figure 3.5.11a. Estimated capelin biomass during August-September by decade (1970s, 1980s, 1990s, 2000s, and 2010s). Biomasses presented for World Meteorological Organization (WMO) squares system of geocodes which divide areas into latitude-longitude grids (1° latitude by 2° longitude). One dot is equal to 500 tonnes.
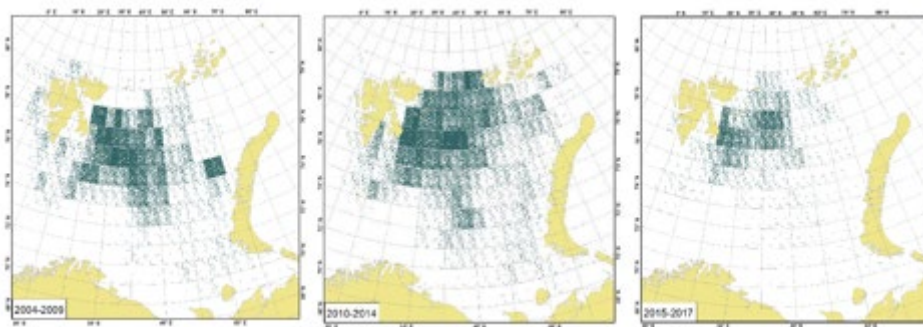

Figure 3.5.11b. Estimated capelin biomass during August-September for recent periods of record high temperature condition and increased cod stock size. Time periods are further broken down into sub-periods (2004-2009, 2010-2014 and 2015-2018). Biomass is presented for WMO squares. One dot is equal to 500 tonnes.

Herring

Young-of-the-year

Estimated abundance of 0group herring varied from 37 million individuals in 1981 to 773,891 million individuals in 2004 with a long-term average of 163,247 million indi- viduals for the 1980-2017 period (Figure 3.5.12). In 2018, the total abundance index for 0-group herring was not esti-mated due to lack of coverage.

Estimated abundance of 0group herring varied from 37 million individuals in 1981 to 773,891 million individuals in 2004 with a long-term average of 163,247 million indi- viduals for the 1980-2017 period (Figure 3.5.12). In 2018, the total abundance index for 0-group herring was not esti-mated due to lack of coverage.
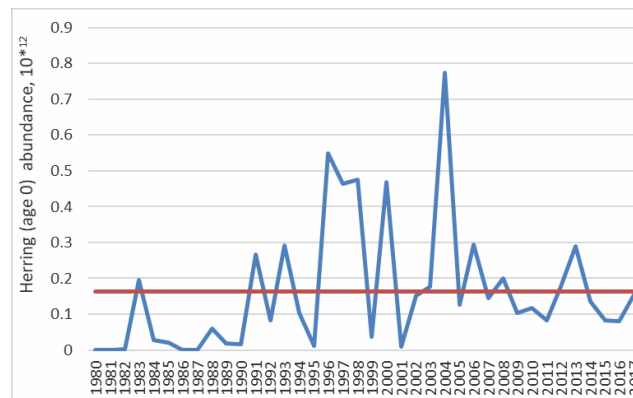
Figure 3.5.12. 0-group herring abundance in the Barents Sea for the 1980–2017 period, corrected for trawl efficiency. Orange line shows the long-term average, while the blue line shows abundance fluctuation.

In 2018, the western Barents Sea (west of the Norwegian-Russian border was surveyed and spatial indices were estimated for eight regions (South West, Bear island Trench, Thor Iversen Bank, Hopen Deep, Svalbard South, Svalbard North, Central Bank, and Great Bank) (ICES 2018 Annex 4). 0-group herring were distributed in southwestern and central regions (Figure 3.5.13.). Abundance in these eight regions was highest when strong year classes occurred during 1996-1998 and 2004. Very low numbers of 0- group herring were observed in these areas likely indicating that a strong year class did not occur in 2018. However, herring usually occur in southern areas also, likely indicating that 0-group abundance was underestimated.
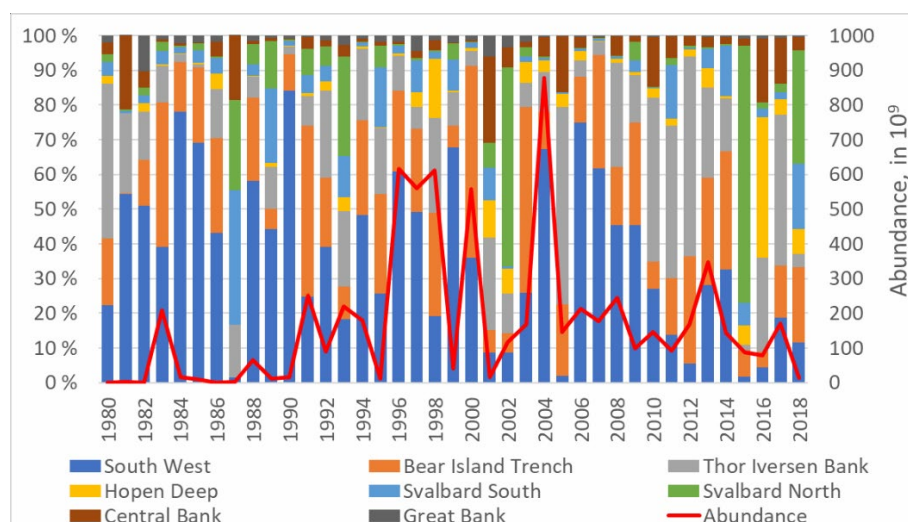

Figure 3.5.13. Percentage of 0-group herring abundance distributed in the Barents Sea (1980–2018) in the South West, Bear Island Trench, Thor Iversen Bank, Hopen Deep, Svalbard South, and Sval- bard North. More detail about these spatial indices can be found in ICES WGIBAR 2018 Annex 4.

Spatial distribution of 0-group herring varied over the last four decades, was most limited during the 1980s and has increased since that time. Extent of the area occupied was assosiated with the occurance or lack of occurance of strong year classes (Figure 3.5.14.). Higher densities of herring have been observed in the northwestern areas during the last decade than during the previous three decades.
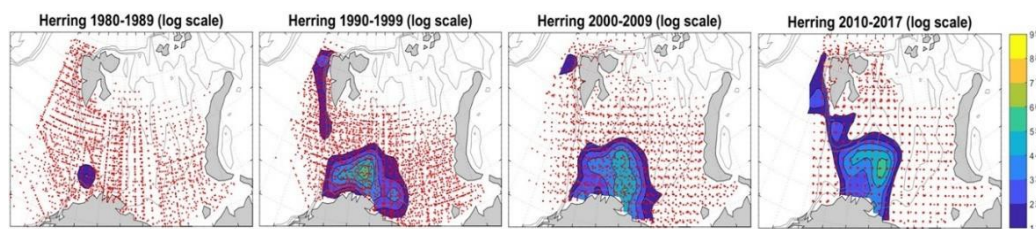
Figure 3.5.14. Distribution of 0-group herring abundance in the Barents Sea during 1980s, 1990s, 2000s, and 2010s. Abundance estimates were log-transformed (natural logarithms) before mapping. Fish density varied from low (blue) to high (yellow). Red dots indicate sampling locations. The map is taken from Eriksen et al. (Progress in Oceanography, under revision).

Herring age 1-2

Figure 3.5.15 shows biomass of age 1 and 2 herring in the Barents Sea, calculations are based on the last ICES assessment for age 2+ herring, assuming M=0.9 for age 1. During 2013–2017, abundance of young herring sampled during the ecosystem survey has been relatively stable, while it increased from 2017 to 2018 due to the strong 2016-year class. Biomass of young herring in 2018 was the highest since 2005, and well above the long-term average. Figure 3.5.16 shows herring distribution in 2018 with highest amounts in the southern Barents Sea, but sampling coverage was incomplete.
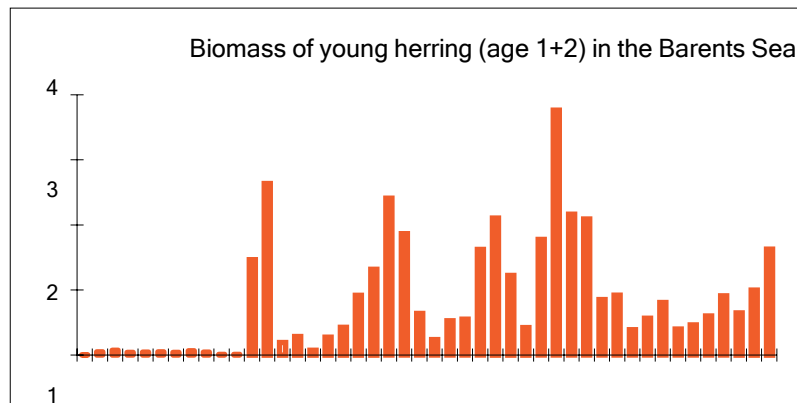
Figure 3.5.15. Age 1 and 2 Norwegian Spring Spawning herring biomass in the Barents Sea – based on Working Group on Widely Distributed Stocks (WGWIDE) VPA estimates (ICES 2018b).
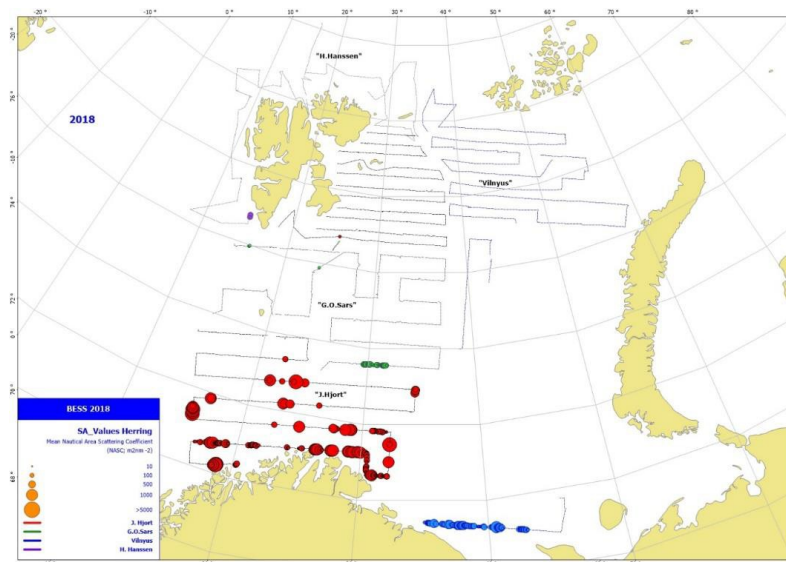

Figure 3.5.16. Estimated distribution of herring, August-October 2018. Circle sizes corresponding to SA (area back-scattering coefficient) values per nautical mile.

Polar cod

Polar cod is a true Arctic species with a circumpolar distribution. Historically, the world's largest population of this species has been observed in the Barents Sea.

Young of the year

Estimated abundance of 0-group polar cod varied from 201 million in 1995 to 2 billion individuals in 1994 with a long-term average of 317,204 million individuals for the 1980-2017 period (Figure 3.5.17). In 2018, the total abundance index for 0-group polar cod was not estimated due to lack of coverage in the main 0-group area (the southeast- ern Barents Sea).
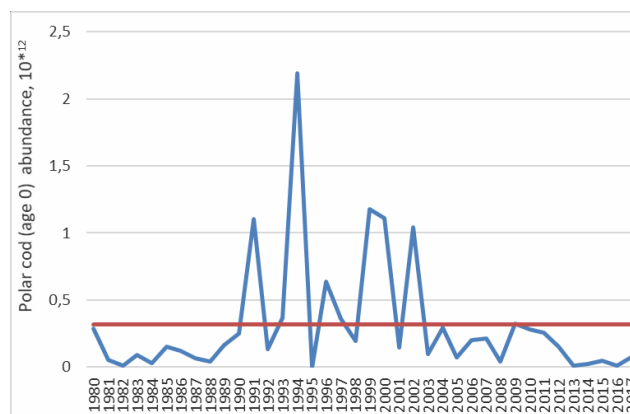
Figure 3.5.17. 0-group polar cod abundance (corrected for trawl efficiency) in the Barents Sea during the 1980–2017 period. Red line shows long-term average, while the blue line indicates 0-group abundance fluctuation.

In 2018, the western Barents Sea (west of the Norwegian-Russian border) was covered and the spatial indices were estimated for eight regions (South West, Bear Island Trench, Thor Iversen Bank, Hopen Deep, Svalbard South, Svalbard North, Central Bank, and Great Bank) (ICES 2018 Annex 4). Within these eight regions, highest abundance was observed during 1990-1991 and 2000-2002. 0-group polar cod were distributed mainly in the Svalbard South and Svalbard North regions (Figure 3.5.18.). Abun- dance of polar cod in these two regions is not associated with occurrence of strong year classes as the most important 0-group area is situated in the southeast- ern Barents Sea (Eriksen et al. 2017). In 2018, abundance of 0-group polar cod was low, as ob- served in previous years.
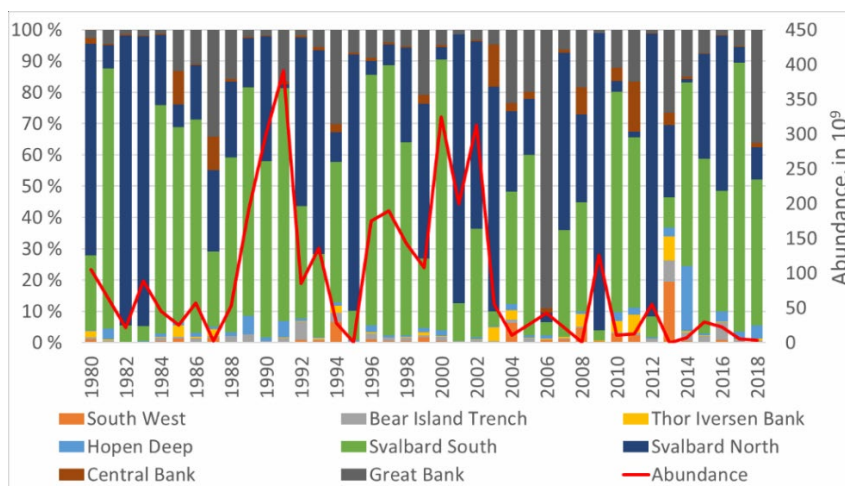

Figure 3.5.18. Percentage of 0-group polar cod abundance in South West, Bear Island Trench, Thor Iversen Bank, Hopen Deep, Svalbard South, and Svalbard North regions of the Barents Sea during the 1980–2018 period. More detail about these spatial indices can be found in ICES 2018 Annex 4.

The distribution of 0-group polar cod varied over the last four decades, and was largest during the 1990s and 2000s. Size of area occupied was associated with the occurrence or non-occurrence of strong year classes from the Pechora Sea, southeast of the Barents Sea (Figure 3.5.19.).
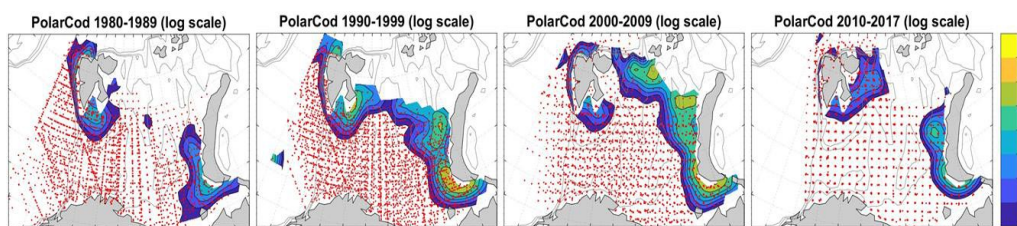
Figure 3.5.19. Distribution of 0-group polar cod abundance in the Barents Sea during the 1980s, 1990s, 2000s, and 2010s. Abundance estimates were log-transformed (natural logarithms) before mapping. Fish density varied from low (blue) to high (yellow). Red dots indicated sampling loca- tions. The map is from Eriksen et al (Progress in Oceanography, under revision).

Adult polar cod

In 2018, the area of polar cod distribution was not well covered. The total stock was estimated to be 46 thousand tonnes, which likely does not reflect the actual stock size. Thus, there is no new information about polar cod stock in 2018. Polar cod density in 2018 in the same area was lower than in 2017. Thus, it can be assumed that the polar cod stock in the Barents Sea remains at a low level. In 2017, estimated total abundance and biomass of polar cod in the Barents Sea decreased significantly. Estimated total- stock biomass (TSB) was only 357 thousand tonnes; approximately 38% of the 2016 estimate. Total stock number (TSN) was only about 23% of the 2016 estimate. The 2015- year class decreased from an estimated 95 billion in 2016 to 8.27 billion individuals in 2017 (Figure 3.5.20). Such a decrease in the polar cod stock may be the result of increased natural mortality due to consumption by cod and other predators; it may also be due to a significant portion of the polar cod stock having been distributed outside the survey area (Figure 3.5.21).
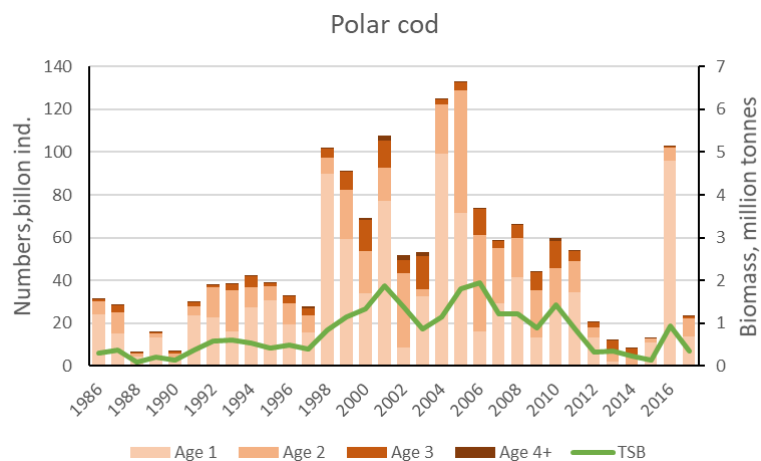
Figure 3.5.20. Total abundance in billions (coloured bars / left axis) and biomass in millions of tonnes (green line / right axis) of polar cod in the Barents Sea (acoustic survey and BESS data) col- lected August-September during the 1986–2017 period. (2003 values based on VPA due to poor sur- vey coverage. A reliable estimate is not available for 2018).
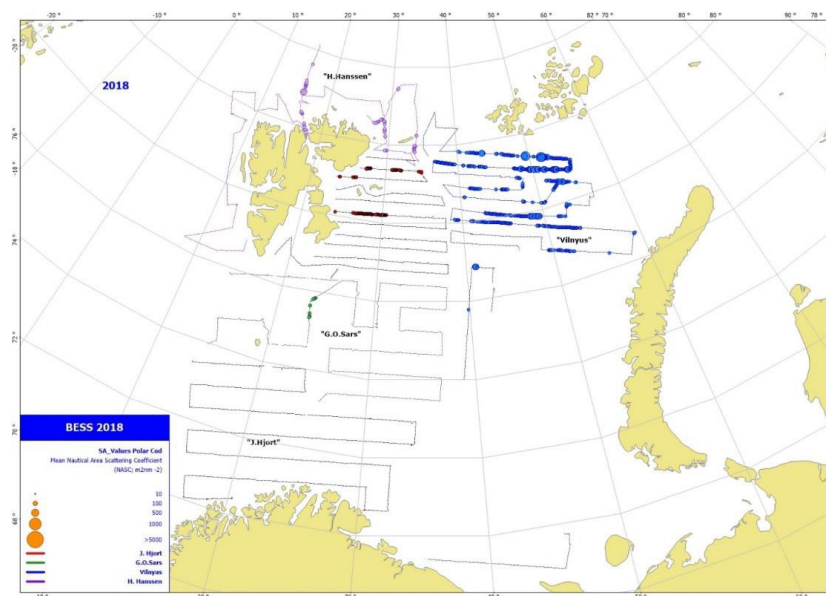

Figure 3.5.21. Estimated distribution of polar cod during August–October 2018. Circle size corre- sponds to SA (area back-scattering coefficient) values per nautical mile.

Blue whiting

Acoustic estimates for the Barents Sea blue whiting stock have been made since 2004. In 2017, the BESS data time-series was recalculated using a newer target strength equa- tion (Pedersen *et al.*, 2011), and a standardized area; this resulted in an overall reduc- tion in estimated biomass to about one third of previous estimates. During 2004–2007, estimated biomass of blue whiting in the Barents Sea was >200 000 tonnes (Figure 3.5.14) but decreased abruptly in 2008 and remained low until 2012; after which time it has been variable. In 2017, blue whiting biomass was estimated at about 115 000 tonnes; a decrease from 2016 (Figure 3.5.22). Blue whiting migrate from the Norwegian Sea into deeper parts of the Barents Sea (Figure 3.5.23) when the stock is large and sea tem- peratures are high. Survey coverage for blue whiting during BESS 2018 was complete, but final estimates are not available yet.
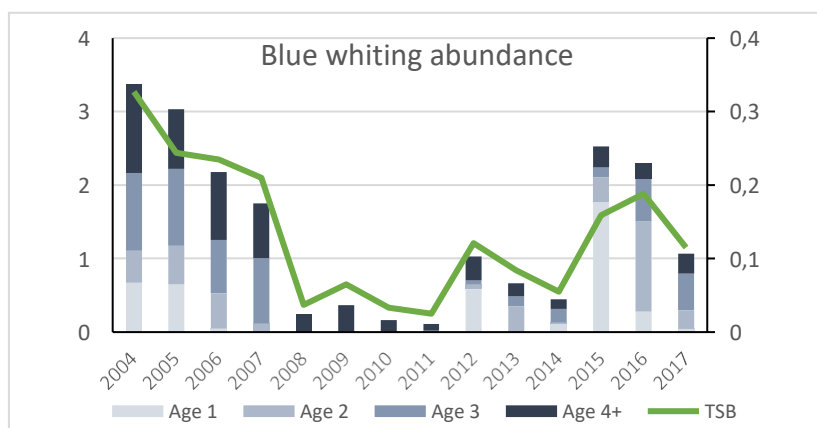
Figure 3.5.22. Total abundance in billions (coloured bars / left axis) and biomass in millions of tonnes (green line / right axis) of blue whiting in the Barents Sea (BESS data revised in 2017) col- lected August–September during the 2004–2017 period. (The 2018 estimate is being updated).
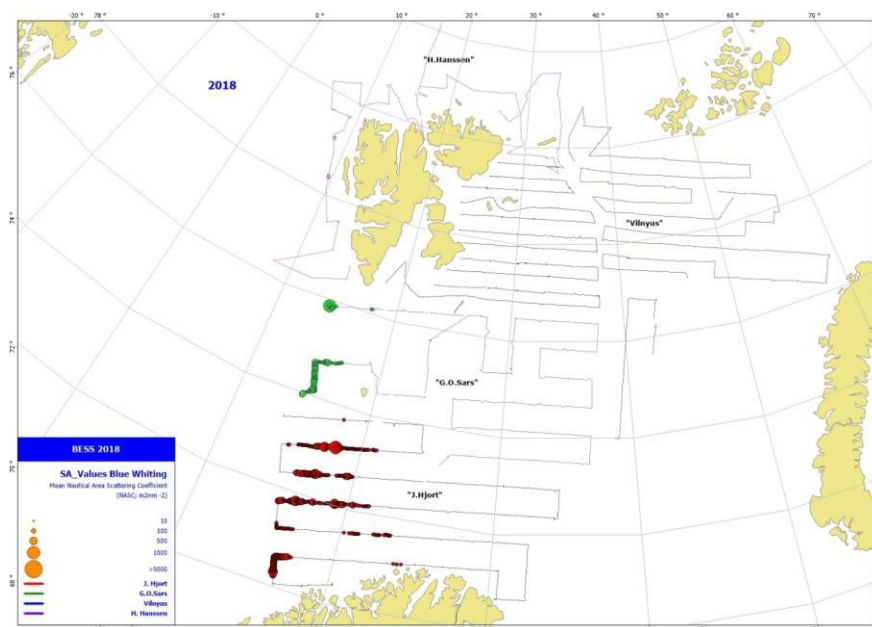

Figure 3.5.23. Estimated distribution of blue whiting during August-October 2018. Circle size cor- responds to SA (area back-scattering coefficient) values per nautical mile.

3.6   Demersal fish

B.Bogstad (IMR), D. Prozorkevich (PINRO), E.Eriksen (IMR), T.Prokhorova (PINRO) and Pavel Krivosheya (PINRO)

Most Barents Sea fish species are demersal (Dolgov *et al.*, 2011); this fish community consists of about 70–90 regularly occurring species which have been classified into zo- ogeographic groups. Approximately 25% are either Arctic or mainly Arctic species. The commercial species are all bo- real or mainly boreal species (Andriashev and Chernova, 1995), except for Greenland halibut (*Reinhardtius hippoglossoides*) that is classified as either Arcto-boreal (Mecklenburg *et al.*, 2013) or mainly Arctic (Andriashev and Cher- nova, 1995).

Distribution maps based on Barents Sea Ecosystem Survey (BESS) data for cod, had- dock, long rough dab, Greenland halibut, redfish, and six other demersal fish species can be found at: http://www.imr.no/tokt/okosystemtokt_i_barentshavet/utbredelseskart/en

Abundance estimates are available for commercial species that are assessed routinely. Figure 3.6.1 shows biomass estimates for cod, haddock, and saithe (*Pollachius virens*) from the ICES AFWG assessments conducted in 2018. Saithe occurs mainly along the Norwegian coast and along the southern coast of the Barents Sea; few occur farther offshore in the Barents Sea itself. Total biomass of these three species peaked in 2010- 2013 and has declined since; but remains above the long-term average for the timeseries dating back to 1960. Greenland halibut and red-fish, deepwater redfish (*Sebastes men- tella)* in particular are important commercial species with large parts of their distribu- tion within the Barents Sea. Time-series of biomass estimates for deep-water redfish and Greenland halibut are much shorter than those for haddock, cod, and saithe. Other than these main commercial stocks, long rough dab is the demersal stock with the high- est biomass. Overall, cod is the dominant demersal species.
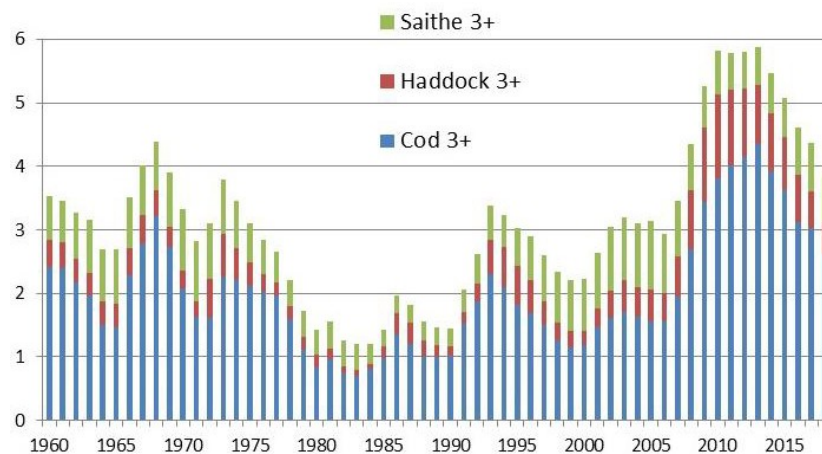
Biomass cod, haddock, saithe (million tonnes)

Figure 3.6.1 Biomass estimates for cod, haddock, and saithe during the 1960–2018 period from AFWG 2018 (ICES 2018c). Note: saithe is only partly distributed in the Barents Sea.

Cod

Young-of-the-year

Estimated abundance of 0-group cod varied from 276 million in 1980 to 464,124 million individuals in 2014 with a long-term average of 114,452 million individuals for the 1980-2017 period (Figure 3.6.2). In 2018, the total abundance index for 0-group cod was not estimated due to lack of coverage.
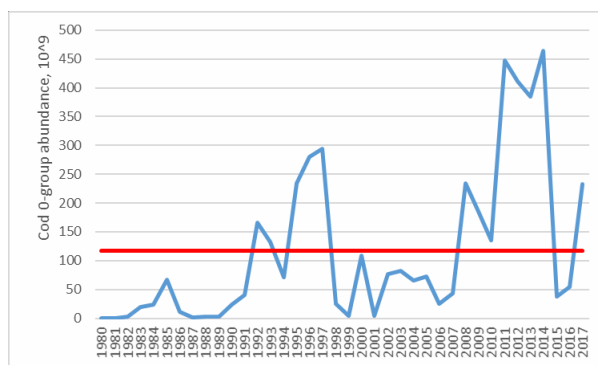
Figure 3.6.2. 0-group cod abundance (corrected for trawl efficiency) in the Barents Sea during the 1980–2017 period. Red line shows the long-term average for the 1980–2017 period; the blue line indicates 0-group abundance fluctuation.

In 2018, the western Barents Sea (west of the Norwegian-Russian border) was covered and spatial indices were estimated for eight regions (South West, Bear island Trench, Thor Iversen Bank, Hopen Deep, Svalbard South, Svalbard North, Central Bank, and Great Bank (ICES 2018 Annex 4). 0-group cod were distributed mainly in western and central regions (South West, Bear Island Trench, and Thor Iversen Bank) (Figure 3.6.3.). In these eight regions, highest abundance was observed when strong year classes occurred during 2011-2014. Low abundance of 0-group cod was observed in these regions and, thus, it is likely that a strong year class did not occur in 2018.
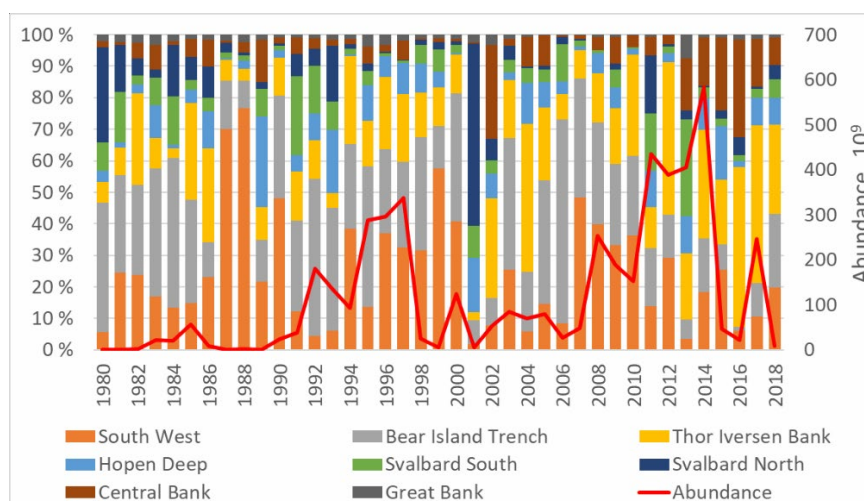

Figure 3.6.3. Percentage of 0-group cod abundance distributed in western, central, and northern regions of the Barents Sea during the 1980–2018 period. Red line shows total abundance for these eight regions.

Distribution of 0-group cod has varied during the last four decades, and the total area of distribution was smallest during the 1980s and largest during the current decade. Size of the area occupied was associated with the occurrence or non-occurrence of strong year classes (Figure 3.6.4.).
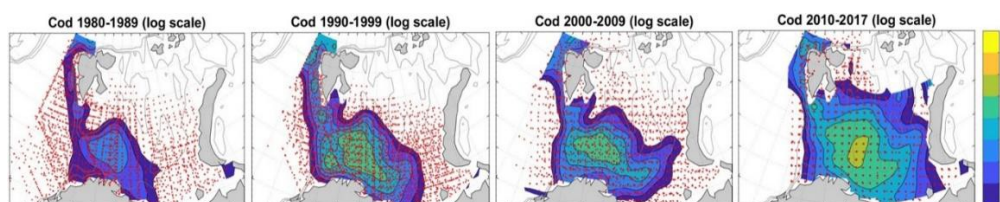

Figure 3.6.4. Distribution of 0-group cod abundance in the Barents Sea during the 1980s, 1990s, 2000s, and 2010s. Abundance estimates were log-transformed (natural logarithms) before mapping. Fish density varied from low (blue) to high

(yellow). Red dots indicated sampling locations. The map is from Eriksen et al. (Progress in Oceanography, under revision).

Older cod

The northeast Arctic cod stock is currently in good condition, with high total stock size, and high spawning-stock biomass (Figure 3.6.5). 2004 and 2005 being were strong year classes, subsequent recruitment at age 3 was at an average level (Figure 3.6.6). 0-group abundance has been very high in recent years (2011–2014); but this has not resulted in strong year classes, as seen from the updated stock-recruitment plot shown in Figure 3.6.7.
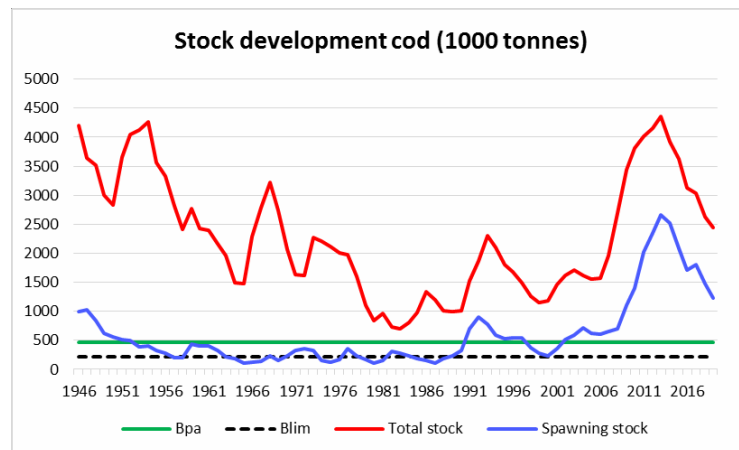
Figure 3.6.5. Cod total stock and spawning stock biomass during the 1946-2018 period, including forecast for 2019. From AFWG (ICES 2018).

Figure 3.6.6. Cod recruitment at age 3 during the 1950-2018 period and forecast for 2019-2020 (ICES 2018).

Figure 3.6.7 Spawning stock recruitment plot for cod cohorts 1946-2014 period. Cohorts 2010-2014 shown as black dots.

Strong 2004 and 2005 year classes have, together with a low fishing mortality, led to rebuilding of the cod stock's age structure to that observed in the late 1940s (Figure 3.6.8).

Figure 3.6.8. Age composition of the cod stock (biomass) during periods between 1946 and 2018. From data in ICES 2018.
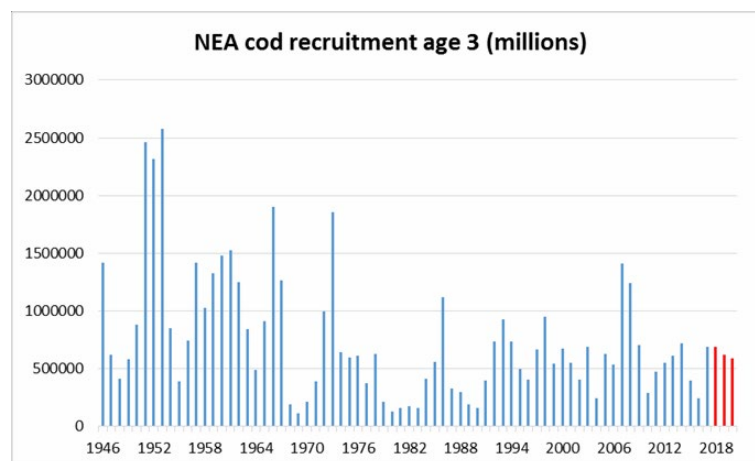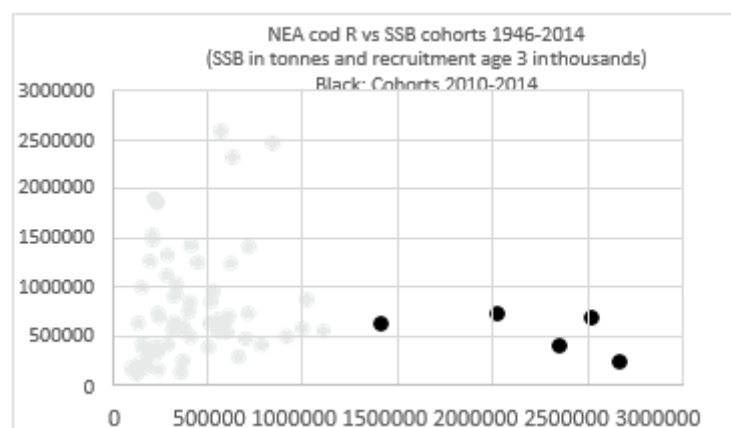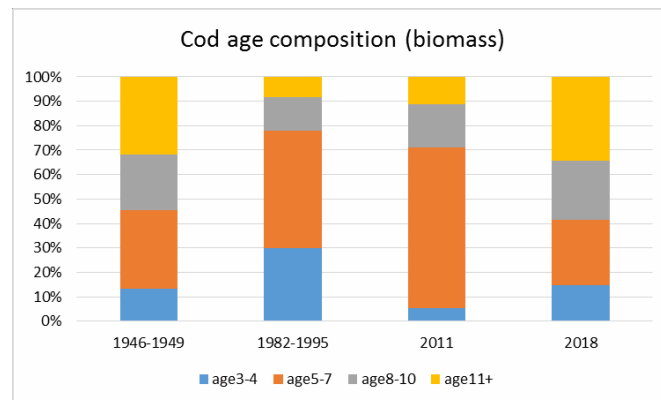
Cod expanded the area occupied during the period, as seen from the average distribution for three periods (2004-2009, 2010-2014, and 2015-2017, Figure 3.6.9). Higher catches of cod were distributed over larger area during the 2004-2009 period, while distribution was limited in the north and northeast Barents Sea. During the 2010-2014 period, higher catches of cod were observed mainly in the north and southeast, while their distribution extended northward and slightly north-eastward. Occupation of larger areas and redistribution of higher catches was most likely influenced by record high stock sizes, dominated by larger and older fish. During the 2015-2017 period, smaller catches of cod were taken and the area of occupation decreased slightly com- pared to the 2010-2014 period. Since 2004, ice free areas have generally increased in the northern Barents Sea, increasing areas of suitable habitat for cod and allowing record high production.
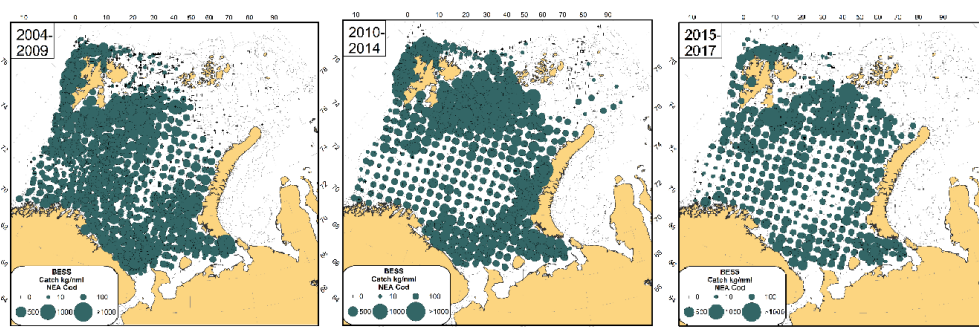
Figure 3.6.9. Distribution of cod catches (kg/nm) during August-September; averaged over 3 peri- ods (2004-2009, 2010-2014, and 2015-2017).

Figure 3.3.10 show the distribution of cod ≥50cm based on data from the BESS (January- March during 2008, 2011, and 2018. Note: the survey area was extended northwards in 2014 and coverage is often limited by ice conditions. Cod distribution observed during this survey increased throughout the period, but it is unknown when cod began to inhabit areas north of Bear Island and west of Svalbard during winter.

Figure 3.6.10. Distribution of cod larger than 50 cm during winter 2008, 2011, and 2018.

It should also be noted that during summer/autumn 2018 fishable concentrations of large cod (> 65 cm) were observed in the Jan Mayen area by a Norwegian long-liner; 450 tonnes were caught in total. This is a new development. As late as 2011, very low cod abundance (only 19 specimens in 9 trawl hauls) was observed during a survey in the area. Analyses of both otolith pattern and genetics showed this specimen to be a hybrid of Barents Sea and Icelandi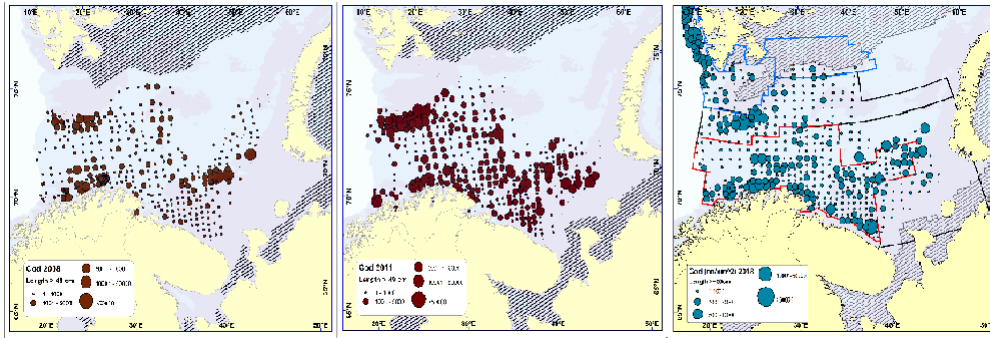c cod. An exploratory fishery will be conducted in this area during each quarter of 2019 to further investigate the spatial and temporal variation of cod in this area. Biological sampling and tagging will be carried out.

NEA haddock

Young-of-the-year

Estimated abundance of 0-group haddock varied from 75 million in 1981 to 91,606 mil- lion individuals in 2005 with a long-term average of 11,740 million individuals for the 1980-2017 period (Figure 3.6.11). In 2018, the total abundance index for 0-group had- dock was not estimated due to lack of coverage.
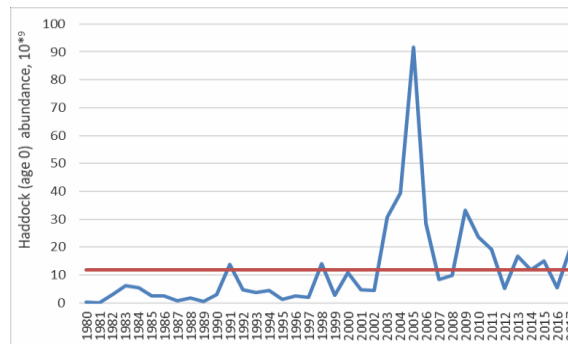
Figure 3.6.11. 0-group haddock abundance, corrected for trawl efficiency, in the Barents Sea 1980– 2017. Red line shows long-term mean for the period 1980–2017, while the blue line indicates 0- group abundance fluctuation.

In 2018, the western Barents Sea (west of the Norwegian-Russian border) was covered, and spatial indices were estimated for eight regions (South West, Bear Island Trench, Thor Iversen Bank, Hopen Deep, Svalbard South, Svalbard North, Central Bank, and Great Bank (ICES 2018 Annex). 0-group haddock were distributed mainly in western regions (South West and Bear Island Trench) (Figure 3.6.12). Highest abundance in these eight regions was observed in 2005, a year of record high 0-group abundance, and in 2009, when a very strong year class occurred. Low abundance of 0-group had- dock in 2018 indicates that a strong year class did not occur.

Figure 3.6.12. Percentages of 0-group haddock abundance in the South West, Bear Island Trench, Thor Iversen Bank, Hopen Deep, Svalbard South, and Svalbard North during the 1980–2018 period in the Barents Sea. More details about these spatial indices is given in ICES 2018 Annex 4.

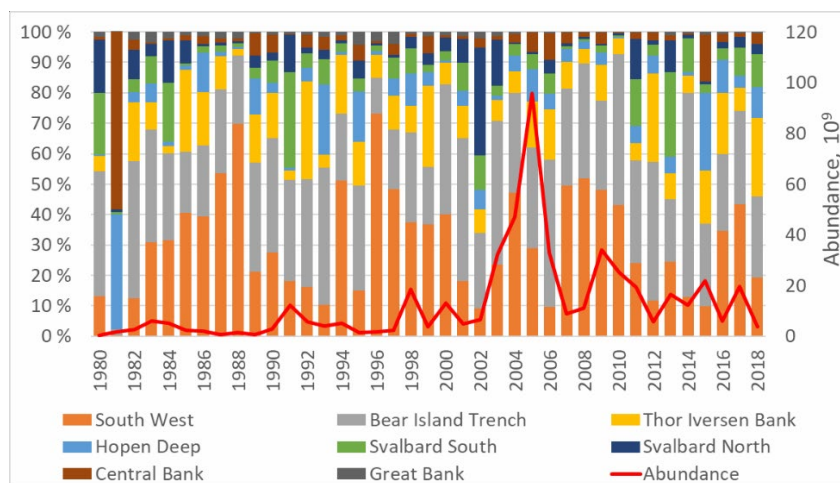During the last four decades 0-group haddock have been distribution in the western and central Barents Sea. The smallest area of occupation was observed in the 1980s, and has since increased. Size of area occupied was assosiated with year-class strength (Figure 3.6.13).
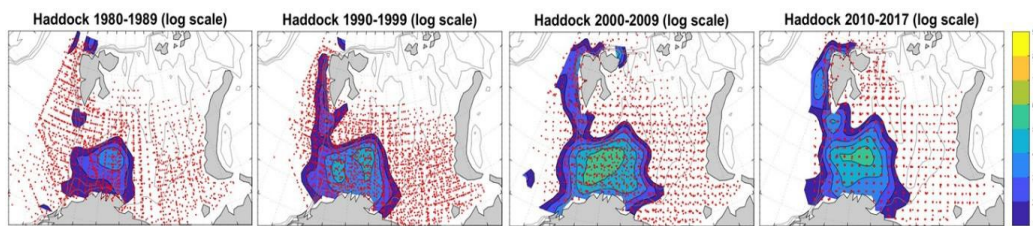
Figure 3.6.13. Distribution of 0-group haddock abundance in the Barents Sea during the 1980s, 1990s, 2000s, and 2010s. Abundance estimates were log-transformed (natural logarithms) before mapping. Fish density varied from low (blue) to high (yellow). Red dots indicated sampling loca- tions. The map is from Eriksen et al. (Progress in Oceanography, under revision).

Older haddock

The Northeast Arctic haddock stock reached record high levels in 2009–2013, due to very strong 2004-2006 year classes. Subsequent recruitment has normalized; the stock remains at a relatively high level but has declined in recent years. Forecasts based on survey indices indicate that abun- dant 2016 and 2017 year classes may increase stock size rapidly in future years if survival is good. (Figures 3.6.14 and 3.6.15). The large spawning stock did not, until 2014, result in strong year classes (Figure 3.6.16).

Figure 3.6.14. Haddock total stock and spawning stock development during the 1950-2018 period and forecast for 2019 from AFWG (ICES 2018).
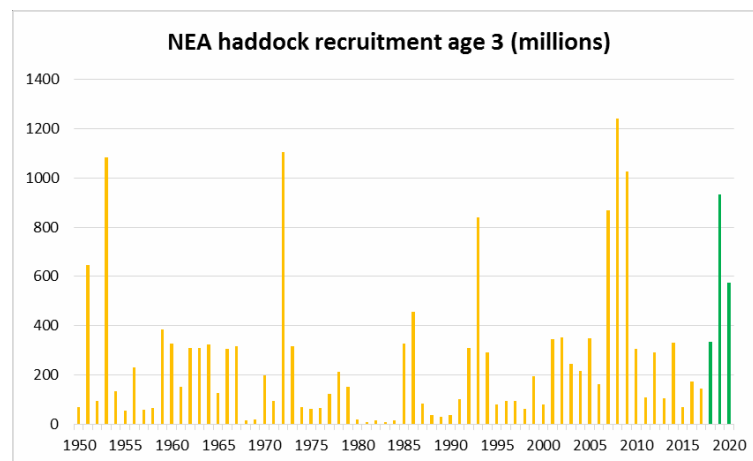
Figure 3.6.15 Recruitment of haddock during the 1950-2018 period and forecast for 2019-2020 from AFWG (ICES 2018).
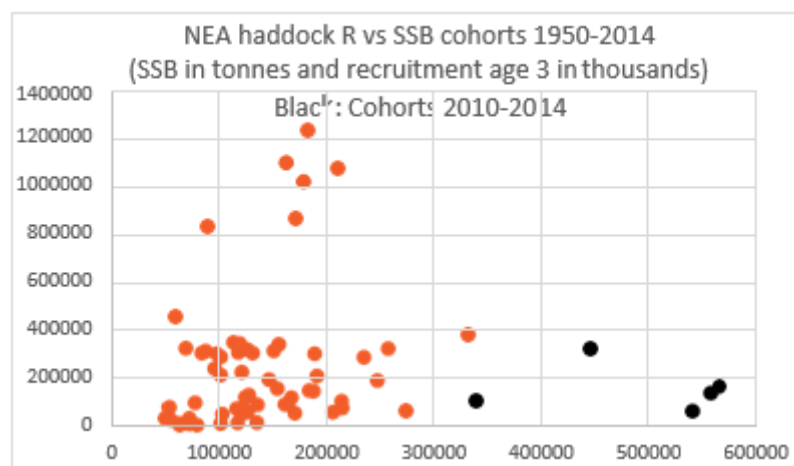
Figure 3.6.16. Spawning stock-recruitment plot for haddock cohorts 1950-2014. Cohorts 2010-2014 shown as black dots.
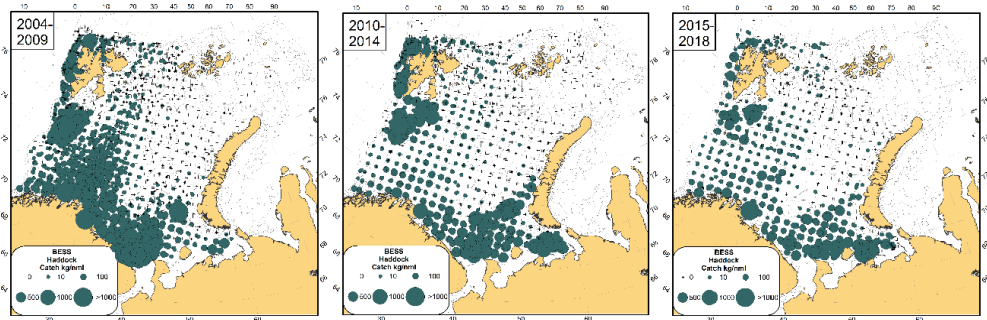
Figure 3.6.17. Distribution of haddock catches (kg/nm) during August-September averaged over 3 periods (2004-2009, 2010-2014, and 2015-2017).
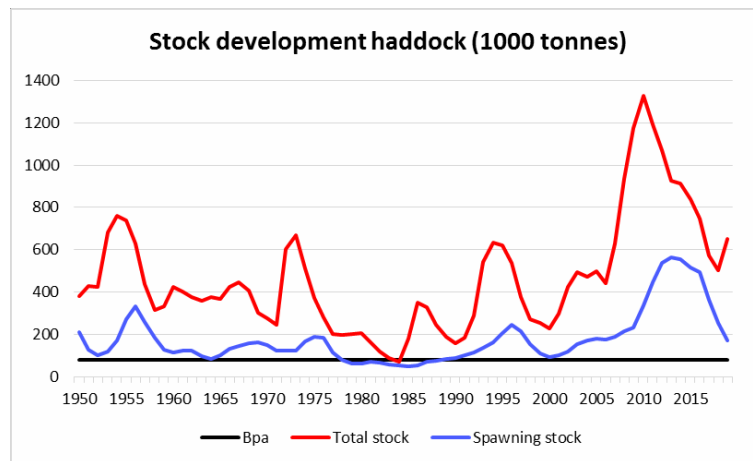
The distribution area of haddock expanded in the southeast from 2004 onwards (Figure 3.6.17). Figure 3.6.18 shows the distribution of haddock ≥ 50cm based on BESS data (January-March) from 2008, 2011, and 2018. Note that the survey area was extended northwards in 2014 and that coverage often is limited by ice extent. Haddock distribution observed during this survey increased during this period, but when haddock began to inhabit areas north of Bear Island and west of Svalbard during winter is un- known.
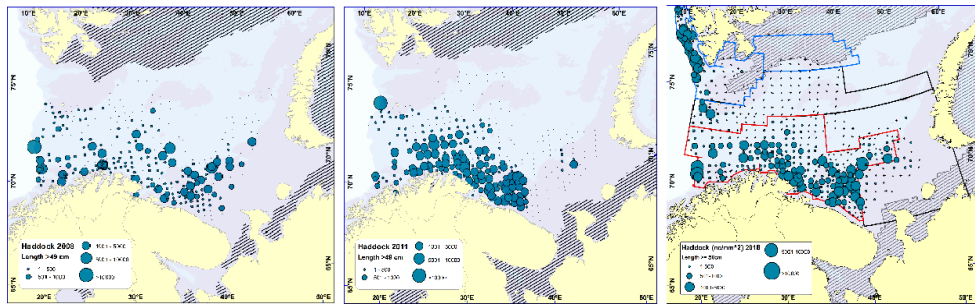
Figure 3.6.18. Distribution of haddock larger than 50 cm during winter 2008, 2011, and 2018.

Long rough dab

Young-of-the-year

An abundance index for 0-group fish is available for 2018 due to a lack of survey coverage. Figure 3.6.19 shows the time series for the 1980-2017 period.
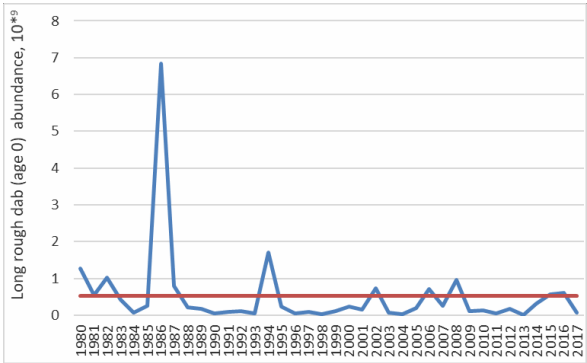
Figure 3.6.19. 0-group long rough dab abundance in the Barents Sea during the 1980-2017 period corrected for trawl efficiency. Red line shows the long-term average; the blue line indicates fluctuating abundance.

Older long rough dab

Older long rough dab (age 1+) are widely distributed in the Barents Sea. During the Russian Autumn-Winter Survey (October-December) and the BESS (August–September), major concentrations of long rough dab were observed in the central, northern, and eastern areas. Many small fish were observed in trawl catches especially in eastern areas during the 2015-2017 BESS. This is agrees with the CPUE index from the Russian Autumn-Winter Survey, which in 2017 was twice as high as the long-term average. It is difficult to track trends with this index, however; in 2016 and 2018 the survey was not performed, and in 2017 it was performed in a limited area where the main concentration of young long rough dab occurred. Excluding areas with low fish concentrations in calculations can lead to overestimates in this index (Figure 3.6.20). Long rough dab abundance estimates based on results from the BESS time-series have been relatively stable during the current decade. The 2018 index was not calculated due to limited survey coverage in the eastern region of the Barents Sea. (Figure 3.6.21).
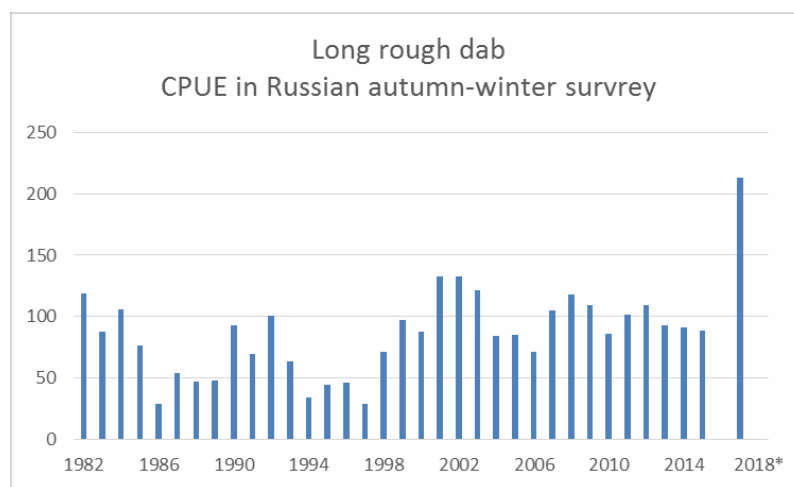
Figure 3.6.20. Estimated catch-per-unit-effort of long rough dab from the Russian Autumn-Winter Survey (October-December) during the 1982–2018 period. No survey coverage in 2016 and 2018 and limited survey coverage in 2017.
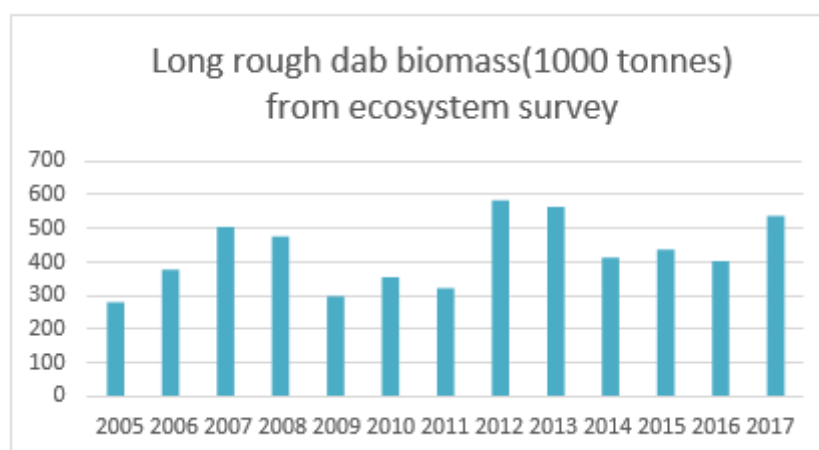
Figure 3.6.21. Stock biomass of long rough dab based on BESS data during the 2005–2017 period, calculated using bottom-trawl estimated swept area.

Greenland halibut

Young-of-the-year

The 2018 index for 0-group fish is not available due to lack of survey coverage.

Older Greenland halibut

The adult component of the stock was, as usual, mainly distributed outside the ecosystem survey area. In recent years, however, an increasing number of large Greenland halibut has been captured in deeper waters of the area surveyed by the BESS (Figure 3.6.22). Northern and northeastern areas of the Barents Sea serve as nursery grounds for the stock. Greenland halibut are also relatively abundant in deep channels running between the shallowest fishing banks. Figure 3.6.23 shows an index for Greenland halibut at the nursery grounds based on the BESS results north of 76.5°N, from northwest of Svalbard and east to Franz Josef Land (for details see Hallfredsson and Vollen 2015, WD 1 ICES IBPhali 2015).

The fishable component of the stock (length ≥45 cm) increased from 1992 to 2012 and has remained stable since that time (Figure 3.6.24). The harvest rate has been low and relatively stable since 1992.
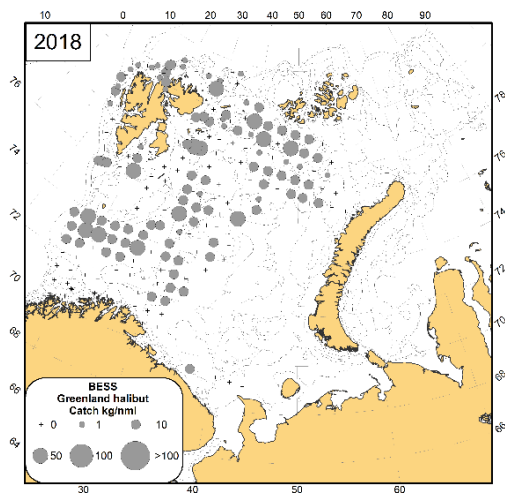
Figure 3.6.22 Greenland halibut distribution (specimens/nautical mile) during August–September 2018 based on the BESS data.
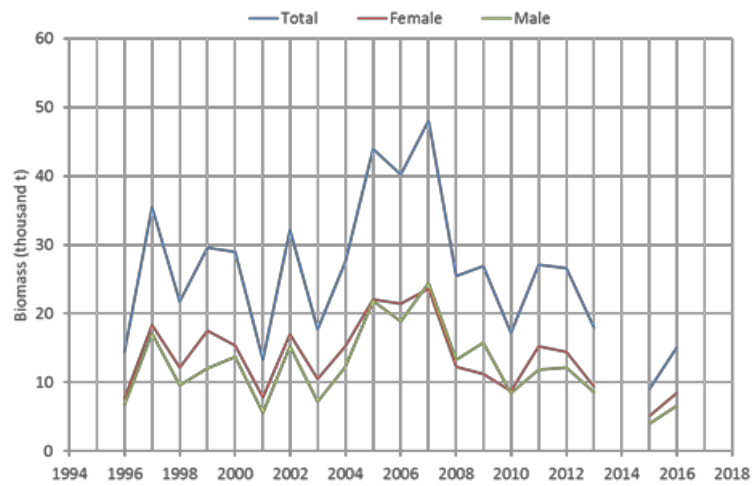
Figure 3.6.23. Biomass index for Greenland halibut at nursery areas; 2014 excluded due to poor area coverage.
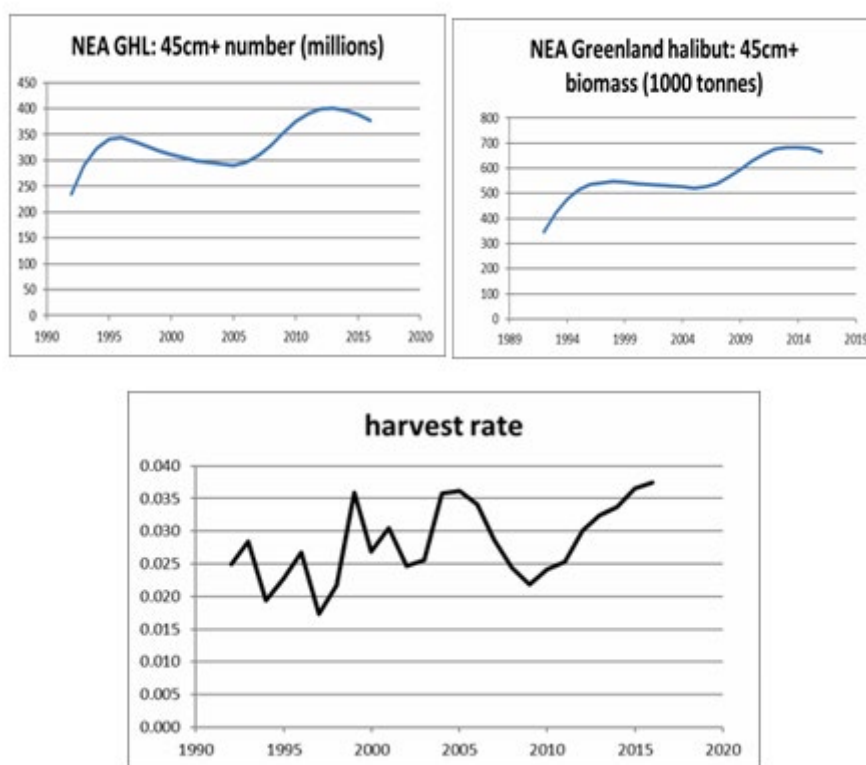
Figure 3.6.24. Northeast Arctic Greenland halibut: numbers (upper left); biomass (upper right) for 45+ cm Greenland halibut as estimated by the GADGET model; and estimated exploitation rates (lower center) during the 1992–2016 period (ICES 2017).

Deepwater redfish

Young-of-the-year

Estimated abundance of 0-group deepwater redfish varied from 6 million individuals in 2001 to 156,548 million in 2007 with an average of 60,307 million individuals for the 1980-2017 period (Figure 3.6.25). In 2018, the total abundance index for 0-group deep- water redfish were not esti- mated due to lack of survey coverage.
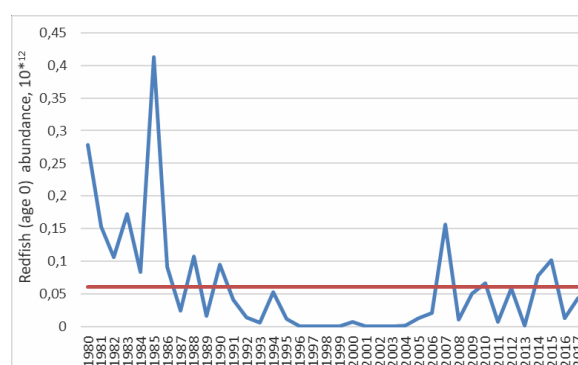
Figure 3.6.25. 0-group deepwater redfish abundance (corrected for trawl efficiency) in the Barents Sea during the 1980–2017 period. Red line shows the long-term average, while the blue line indicates 0-group abundance fluctuation.

In 2018, the western Barents Sea (west of the Norwegian-Russian border) was covered and spa- tial indices were estimated for eight regions (South West, Bear Island Trench, Thor Iversen Bank, Hopen Deep, Svalbard South, Svalbard North, Central Bank, and Great Bank (ICES 2018 Annex 4). 0-group deepwater redfish were distributed mainly in regions of Svalbard (South West, Bear Island Trench, Svalbard South, and Svalbard North (Figure 3.6.26). Highest abundance in these

eight regions was observed in years with strong year classes: 1980, 1985, and 2007. During the last 5 years, deepwater redfish have mainly been observed in Svalbard South and Svalbard North.
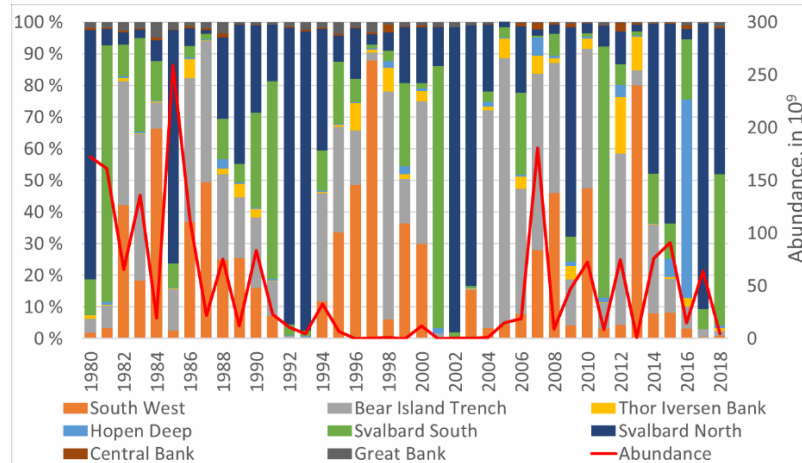
Figure 3.6.26. Percentage of 0-group deepwater redfish abundance in western, central, and northern regions of the Barents Sea during the 1980–2018 period. Red line shows total abundance for these eight regions.

Distribution of 0-group deepwater redfish has varied during the last four decades: it was largest during the 1980s; decreased during next two decades; and has increased during the 2010s (Figure 3.6.27). Size of area occupied was associated with occurrence or non-occurrence of strong year classes.
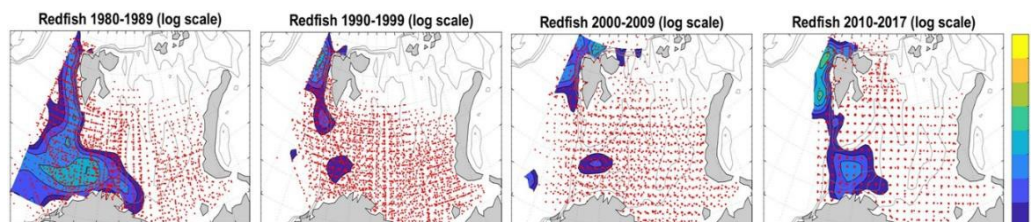
Figure 3.6.27. Distribution of 0-group deepwater redfish abundance in the Barents Sea during 1980s, 1990s, 2000s, and 2010s. Abundance estimates were log-transformed (natural logarithms) before mapping. Fish density varied from low (blue) to high (yellow). Red dots indicated sampling locations. The map is taken from Eriksen et al. (Progress in Oceanography, under revision).

Older deepwater redfish

In 2018, deepwater redfish were widely distributed in the Barents Sea. During the BESS and the winter survey, largest concentrations were observed, as usual, in western and north western parts of the Barents Sea. Biomass was higher during 2013–2018 than in preceding years. Geographic distribution of deepwater redfish during the 2018 BESS is shown in Figure 3.6.28. The area of coverage for redfish during BESS 2018 was almost complete. Most adult fish are observed in the Norwegian Sea. Stock development trends from the latest ICES AFWG assessment are shown in Figure 3.6.29. During the current decade the deepwater redfish stock biomass has remained relatively stable and varied around 1 million tonnes.
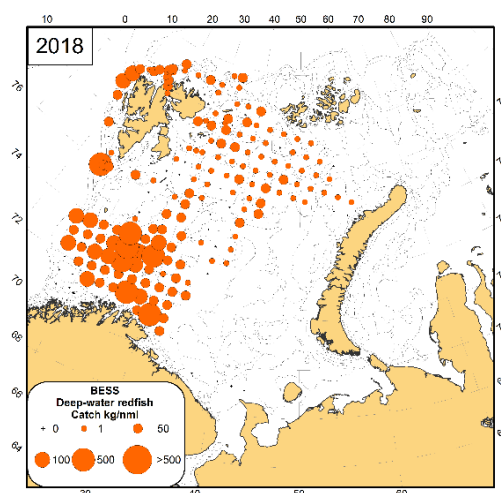
Figure 3.6.28. Geographic distribution of deepwater redfish during the 2018 BESS survey.
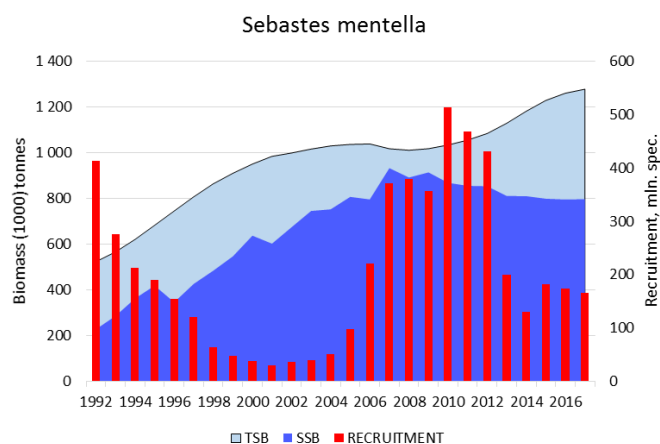
Figure 3.6.29. Results from a statistical catch-at-age model showing trends in total stock biomass (TSB) ('000s), spawning-stock biomass (SSB) and recruitment-at-age 2 (millions of individuals) during the 1992–2017 period for S. mentella in ICES Subareas 1 and 2 (ICES, 2018).

3.7 Zoogeographical groups of non-commercial species

E. Johannesen (IMR), T. Prokhorova (PINRO) and R. Primicerio (UIT)

During the 2018 Barents Sea Ecosystem Survey (BESS) 83 fish species from 28 families were recorded in pelagic and bottom trawl catches, some taxa were recorded at genus or family level only (Prokhorova et al 2019).

All recorded species belonged to seven zoogeographic group (Widely Distributed, South Boreal, Boreal, Mainly Boreal, Arcto-Boreal, Mainly Arctic and Arctic) defined in Andriashev and Chernova (1994). In the following only bottom trawl catches of non-commercial fishes were used. Both demersal (including bentho-pelagic) and pelagic (neritopelagic, epipelagic, bathypelagic) species were included (Andriashev and Chernova, 1994, Parin, 1968, 1988).

The survey coverage at BESS in 2018 was poor (Figure 3.7.1) so we cannot easily compare the abundance and distribution of zoogeographical groups in 2018 with previous years.
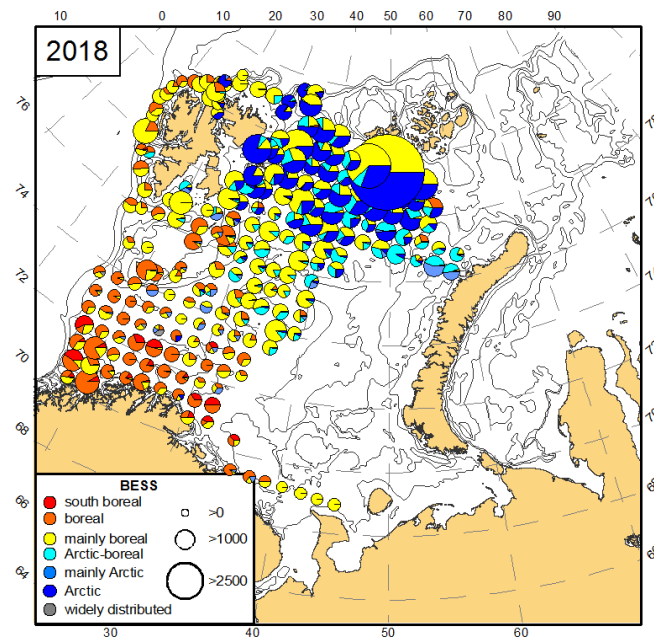
Figure 3.7.1 Distribution of non-commercial fish species from different zoogeographic groups during the ecosystem survey 2018. The size of circle corresponds to abundance (individuals per nautical mile, only bottom trawl stations were used, both pelagic and demersal species are included). Taken from the 2018 BESS survey report (Prokhorova et al 2019).

We calculated average catch rates by zoogeographical groups by TIBIA area (see section 2.1). These are presented in Figure 3.7.2. An increase in Mainly boreal species are evident in the Central Bank are, Southeastern Basin, Pechora Sea, North East, Great Bank, Franz Josef Land and the Victoria Trough area and a decline in catch rates Arctic species was evident in the Central Bank, Great Bank and Southeastern Basin and Pechora Sea. Our results are in agreement with findinga by e.g. Fossheim et al(2015), Johannesen et al (2017), and Frainer et al (2017) using different methods based on fewer years from the same survey.

A preliminary check to see how the zoogeographic groups which are primarily defined based on distribution in relation to water masses (Andriashev and Chernova 1994) correspond to a classification based on life history traits (see Frainer et al 2018 for details on the life history traits) reveal a relatively good consistency (Figure 3.7.3) but this needs to be further explored in detail, including also data on distribution within the Barents Sea and abiotic habitat variables. Three main clusters were identified, one included the most species and grouped most of the Arctic species, a second smaller group consisted of six species (one Boreal, one Arctic and four Mainly Boreal) whereas the third group consisted of Widely Distributed, South boreal, Boreal and Mainly Boreal species.
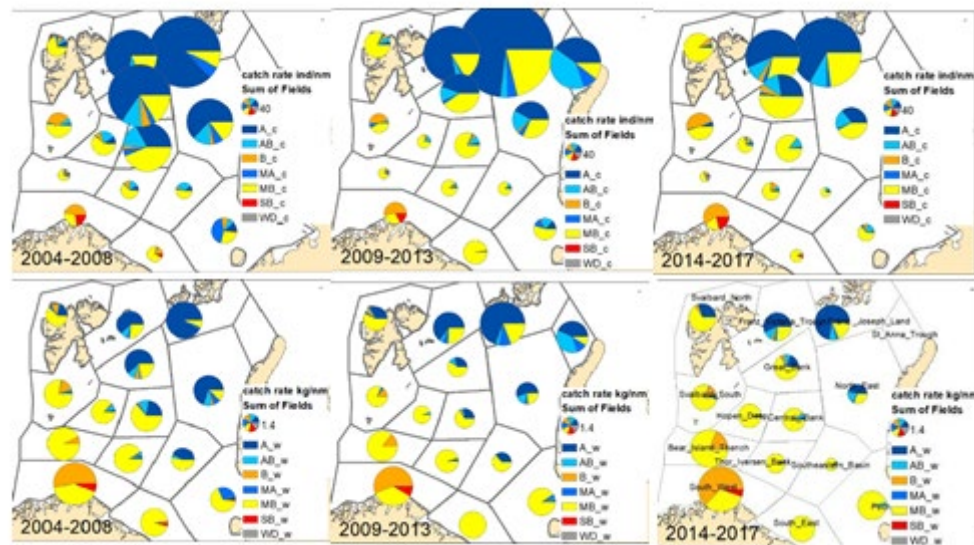
Figure 3.7.2. Catch rates by TIBIA area, first averaged by year and then by period (upper individuals per nautical mile, lower kg per nautical mile. Species included: Arctic: *Amblyraja hyperborea, Arctogadus glacialis, Artediellus scaber, Aspidophoroides olrikii, Eumicrotremus derjugini, Gaidropsarus argentatus, Liparidae, Triglops nybelini, Mainly Arctic: Cottunculus microps, Eumicrotremus spinosus, Gymnocanthus tricuspis, Icelus spp, Lumpenus fabricii, Arcto-boreal: Leptagonus decagonus, Osmerus mordax dentex, Triglops pingelii, Mainly boreal: Amblyraja radiata, Ammodytes marinus, Artediellus atlanticus, Bathyraja spinicauda, Brosme brosme, Cyclopterus lumpus, Gasterosteus aculeatus, Glyptocephalus cynoglossus, Hippoglossus hippoglossus, Leptoclinus maculatus, Lethenteron camtschaticum, Limanda limanda, Lumpenus lampretaeformis, Myoxocephalus scorpius, Rajella fyllae, Salmo salar, Pungitius pungitius, Boreal: Agonus cataphractus, Anisarchus medius, Argentina silus, Chimaera monstrosa, Enchelyopus cimbrius, Macrourus berglax, Maurolicus muelleri, Microstomus kitt, Molva molva, Myxine glutinosa, Pollachius pollachius, Rajella lintea, Triglops murrayi, Zeugopterus norvegicus, South Boreal: Gadiculus argenteus, Lophius piscatorius, Merlangius merlangus, Merluccius merluccius, Nansenia groenlandica, Phycis blennoides, Widely distributed: Arctozenus risso , Coryphaenoides rupestris, Etmopterus spinax, Diastobranchis capensis.*
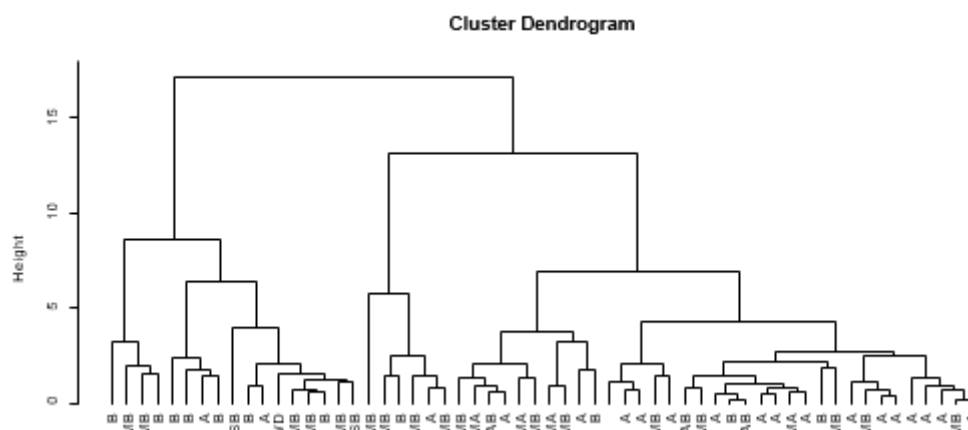
Figure 3.7.3 Cluster analysis based on life history traits of non-commercial fishes caught at BESS 2004-2017.

References

Andriyashev, A.P. and Chernova, N.V. 1995. Annotated list of fish-like vertebrates and fishes of the Arctic Seas and adjacent waters. Journal of Icthyology, 34: 435-456.

Fossheim M, Primicerio R, Johannesen E, Ingvaldsen RB, Aschan M and Dolgov AV. 2015. Recent warming leads to a rapid borealization of fish communities in the Arctic. Nature Climate Change , 5: 673–677.

Frainer A, Primicerio R, Kortsch S, Aune M, Dolgov AV, Fossheim M and Aschan MM. 2017. Climate-driven changes in functional biogeography of Arctic marine fish communities. PNAS, 114 (46): 12202-12207.

Johannesen E., Mørk H.L., Korsbrekke K., Wienerroither R., Eriksen E., Fossheim M., de Lange Weenck T., Dolgov A., Prokhorova T. and Prozorkevich D. 2017. Arctic fishes in the Barents Sea 2004-2015: Changes in abundance and distribution. Joint IMR/PINRO report series No 1. 2017. 46 p.

Parin,N.V. 1968. Ichthyophauna of the oceanic pelagial. "Nauka", Moscow, 185 p. (in Russian) Parin, N.V. 1988. Fishes of the open ocean. "Nauka", Moscow. 272 p. (in Russian)

Prokhorova T., Johannesen E., Dolgov A. and Wienerroither R. 2019. Zoogeographic groups. In: Survey report from the joint Norwegian/Russian ecosystem survey in the Barents Sea and adjacent waters, August-October 2018 (eds by van der Meeren, G.I and Prozorkevich D.). IMR/PINRO Joint Report Series, No. 2/2019.

Benthos: Inter-annual fluctuation of the fauna biogeographical structure

N.A. Strelkova (PINRO)

The biogeographical status of the Barents Sea can be temporally assessed by drawing the boundary between the Arctic and the Boreal areas for different time periods. The temporal fluctuation of this boundary reflects the water temperature impact on the bottom fauna. To visualize this boundary and areas with prevailing of Boreal and Arc- tic component of the fauna, the Biogeographical Index (BGI) (Manushin *et al.*, 2012) was used:

$$BGI = (Bb-Ba)/(Bb+Ba)$$

where: Bb – biomass of the boreal species; Ba – biomass of the Arctic species.

BGI shows the ratio between the boreal and the arctic components of the fauna. The value of the BGI varied from -1 (only Arctic species) to +1 (only boreal species). In the case of no, or equal, amounts of boreal and Arctic species, the BGI for a station is zero. These stations where BGI=0 are the hypothetical boundary between the Atlantic boreal and Arctic biogeographical regions.

The distribution of the BGI values in the Barents Sea during the period between 2005- 2017 shows that Arctic species dominate in the north and eastern Barents Sea while the southern and western parts are dominated by Boreal species, and that these two regions are separated by a temporally varying Boreal-Arctic boundary (fig. 3.7.4).
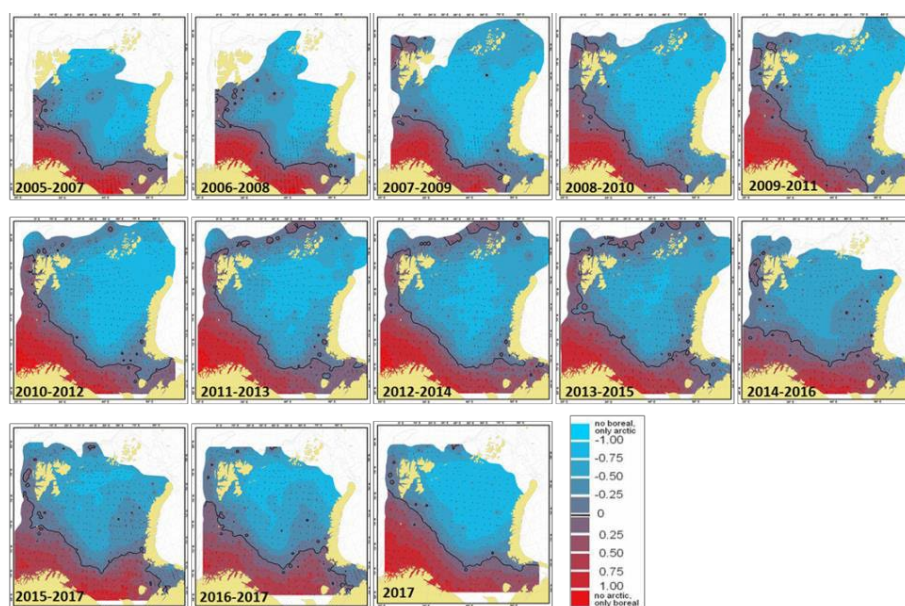
Figure 3.7.4. The temporal distribution of the Arctic (blue) and boreal (red) regions of the Barents Sea from 2005 to 2017. The black line shows the position of the boreal-Arctic boundary.

The location of the boreal-Arctic boundary closely follows the three main currents of Atlantic water in the Barents Sea: along the western slope of the Barents Sea shelf, to the Central Bank and along the western shelf of the Novaya Zemlya archipelago (fig. 3.7.4).

The position of the boreal-Arctic boundary varies between years and locations (fig. 3.8.1). In the southeastern part of the Sea, the positions of the boundary changed in the order of 150-200 nm during 2005-2017, about 150 nm on Spitsbergen Bank, and less than 50 nm in the central part of the sea. The inter-annual fluctuation in the boreal-Arctic boundary position is most distinct in the south-eastern part of the Barents Sea and demonstrates two periods – during 2006-2010 the boundary moved towards the south-west (upper five pictures in fig. 3.8.1), while during the next six years (2011-2016) it moved back in a northwards direction.

The temporal variation of the mean BGI, calculated for the south-middle part of the Barents Sea constrained by 69-76° N and 20-55° E, demonstrates a prevalence of the Arctic species during 2007-2014, with a minimum value in 2010, followed by a Boreal prevalence during 2014-2017 (fig. 3.7.5).

There are the reason to suggest that both the minimum value of BGI and shift in the boundary between the Arctic and the boreal areas toward the most southern position in 2009-2011 may be caused by the 2003 year, coldest since beginning of the century, i.e. six-eight years before, also resulting in the largest negative anomaly of mega- benthos biomass in 2010 (see section 3.4.1).
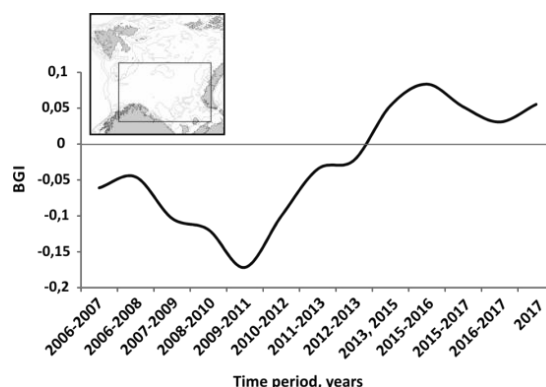
Figure 3.7.5 The temporal variation of the mean BGI calculated for the area of the Barents Sea con- strained by 69-76° N and 20-55° E (embedded map) during 2006-2017. The years 2005, 2014 and 2018 are excluded from the calculation due to the lack of data.

So the spatial distribution of the BGI (fig. 3.7.5) shows that in current period, the majority of the Barents Sea can be defined as an intermediate state between an Arctic and a boreal region due to the wide distribution of boreal species to the north and Arctic species in the south. Dynamic of the mean BGI (Figure 3.7.5) within the central-southern part of the Barents Sea, suggests that from around 2013-2014 the largest part of the Barents Sea can be characterized as a predominantly boreal intermediate area.

3.8   Marine mammals and seabirds

3.8.1   Marine mammals

By Nils Øien and Roman Klepikovskiy

The summer abundance of minke whales in the Barents Sea has recently increased from a stable level of about 40,000 animals to more than 70,000 animals. Also, humpback whale have in- creased their summer abundance in the Barents Sea from a low level prior to year 2000 to about 4,000 animals thereafter. The other cetacean populations have remained stable in numbers. In 2018, 2119 individuals of nine species of marine mammals were sighted during the Barents Sea Ecosystem Survey (BESS) in August-October 2018, as well as an additional 77 individuals which were not identified to species.

During the Barents Sea ecosystem survey in August-October 2018 marine mammal observers were onboard all vessels. In total, 2119 individuals of 9 species of marine mammals were ob- served and an additional 77 individuals were not identified to species. The observations are pre- sented in Table 3.8.1.1 and distributions in the Figures 3.8.1.1 (toothed whales) and 3.8.1.2 (baleen whales).

As in previous years, white-beaked dolphin (*Lagenorhynchus albirostris*) was the most common species (more than 70% of all individual registrations). This species was widely distributed in the survey area and expanded somewhat to the northeast com- pared to the 2017 survey. The highest densities of this species apparently overlap with the distributions of capelin, codfishes, herring and polar cod in the survey area.

Although in modest numbers, the toothed whales were also represented by sperm whales (*Physe- ter macrocephalus*), harbour porpoises (*Phocoena phocoena*), and killer whales (*Orcinus orca*) besides the numerous white-beaked dolphins. The sperm whales were observed at deeper waters along the continental slope and other parts of the re- search area westward of 27°E. The harbour por- poise and killer whale sightings were mainly made in the southern parts of the research area.

Table 3.8.1.1. Numbers of marine mammal individuals observed from the RV "Johan Hjort", "G.O. Sars", "H. Hansen" and "Vilnyus" during the ecosystem survey in 2018.

Order/ suborder	Name of species	G.O.Sars	J. Hjort	H. Hansen	Vilnyus	Total	%
Cetacea/ Baleen whales	Fin whale	12	50	36	7	105	4.8
	Humpback whale	2	172	6	22	202	9.2
	Minke whale	7	123	37	16	183	8.3
	Blue whale	-	-	1	-	1	0.05
	Unidentified whale	9	18	3	3	33	1.5
Cetacea/ Toothed whales	White-beaked dolphin	725	219	217	439	1600	72.9
	Harbour porpoise	-	12	-	1	13	0.6
	Killer whale	-	-	-	2	2	0.1
	Sperm whale	1	7	4	-	12	0.5
	Unidentified dolphin	24	-	14	-	38	1.7
	Unid. small cetacean	4	-	-	-	4	0.2
Pinnipe-dia	Ringed seal	-	1	-	-	1	0.05
	Unidentified seal	-	1	1	-	2	0.1
	Total sum	784	603	319	490	2196	100

The baleen whale species minke (*Balaenoptera acutorostrata*), humpback (*Megaptera novaeangliae*) and fin (*Balaenoptera physalus*) whale were quite abundant as 22 % of the total animals registered belonged to these species. There main concentrations were found east of Svalbard. There were fewer observations of minke whales in 2018 than in 2017, and although they are widely distributed over all the survey area, their highest concentrations were in the northern areas with spatial overlap with capelin and polar cod aggregations.

The humpback whales were as usual recorded mainly in the waters to the east of the Svalbard Archipelago and in the area of the Great Bank. In 2018, more humpback whales were observed than in the previous year, however, the sizes of the groups of these whales were in general smaller and no more than 5 individuals. The humpback whales were recorded in areas with aggregations of capelin, often with fin and minke whales in the same areas. In 2018, fewer fin whales were observed during the survey as compared to 2017.

In previous years, blue whales (*Balaenoptera musculus*) were observed north of Spitsbergen, especially off the Hinlopen Strait. During the 2018 survey only one blue whale was sighted, on the shelf west of Bellsund, Spitsbergen.

The only identified pinniped observed during the 2018 ecosystem survey was a ringed seal (*Phoca hispida*). Harp seal (*Pagophilus groenlandicus*), bearded seal (*Erignathus barbatus*), walrus (*Odobenus rosmarus*) and polar bears (Ursus maritimus) were not observed during the survey, most likely due lack of ice coverage in the surveyed area.
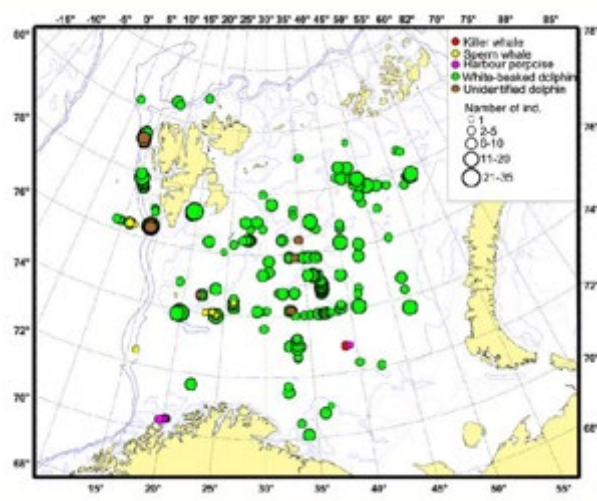
Figure 3.8.1.1. Distribution of toothed whales in August–October 2018.
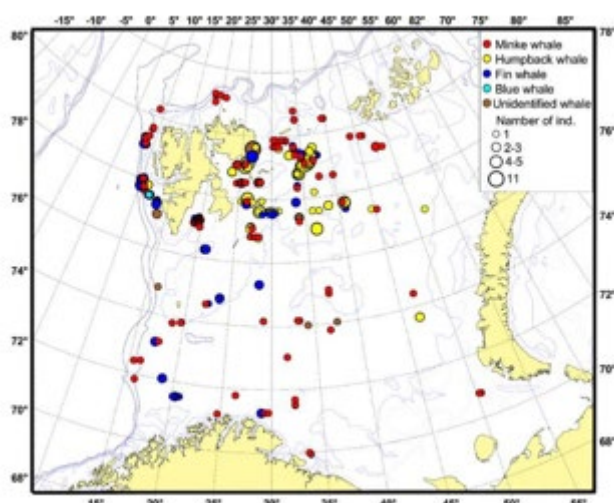
Figure 3.8.1.2. Distribution of baleen whales in August–October 2018.

Since the late 1980ies Norway has conducted visual sighting surveys in the Northeast Atlantic with minke whales as target species to estimate summer abundance of the species as well as other cetacean species. The surveys have been run as mosaic cover- ages of the total survey area over six-year periods. In the Barents Sea the species most often observed during these surveys have been the minke whale, followed by white-beaked dolphins, harbour porpoises, humpback whales and fin whales. The impression is that minke whales are abundant in the northern and eastern areas during sum- mer. Harbour porpoises are mostly observed in the southern parts of the area and we know that they are associated with the coastal areas along Kola and the fjord systems. Humpback whales are mainly sighted in the northwest and associated with the capelin distribution. The white-beaked dolphins are observed in the southern and central parts of the sur- vey area, especially over the Sentralbanken. From these surveys a series of abundance estimates can be compiled to illustrate the status over a time period of nearly 30 years. Over the period from about 1995 to 2015 the summer abundance of minke whales has been quite stable but has recently shown a considerable increase to the present 73,000 animals (**Figure 3.8.1.3**). Also, hump-back whales have shown a large increase in summer abundance in the Barents Sea from very low

numbers prior to year 2000 to around 4,000 animals afterwards. Other cetacean species have shown relatively stable abundances within the Barents Sea over the survey period.
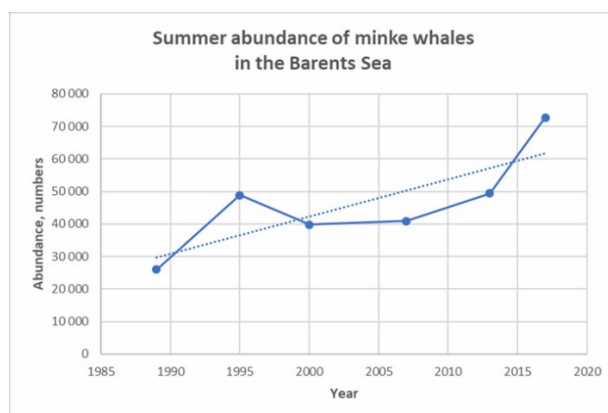
Figure 3.8.1.3. Summer abundance of minke whales in the Barents Sea over the past nearly 30 years.

3.8.2 Seabirds

By Per Fauchald

About six million pairs from 36 seabird species breed regularly in the Barents Sea (Barrett et al. (2002), Table 3.8.2.1). Allowing for immature birds and non-breeders, the total number of seabirds in the area during spring and summer is about 20 million individuals. 90% of the birds belong to only 5 species; Brünnich's guillemot, little auk, Atlantic puffin, northern fulmar and black-legged kittiwake. The distribution of colonies is shown in Figure 3.8.2.1. Colonies in the high-Arctic archipelago are dominated by little auks, Brünnich's guillemots and kittiwakes. These birds utilize the intense secondary production that follows the retreating sea ice. Little auks feed mainly on lipid rich Calanus species, amphipods and krill while Brünnich's guillemots and black-legged kittiwakes feed on polar cod, capelin, amphipods and krill. The seabird communities, as well as their diet change markedly south of the polar front. In the Atlantic part of the Barents Sea, the seabirds depend more heavily fish, including fish larvae, capelin, I-group herring and sandeels. The shift in diet is accompanied by a shift in species composition. In the south, Brünnichs' guillemots are replaced its sibling species, the common guillemot. Large colonies of puffins that largely sustain on the drift of fish larvae along the Norwegian coast, are found in the southwestern areas.
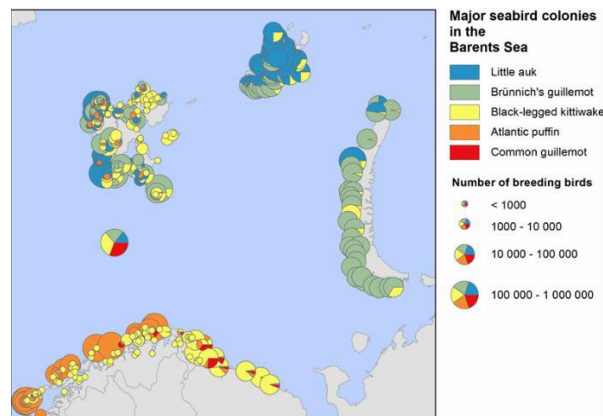
Figure 3.8.2.1. Major seabird colonies in the Barents Sea. Data compiled from SEAPOP (www.seapop.no), Fauchald *et al.* (2015), Anker-Nilssen *et al.* 2000 and The Seabird Colony Registry of the Barents and White Seas.

Table 3.8.2.1. Seabirds in the Barents Sea sorted by breeding population size in decreasing number. Breeding pairs are from Strøm *et al.* (2009). Observations on BESS 2018 are the observations from Norwegian and Russian vessels during the ecosystem survey in 2018.

Species name	Scientific name	Breeding pairs	Observations on BESS 2018
Brünnich's guillemot	*Uria lomvia*	1 250 000	8854
Little auk	*Alle alle*	>1 010 000	3231
Atlantic puffin	*Fratercula arctica*	910 000	605
Northern fulmar	*Fulmarus glacialis*	500 000-1 000 000	37645
Black-legged kittiwake	*Rissa tridactyla*	682 000	6914
Common eider	*Somateria mollisima*	157 000-159 000	2
Herring gull	*Larus argentatus*	122 600	842
Common guillemot	*Uria aalge*	104 000	92
Arctic tern	*Sterna paradisaea*	65 000	86
Black guillemot	*Cepphus grylle*	58 000	37
Great black-backed gull	*Larus marinus*	22 930	542
Razorbill	*Alca torda*	19 600	21
Mew gull	*Larus canus*	14 200	0
Glaucous gull	*Larus hyperboreus*	9 000-15 000	1505
Great cormorant	*Phalacrocorax carbo*	11 570	0
European shag	*Phalacrocorax aristotelis*	6 350-6 400	0
European storm-petrel	*Hydrobates pelagicus*	1 000-10 000	0

Lesser Black-backed gull	*Larus fuscus*	3 500	2
Ivory gull	*Pagophila eburnea*	2 200-3 750	28
Northern gannet	*Morus bassanus*	1 900-2 150	92
Arctic skua	*Stercorarius parasiticus*	1 150	80
King eider	*Somateria spectabilis*	1 000	0
Common tern	*Sterna hirundo*	>1 000	0
Heuglin's Gull	*Larus heuglini*	600-1 100	77
Great skua	*Stercorarius skua*	540-1 100	55
Leach's storm petrel	*Oceanodroma leucorhoa*	100-1 000	0
Steller's eider	*Polysticta stelleri*	10-100	0
Sabine's gull	*Xema sabini*	1-10	1
Great northern diver	*Gavia immer*	0-3	0
Long-tailed duck	*Clangula hyemalis*	?	1
Black scoter	*Melanitta nigra*	?	0
Velvet scoter	*Melanitta fusca*	?	0
Red-breasted merganser	*Mergus serrator*	?	0
Black-throated loon	*Gavia arctica*	?	2
Long-tailed skua	*Stercorarius longicaudus*	?	10
Pomarine skua	*Stercorarius pomarinus*	?	846
Sooty shearwater	*Puffinus griseus*	0	25
Ross's gull	*Rhodostethia rosea*	0	0

Population monitoring in Norway and Svalbard has revealed a marked downward trend for several important seabird species the last 30 years, including puffin, Brünnich's guillemot and kittiwake (Figure 3.8.2.2). The population of common guillemot was decimated in the 1980s mainly due to a collapse in the capelin stock combined with low abundance of alternative prey. The population has increased steadily since then. The status and trends of the large populations of seabirds in the Eastern Barents Sea is less known.
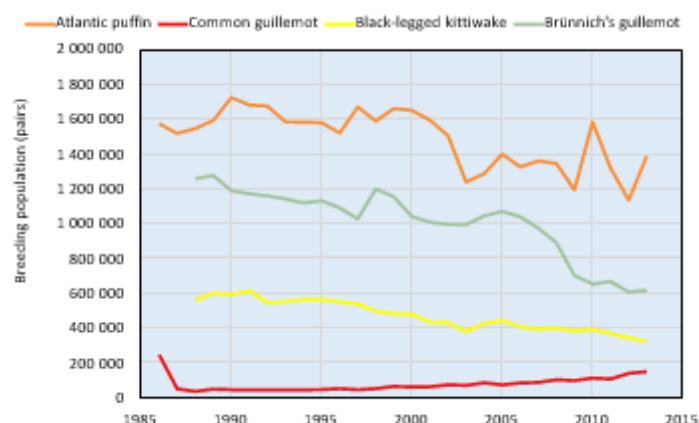
Figure 3.8.2.2: Size and trends of puffin, guillemots and kittiwake populations in the Western Barents Sea (Norway and Svalbard incl. Bjørnøya). Data from Fauchald et al. (2015).

Recent tracking studies (see seatrack.seapop.no) show that after the breeding season, most of the populations of kittiwakes, puffins, little auks, Brünnich's guillemots and common guillemots from colonies along the Norwegian and Russian coasts stay or migrate in to the Barents Sea to feed and molt, possibly increasing the total number of birds in the area in August and September. During September and October, the populations of Brünnich's guillemots and little auks from colonies in West-Spitsbergen and Bjørnøya start their migration westward, crossing the Norwegian Sea to reach their wintering grounds in the Northwest Atlantic. The large north-eastern populations, i.e. little auks and Brünnich's guillemots breeding in East Spitsbergen, Franz Josef Land and Novaya Zemlya, over-winter in the Barents Sea. Kittiwakes leave the Barents Sea in late autumn to spend the winter in the Northwest Atlantic or the North Sea. Common guillemots stay in the south-eastern and south-central parts of the Barents Sea throughout the non-breeding period. Finally, only a few puffins from the eastern colonies over-winter in the Barents Sea, while the rest of the population roam over large areas in the central North Atlantic. Most seabird populations return to the colonies around March and April.

Broadly, the spatial distribution of seabirds during the ecosystem survey in September reflects the climatic gradient from a boreal Atlantic climate with common guillemots, puffins, herring and black-backed gull in the south and west, to an Arctic climate with little auks, Brünnich's guillemots and kittiwakes in the north and east (Figure 3.8.2.3). Seabirds have been surveyed uninterruptedly on Norwegian vessels in the western part of the Barents Sea since 2004. Based on the minimum annual survey extent, the abundance (Figure 3.8.2.4) of different species and the centre of gravity of the spatial distribution (Figure 3.8.2.5) was calculated for each year.
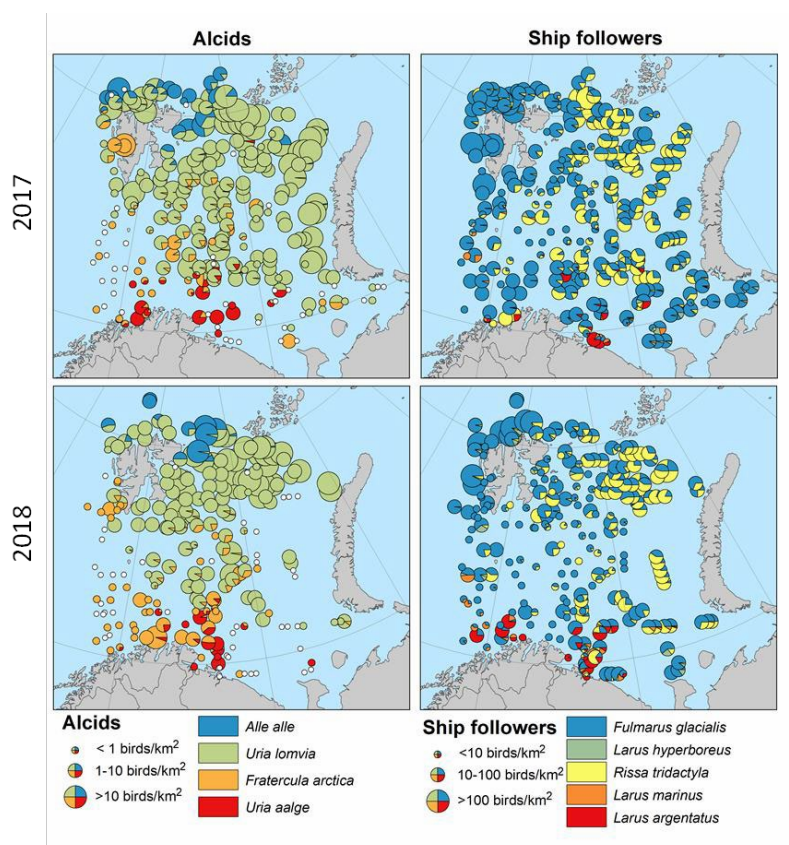
Figure 3.8.2.3. Density of seabirds during the Barents Sea ecosystem surveys in 2016 (top) and 2017 (bottom). Left panel is the distribution of auks (little auk, Bünnich's guillemot, puffin and common guillemot). Right panel is the distribution of shipfollowers (fulmar, glaucous gull. Kittiwake, black-backed gull and herring gull).

Note the large fluctuations in the abundance estimates from the at-sea surveys (Figure 3.8.2.4). These fluctuations do not necessarily reflect the observed population trends from the colonies (cf. Figure 2). This discrepancy could be related to the fact that the at-sea abundances are influenced by annual differences in migration pattern which would mask the general population trends. There is not yet an evidence for a wide- spread "borealization" (Fossheim et al. 2015) of the seabird communities in the Barents Sea, although there is a tendency for a slight northward displacement of puffins, kittiwakes and glaucous gull (Figure 3.8.2.5). During the last 14 years, the different seabird species seem to stay relatively fixed within their respective geographic niche.
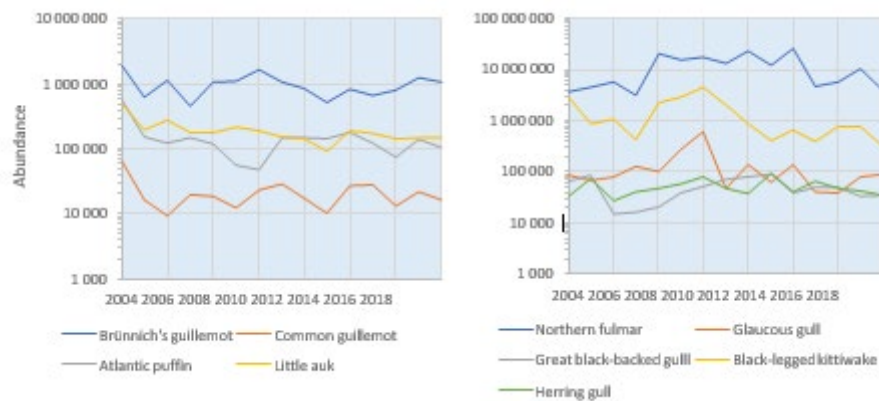
Figure 3.8.2.4. Abundance of auks (left) and shipfollowers (right) in the Western Barents Sea during the ecosystem surveys 2004-2018.
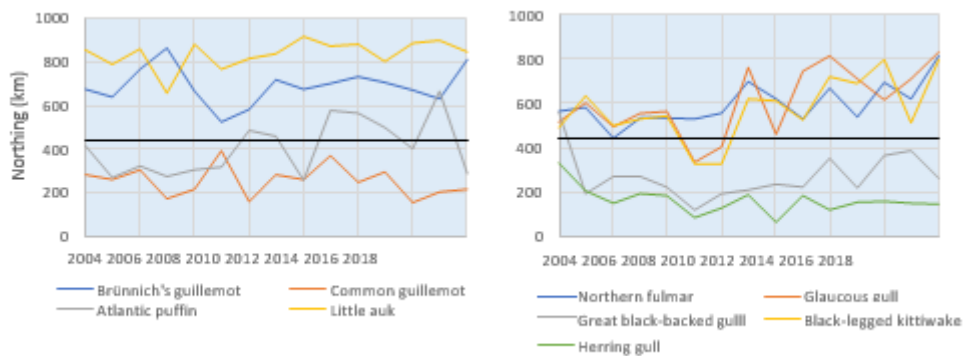
Figure 3.8.2.5. Center of gravity in the north direction of the distribution of auks (left) and shipfolowers (right) in the Western Barents Sea during the ecosystem surveys 2004-2018. Black line indicates the position of Bjørnøya.

References

Anker-Nilssen, T., Bakken, V., Strøm, H., Golovkin, A.N., Bianki, V.V. and Tatarinkova, I.P.

2000. The Status of Marine Birds Breeding in the Barents Sea Region. Norsk Polarinstitutt Rapportserie, 113. 213 pp.

Barrett, R.T., Anker-Nilssen, T., Gabrielsen, G.W. and Chapdelaine, G. 2002. Food consumption by seabirds in Norwegian waters. - ICES Journal of Marine Science, 59: 43-57.

Fauchald, P., Ziryanov, S. V., Strøm, H. and Barrett, R. T. 2011. Seabirds of the Barents Sea. Pages 373-394 in Jakobsen T, Ozhigin VK (Eds) The Barents Sea. Ecosystem, Re- sources, Management. Tapir Academic Press, Trondheim, Norway.

Fauchald, P., Anker-Nilssen, T., Barrett, R., Bustnes, J. O., Bårdsen, B. J., Christensen- Dalsgaard, S., Descamps, S., Engen, S., Erikstad, K. E., Hanssen, S. A., Lorentsen, S.- H., Moe, B., Reiertsen, T., Strøm, H. and Systad, G. H. (2015). The status and trends of seabirds breeding in Norway and Svalbard. NINA report 1151: 84 pp.

Fossheim M, Primicerio R, Johannesen E, Ingvaldsen RB, Aschan M and Dolgov AV. 2015. Re- cent warming leads to a rapid borealization of fish communities in the Arctic. Nature Climate Change 5, 673–677.

Strøm, H., Gavrilo, M.V., Krasnov, J.V. and Systad, G.H. 2009. Seabirds. In Joint Norwegian- Russian Environmental Status 2008 Report on the Barents Sea Ecosystem. Part II – Complete report, pp. 67-73. Ed. by J.E. Stiansen, O. Korneev, O. Titov, P. Arneberg, A. Filin, J.R. Hansen, Å. Høines and S. Marasaev. IMR/PINRO Joint Report Series, 3/2009.

3.9 Anthropogenic impact

3.9.1 Fisheries

By B.Bogstad (IMR), A. Russkikh (PINRO), Y. Kovalev (PINRO), K.Nedreaas (IMR)

Total catches

Fishing has the largest anthropogenic impact on fish stocks in the Barents Sea, and thereby, on the functioning of the entire ecosystem. However, observed variations in both fish species and ecosystem are also strongly affected by climate and trophic inter- actions. During the last decade, catches of most important commercial species in the Barents Sea and adjacent waters of Norwegian and Greenland Sea varied around 1.5– 3 million tonnes and has decreased in the last years (Figure 3.9.1.1).

Catch variation within the region depends on both the ecosystem dynamics effecting commercial stocks and management considerations. Agreed-upon harvest control rules exist for all major species, which are usually applied when setting TACs; actual catch removals tend to be very close to the agreed TACs.
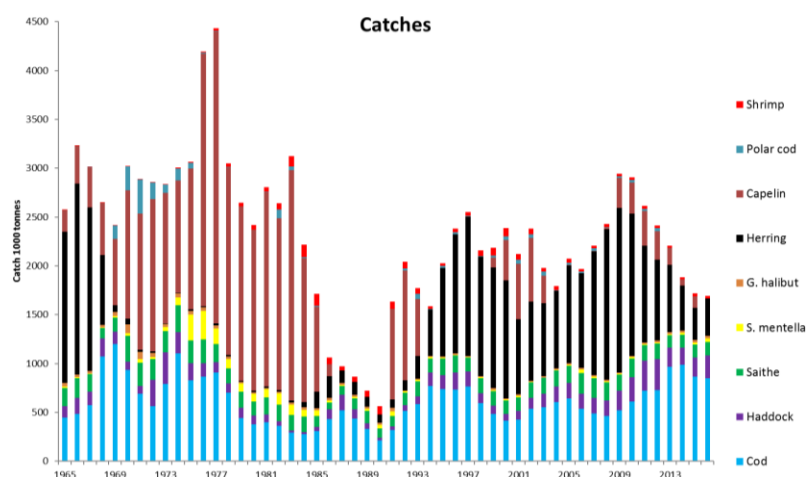
Figure 3.9.1.1. Total catches of the most important stocks in the Barents Sea and adjacent waters of Norwegian and Greenland Sea (including catches in all of ICES Division 2.a, i.e. along the Norwegian coast south to 62°N) from 1965–2017. Catches of Norwegian spring-spawning herring outside ICES Division 2.a are also included. Minor catches of other stocks are taken in the Barents Sea (see ICES website).

Fishing mortalities and harvesting strategies

Fisheries influence the ecosystem by removing substantial quantities of fish for human consump-tion and for other purposes. A fishery is not considered sustainable if it impairs recruitment to the fish stock. Single species management often focuses on measuring stock status through benchmarks called biological reference points (BRPs). BRPs for single species management are usually defined in terms of fishing mortality rate (F), total-stock biomass (TSB), spawning-stock biomass (SSB), and in terms of target and limit reference points. Limit BRPs suggest maximum F levels and minimum B levels that should adhered to. These BRPs are then compared to estimates of F and B from stock assessments to determine the state of the fishery and suggest management actions.

Fishing above the limiting reference point for fishing mortality (F_{lim}) will eventually bring the spawning stock down to B_{lim}; below which recruitment will be impaired. As such, F_{lim} may hence be used as an indicator for unsustainable exploitation which may negatively influence both the

stock and the ecosystem. Keeping F below F_{lim} and the stock above B_{lim} may, however, not provide sufficient protection. Proliferation of smaller and younger adults within a stock as result of high fishing pressure, results in a lower stock reproductive potential; compared to a stock having adults with a wider range of sizes and ages. The harvest rate and fishing pattern should hence fit with these biological requirements.

Recently the Maximum Sustainable Yield (MSY) concept was implemented in ICES advisory work. The ICES approach to fisheries advice integrates the precautionary approach, maximum sustainable yield, and an ecosystem approach into one advisory framework. The goal is, in accordance with the aggregate of international guidelines, to inform policies on sustainable fisheries removals from productive fish stocks within healthy marine ecosystems. Maximum sustainable yield is a broad conceptual objective aimed at achieving the highest possible yield over an infinitely long period of time. For several stocks, MSY reference points have been identified and implemented into fishery management strategies.

Furthermore, a fishery may not be considered optimal if the fish are caught too early, i.e. if the net natural growth potential is not utilized. This is called growth overfishing and makes the total yield less than it would be if the fish had been allowed to grow to a reproductive size/age. Introduction of minimum fish catch size limits and selective gears are the most common management measures to avoid growth overfishing.

Larvae and juveniles of all groundfish species are important predators on zooplankton. Accordingly, it is important that a healthy marine foodweb have sufficient plankton production to support plankton-eating invertebrate and fish species, as well as production at higher trophic levels, including: fish species; seabirds; marine mammals; and humans. For an ecosystem approach to management of commercial fish stocks it is essential to consider production at all trophic levels from a multispecies perspective.

Cod, haddock and saithe

Barents Sea stocks of cod, haddock, and saithe all have fishing mortality (F) based management plans which are largely followed by managers when setting TACs; all are currently harvested close to or below MSY (Figure 3.9.1.2), and all are above B_{pa} at present. Several variants of harvest control rules (HCR) for cod and haddock were tested by ICES in 2016. A new harvest control rule for cod, with increasing F at high stock sizes, was adopted by the joint Russian-Norwegian Fisheries Commission in autumn 2016. The HCR for haddock was not changed. The current HCR for saithe was set by Norway in 2013.
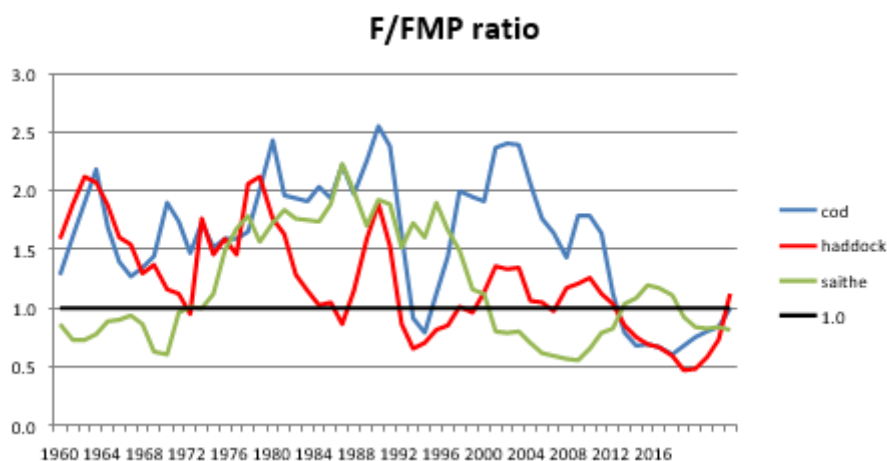

Figure 3.9.1.2. Annual fishing mortalities of the northeast Arctic cod, haddock and saithe stocks relative to fisheries management plan (FMP), i.e. the level used in the management plans for these stocks when SSB>Bpa (and SSB<2*Bpa for

cod) (ICES 2018). Note that saithe is mainly found along the Norwegian coast and off the coast south of the Barents Sea – little in the Barents Sea itself.

The exploitation rate has during some periods been critically high. Because of the harvest control rules, better regulation, and enforcement, this problem has been reduced in recent years. However, the recent increased exploitation rate for cod requires careful monitoring. The 2019 TAC for cod was set 50 kt above the advice from ICES and corresponds to an expected fishing mortality of 0.50 (not shown in Figure 3.9.1.2).

The large cod stock in recent years has caused concern about it being 'too large' relative to food availability, and ecosystem carrying capacity. Thus far, cod population dynamics appear little affected by the large stock size, but the question remains valid. The introduction of a harvest control rule to increase F levels at high stock sizes could be a step taking such concerns into account. However, the concept of a stock being 'too large' is not, at present, incorporated in the ICES advice framework; although, such issues are well recognized, e.g. in management of freshwater fisheries and wildlife.

Capelin

The capelin fishery is managed through a target escapement strategy. MSY for capelin will depend strongly on size of the cod stock, and offers little meaning within a single-species context. There was no fishery for capelin in the Barents Sea during 2004–2008 due to poor stock condition. During 2009–2013 the stock was sufficiently large to support a quota between 200 000 and 400 000 tonnes. After which time, both stock and catch decreased, and there was a 'mini-collapse' of the stock; the fishery was closed during 2016–2017. The fishery reopened in 2018 with TAC set at 205 000 tonnes. However, in autumn 2018 a decreasing of capelin stock was found again. In accordance with the current HCR, fishery in 2019 was not recommended.

Since 1979, the capelin fishery has been regulated through quotas set using a harvest control rule enforced by the Norwegian-Russian Fishery Commission. The harvest control rule is considered by ICES to be in accordance with precautionary and ecosystem approaches to fisheries management. Being a forage fish in an ecosystem where two top predators (cod and haddock) are currently at high levels, the capelin stock is now under heavy predation pressure. The fishery is restricted to the prespawning period (mainly February–March) and exploitation is regulated based on a model that incorporates natural mortality, including predation from cod. A minimum landing size of 11 cm has been in force since 1979. The management plan's harvest control rule is de- signed to ensure that SSB remains above the proposed B_{lim} of 200 000 metric tonnes (with 95% probability).

Greenland halibut

For Greenland halibut, no limit reference points have been suggested or adopted. The assessment is still considered to be uncertain due to problems with the age-reading and input data quality. The exploratory assessment is accepted as indicative for stock trends. Although many aspects of the assessment remain uncertain, fishery-independent indices of stock size from research surveys indicate an increase in stock size over the last decade, which now appears to be levelling off. Due to poor recruitment, some decrease in stock size is expected in the coming years. Therefore, it is important not to increase the exploitation rate and catch above the present level. Reconstruction of historical (pre-1992) stock and exploitation levels is needed to provide a stronger basis to determine reference points and develop sound of harvest control rules.

Beaked redfish (*Sebastes mentella*)

Analytical assessments and advice are provided for ICES Divisions 1 and 2 combined. The fishery for *S. mentella* (beaked redfish) operates in national and international waters, and is managed under different schemes and by different management organizations. A pelagic fishery for *S. mentella* has been conducted since 2004 in the Norwegian Sea outside the EEZ. This fishery is

managed by the Northeast Atlantic Fisheries Com- mission (NEAFC). A new directed demersal and pelagic fishery has been permitted in the Norwegian Economic Zone since 2014, and is managed by the Joint Norwegian- Russian Fisheries Commission (JNRFC). The 44th Session of JNRFC decided to split the total TAC among countries as follows: Norway: 72%, Russia: 18%, Third countries: 10% (as bycatch in the fishery protection zone at Svalbard (Spitsbergen): 4.1%, and international waters of the Norwegian Sea (NEAFC-area): 5.9%). This split was recon- firmed at the 48th session of JNRFC in 2018, but there is no agreement be-tween JNRFC and NEAFC concerning this split.

This is mostly a directed fishery; while part of the TAC is set aside to cover bycatch by Norway, Russia, and third-party countries. The geographical distribution of Norwegian catches during 2017 is shown in Figure 3.9.1.3. The patterns of fleet selectivity at age indicate that most of the fish captured by the demersal fleet are of age 11 years and older, while the pelagic fleet mostly captures fish of age 14 and older. The demersal fleet selectivity appears shifted towards later ages only in 2014.
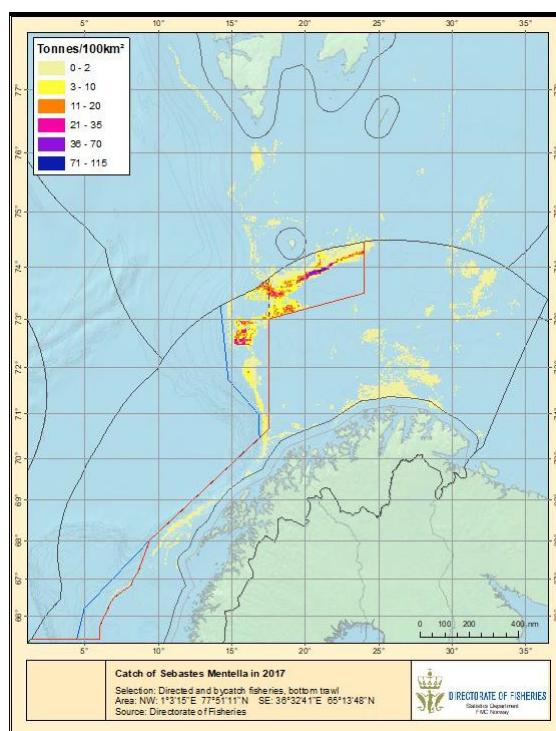
Figure 3.9.1.3. *Sebastes mentella* **in Divisions 1 and 2. Location of** *S. mentella* **catches by Norwegian fishing vessels in 2017, both in a directed fishery and as bycatch.**

ICES advice on beaked redfish in subareas 1 and 2 is to be provided every third year. Based on the JNRFC request, ICES in 2018 evaluated of possible management plans for this stock. A harvest control rule (HCR) with Btrigger = 450 000 t and F19+ = 0.06 has been evaluated and proposed, but has not formally been agreed. According to this rule, the TAC for 2019 was set to 53 757 t. The HCR should be re-evaluated in 2023 after the next surveys on mature *S. mentella* in the Norwe-gian Sea, which are planned for 2019 and 2022.

Golden redfish (*Sebastes norvegicus***)**

An ICES Benchmark Workshop was also held for Sebastes norvegicus (golden redfish) at the beginning of 2018. No limit reference points have yet been adopted. SSB has been decreasing since the 1990s and is currently at the lowest level in the time-series. Fishing mortality is high, but there are some signs of improved recruitment. For many years, ICES has advised no directed fishing on this stock, given the very low SSB (below any possible reference points) and poor

recruitment. Most catch of this stock is bycatch. The fishery is largely concentrated on the mature individuals. With a currently estimated SSB of around 23,000 tonnes, and a Fmsy of 0.05, one would expect a sustainable catch to be in the order of 1,000 to 1,500 tonnes. The current catches are well above this level. A stock rebuilding plan is needed. Sebastes norvegicus is currently on the Norwegian Redlist as a threatened (EN) species according to the criteria given by the International Union for Conservation of Nature (IUCN). Red-listing is understood to mean that a species (or stock) is at risk of extinction.

Polar cod (*Boreogadus saida*)

There has been little economic interest in developing a fishery for polar cod; no fishery has been conducted in recent years. Stock size as measured in the BESS survey, has also been at very low levels, except for a one-year peak in 2016. Reliable information on the polar cod stock size in 2018 is not available, but it is assumed to be at a lower level. The historical fishery was conducted mainly by Russia, and took place in late autumn when concentrations of polar cod were targeted during southward spawning migrations along the coast of Novaya Zemlya.

Wolffish (Catfish)

Three species of wolffish: Atlantic wolffish (*Anarhichas lupus*), Spotted wolffish (*Anarhichas minor*), and Northern wolffish (*Anarhichas denticulatus*) are taken mostly as by-catch in fisheries for gadoids in the Barents Sea, but also in a directed longline fishery. From 1905 to 1950, international catches of wolffish in the Barents Sea and along the northern Norwegian coast increased from 100 to 14 000 tonnes. Until 1998, annual landings were between 6000 and 44 500 tonnes. Large catches during 1997–2001 were primarily due to intensive targeted fishing for northern wolffish related to bycatch regulations on other valuable species (e.g. Greenland halibut) and a growing Russian market. After 2001, total wolffish catch north of 62°N decreased; but has improved slightly in recent years, reaching 25 862 tonnes in 2017. Russian catches increased from about 13 000 tonnes — a level maintained over several years — to 18 000 tonnes in the past two years. Norwegian catches have been around 6000 tonnes in recent years (Figure 3.9.1.6). Northern and spotted wolffish comprise more than 90% of total wolffish catch in the Barents Sea. Atlantic wolffish are mainly caught in the coastal zone, but also beyond the coastal region.
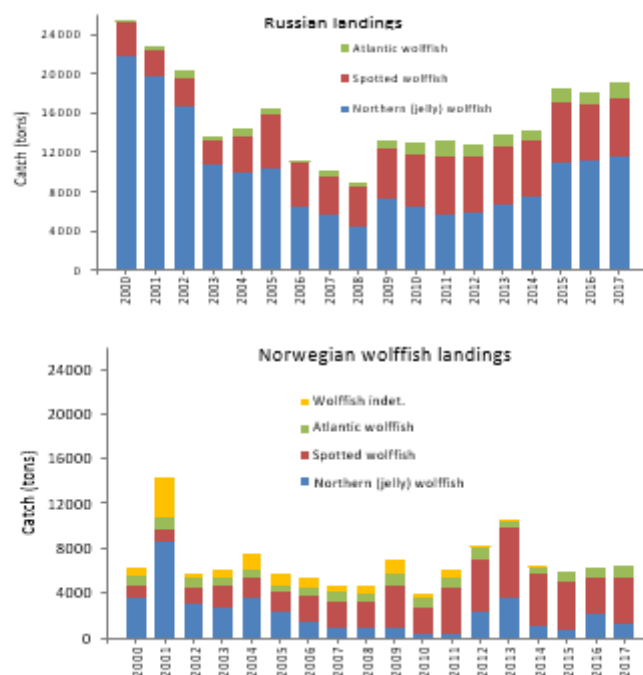
Figure 3.9.1.4. Russian (above) and Norwegian (below) official landings of the different wolffish species north of 62°N in 2000–2017.

Other fish species

Information on the species composition of the Norwegian fisheries north of 67°N is available from the Norwegian Reference Fleet (NRF), i.e. 15 high seas and 24 coastal fishing vessels contracted by the Institute of Marine Research. Such data are now routinely collected from these vessels' fishery each day or every other day. The impact of fishing activity on non-regulated species and on the ecosystem will be a subject for further research.

Gullestad *et al.* (2017) presents practical implementation of the Ecosystem Approach to Fisheries Management (EAFM) in Norway. This involves defining management objectives and developing simple and efficient tools to: obtain an overview of management needs; prioritize these needs; integrate broader conservation issues; and ensure stakeholder involvement.

Species of economic interest not mentioned in this chapter, include: tusk, ling, f grenadiers, Atlantic halibut, other flatfish, lumpsucker, hake, pollack, whiting, Norway pout, argentines, salmon, dogfish, skates, and molluscs.

3.9.2 Catches of shellfish

Northern shrimp (*Pandalus borealis*)

D.V. Zakharov (PINRO)

Norwegian and Russian vessels harvest northern shrimp over the stock's entire area of distribution in the Barents Sea. Vessels from other nations are restricted to trawling shrimp only in the Svalbard zone and the Loophole — a piece of international waters surrounded by the EEZs of Norway and Russia. No overall TAC has been set for north- ern shrimp, and the fishery is regulated through effort control, licensing, and a partial TAC in the Russian zone only. The regulated minimum mesh size is 35 mm. Bycatch is constrained by mandatory sorting grids, and by temporary closures in areas with high bycatch of juvenile cod, haddock, Greenland halibut, redfish, and shrimp (<15 mm car- apace length or <6 cm total length). Catches have varied between

19 000 and 128 000 tonnes per year since 1977. Since the mid-1990s, a major restructuring of the fleet toward fewer and larger vessels has taken place. Since 1995, average engine size of a shrimp vessel in ICES Divisions 1 and 2 increased from 1000 HP (horse power) to more than 6000 HP in the early 2010s, and the number of fishing vessels has declined markedly. Overall catch decreased from approximately 83 000 tonnes since 2000, re- flecting reduced economic profitability in the fishery. After a low of about 20 000 tonnes in 2013, catches again began to increase and reached about 34 000 tonnes in 2015, but decreased to 30 000 tonnes in 2016 and 2017 before increasing considerably to about 55 000 t in 2018. The 2018 stock assessment indicated that the stock has been fished sustainably, and has remained well above precautionary reference limits throughout the history of the fishery. Accordingly, ICES used the MSY-approach to advice a 2019 TAC of 70 000 metric tonnes (ICES 2018x).
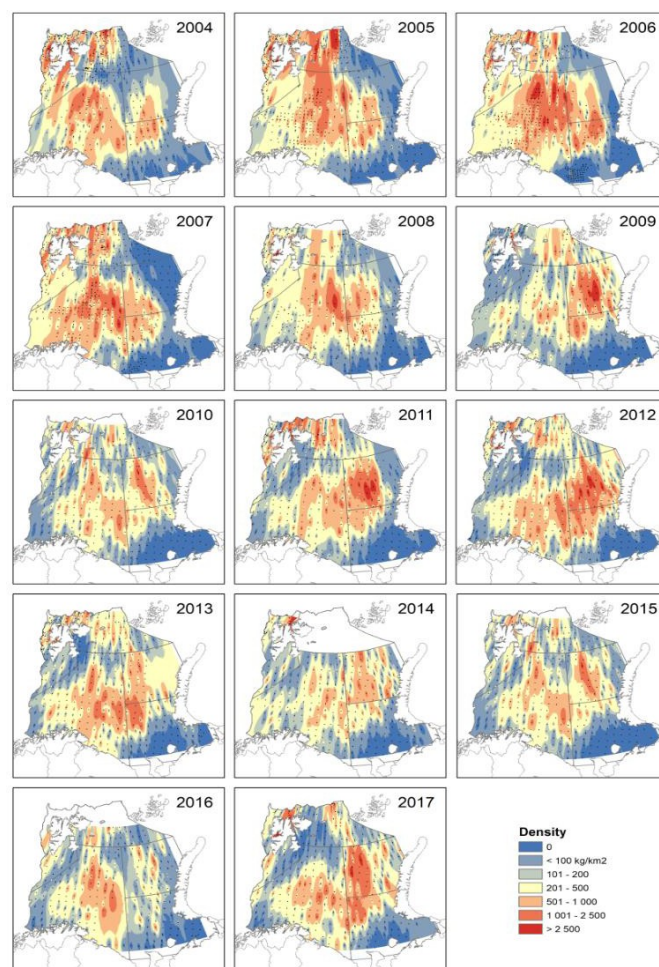
Figure 3.9.2.1 Shrimp density by year from inverse distance weighted interpolation (Fisher *et al.* 1987) between trawl stations (black dots) for the BESS data.

Geographical distribution of the stock in 2009–2015 was more easterly compared to previous years (fig. 3.9.2.1). As results, catch levels from some of the more traditional western fishing grounds have declined. Recent reports indicate lower catch rates than would be expected given the overall good stock condition. This may be related to operation costs for a relatively small fleet to move away from more traditional fishing grounds, and to find new grounds with commercially viable shrimp concentrations.

Fisheries for northern shrimp in the Barents Sea and waters adjacent to Spitsbergen Archipelago have been carried out since the 1950s. The largest catches were recorded in the mid-1980s (more than 120 000 tonnes) and during 1990–1991, 2000 (approximately 80 000 tonnes). Since 2005, total

annual catch of northern shrimp in this area have remained at the 20 000- 40 000 thousand tonnes level (Fig. 3.9.2.2) until 2017.

Figure 3.9.2.2 Total biomass index and catch of the northern shrimp in the Barents Sea and waters around Spitsbergen archipelago in 1982–2017 (Zakharov, 2017 with editions).

Trawl surveys of northern shrimp stocks have been carried out in the Barents Sea since 1982. During the 2005–2016 period, the stock was relatively stable (fig. 3.9.2.2).
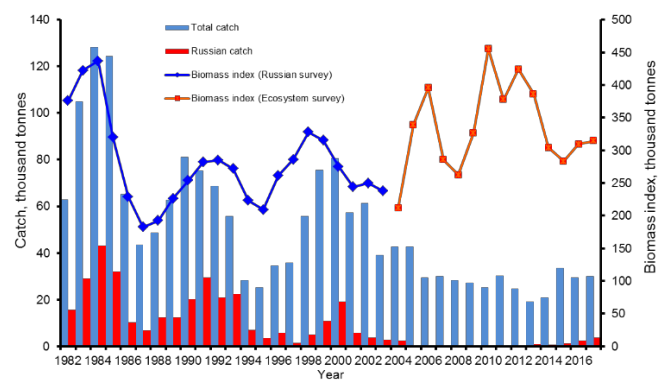
In 2017, estimated total biomass (method of squares) of northern shrimp was 314.2 thousand tonnes; 1.5% higher than in 2016, and 8% lower than the long-term average.

Red king crab (*Paralithodes carntschaticus*)

Red king crab is managed separately in the NEZ and REZ.

The commercial fishery for red king crab in the Russian Economic Zone of the Barents Sea has been carried out since 2004. Russian Fisheries Regulations stipulate that males with carapace width greater than or equal to 150 mm can only be caught using traps.

Heavy exploitation of the stock during 2005–2006 led to a decrease in the commercial component of the red king crab population, and reduced productivity in the fishery. In 2011, decreased fishery pressure prompted population growth, and subsequent stabilization of the commercial stock. Total catch also increased in subsequent years (fig. 3.9.2.3); in 2016, total catch of red king crabs in Russian Economic Zone was 8.3 thou- sand tonnes (Table 3.9.2.1).

Figure 3.9.2.3. Commercial stock index and the total catch of the red king crab in the Russian Economic Zone of the Barents Sea in 2006–2016 (Bakanev and Stesko, 2018). Data of 2018 is a forecast.

Table 3.9.2.1. The main parameters of the red king crab Russian fishery in 2006-2016 (Bakanev and Stesko, 2017).

	Total catch

Year	Commercial stock index, thousand tonnes	thousand ind.	thousand tonnes	Mean weight of commercial crab, kg
2006	73.3	3 082	12.639	4.1
2007	54.9	2 667	10.934	4.1
2008	39.6	2 266	9.291	4.1
2009	22.5	1 971	6.309	3.2
2010	21.4	1 313	3.940	3.0
2011	28.4	1 276	3.702	2.9
2012	39.0	1 736	5.209	3.0
2013	54.8	1 784	5.531	3.1
2014	94.8	1 712	5.995	3.5
2015	90.4	1 725	6.381	3.7
2016	82.5	2 075	8.300	4.0

One of the most detailed trap surveys to assess distribution of the red king crab commercial stock was conducted in 2013. Results from this survey indicated the densest concentrations of commercial sized male crabs (more than 1000 ind./km²) was recorded on Rybachya Bank and Kildinskaya Bank, in the eastern part of Murmansk Rise, and in the southern part of North Kanin Bank (fig. 3.9.2.4). In other parts of this area, the abundance of commercial sized males varied from 100 to 500 ind./km² (fig. 3.9.2.4). Subsequently, aggregations of fishable crabs shifted eastward to the western part of the Kanin-Kolguev Shallow. The most eastern extent of red king crab distribution was recorded in 2015 and 2017. Two adult individuals (male and female with clutch) in eastern Pechora Sea near Vaygach Island, and the southwestern coast of Novaya Zemlya Archipelago. This change in distribution could be caused by both migration to find new food resources and climatic warming.
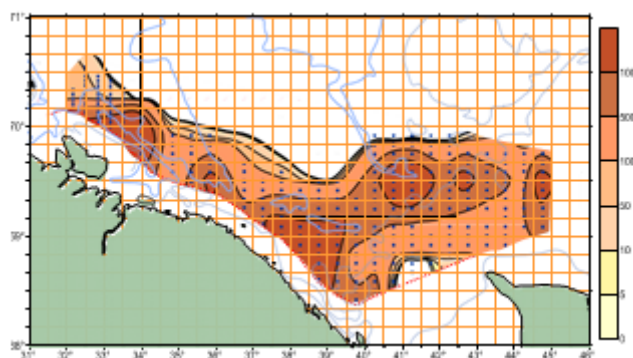

Figure 3.9.2.4. Distribution of the commercial stock of the red king crab (commercial males, ind./km2) in autumn 2013 in Russian Economic Zone of the Barents Sea according to assessment trap's survey (Bakanev and Stesko, 2017).

In 2016, ten Russian vessels fished red king crabs in the eastern Barents Sea, the Murmansk Rise, and Kanin Bank using rectangular and trapezoidal traps. The largest catches were obtained at southeastern Murmansk Rise outside the 12-mile coastal zone. In 2016, the commercial stock index for red king crab was 82.5 thousand tonnes (Table 3.9.2.1, Bakanev and Stesko, 2017).

The Norwegian fishery for the red king crab (RKC) is subjected to two different management regimes; a vessel quota fishery in the quota regulated area (QRA) and a free fishery with a discard ban in the free fishing area (FFA) (See Sundet & Hoel 2016, for detailed information).

The Norwegian fishery for the RKC have taken place since 1994, but the commercial fishery started in 2002. In 2008 there was a dramatic change in the management of this fishery with the introduction of an annual vessel quota in tons, minimum legal-size restrictions fishery for both male and female crabs on 130 mm carapace length and trap limits of 30 traps among other things. Since then, the annual total quotas (TAC) has varied between 900 and 2000 tons (table 3.9.2.2). Number of participating vessels have increased since then and were close to 600 in 2018 (figure

3.9.26). This fishery is strictly monitored and the landings each year were always identical to or close the annual TAC (Table 3.9.2.2).

The fishery in the FFA has varied much between years and has mainly taken place in western Finnmark, close to the western border of the QRA (figure 3.9.2.5).

Table 3.9.2.2. Recommended TAC, fixed TAC and landings of male and female red king crabs from the Norwegian quota regulated area during 2009 – 2018.

| Year	Comments	Recommended quota	Fixed quota	Landed male crabs (tons)	Landed female crabs (tons)
2009	Recommended harvest rate – 50% of legal stock	600 t	1185 t	1 395	54
2010	New models applied – options for quota: 0 – 2600 t	0 [1]	900 t	832	36
2011	Quota-options for different MLS; 120 – 137 mm	900 – 1800 t	1100 t	1267	35
2012		500 t	900 t	1090	32
2013		900 t	1000 t	946	24
2014		1000 t	1000 t	1283	31
2015		1250 t	1040 t	1211	33
2016		2000 t	2000 t	2202	60
2017		1500 t	2000 t[*]	1688	115
2018		1250 t	1750	1508[**]	128[**]
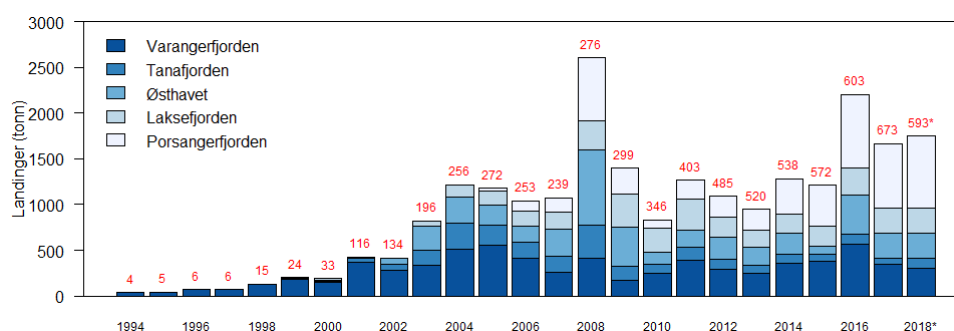
Figure 3.9.2.5. Landings of male red king crabs in Norwegian quota regulated area divided on different areas during 1994 – 2018. Number of participating vessels are shown in red numbers on top of columns each year.
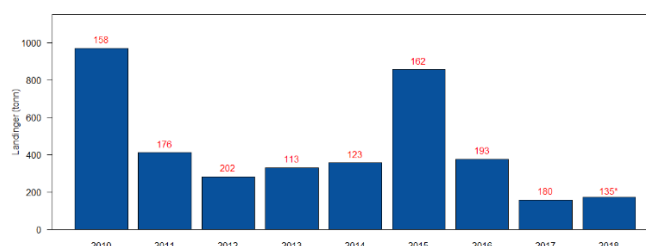
Figure 3.9.2.6. Landings of red king crab from the Norwegian free fishing area west of 26 o E. Number of participating vessels are shown in red numbers on top of columns each year.

Snow crab (*Chionoecetes opilio*)

The snow crab fishery carried out by Norwegian, Spanish, and Russian vessels began in international waters of the Barents Sea (Loop Hole) in 2013. Russian vessels fished crabs in this area until 2016. In 2016, Russian vessels started fishing snow crabs in Russian waters (fig. 3.9.2.5). In 2017, the Russian fishery for snow crabs was conducted only within the Russian EEZ.

Figure 3.9.2.5. Russian fishery of the snow crab location in the Barents Sea in the international waters in 2013-2016 (1) and nationality waters in 2016 (2) (Bakanev and Pavlov, 2017).

Russian vessels mainly use conical traps for the snow crab fishery. Statistics for the Russian snow crab fishery in the Barents Sea during 2013–2016 are shown in Table 3.9.2.2.
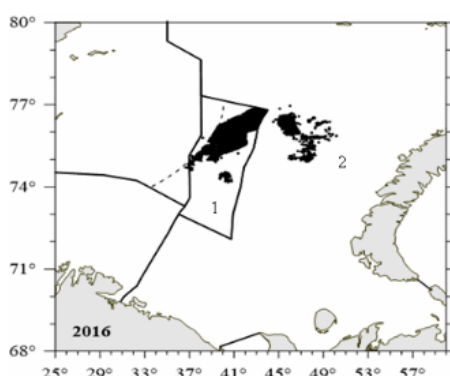
Table 3.9.2.2 Russian fishery statistics for the snow crabs in the Barents Sea during 2013-2016 (Ba- kanev, Pavlov, 2017).

Year	Number of vessels	Total fishery days	Numbers of traps, th.	Total catch, tonnes
International waters (Loop Hole)				
2013	2	22	2,4*	62.0
2014	12	1 153	788.7	4 104.2
2015	20	3 119	2894.7	8 894.6
2016	18	2 576	2687.5	6 486.7
Russian waters				
2016	5	178	91.7	1 499.9

During the 2013–2016 period of unregulated fishing in Loop Hole, the total international catch of snow crabs exceeded 55 thousand tonnes. During 2015–2016, average daily catch declined by 10–20% from the 2014 estimate. (Bakanev and Pavlov, 2017).

Decreased fishery productivity (fig. 3.9.2.6) indicated significant overfishing of the Barents Sea snow crab stock.

In July 2015, Norway and Russia agreed upon the designation of the snow crab as a sedentary species. This decision changed the status from a water column species to a continental shelf resource (Joint Norwegian-Russian Fisheries Commission, 2015). The snow crab stock in the Loophole area then shifted from being in international waters to become Russian and Norwegian property on their continental shelves. So 85% belongs to the Russian continental shelf and the last rest of 15% belongs to the Norwegian continental shelf.
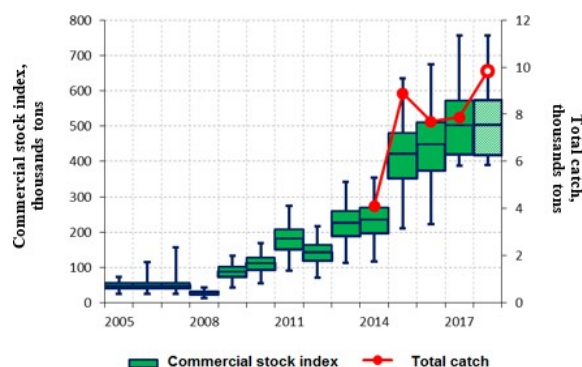
Figure 3.9.2.6. Biomass of commercial stock of snow crab in the Barents Sea in 2005-2017 and its forecast for 2018; catch of snow crab in the Barents Sea in 2014-2017 and expected catch in 2018 (Bakanev and Pavlov, 2018).

The fishery for snow crab conducted by Norwegian vessels, started in 2012 and 2.5 tones was landed. Norwegian vessels fished in the Loophole in the beginning until 2016, but then they moved into Norwegian economic zone and the fishery protection zone around Svalbard. Norway introduced a TAC for the first time in 2017. It was set at 4000 tonnes, and have been stable for 2018 and 2019. Even though the TAC has been on 4000 tonnes, the landings has been around 3000 tonnes the last two years.

References

Sundet, J.H.and Hoel. A.H. 2016. The Norwegian management of an introduced species: the Arctic red king crab fishery. Marine Policy, 72; 278-284. DOI: 10.1016/j.mar.pol.2016.04.04.

3.9.3 Whaling and seal hunting

By Nils Øien (IMR)

Minke whale (*Balaenoptera acutorostrata*)

Management of the minke whale is based on the Revised Management Procedure (RMP) developed by the Scientific Committee of the International Whaling Commission. Inputs to this procedure are catch statistics and absolute abundance estimates. The present quotas are based on abundance estimates from survey data collected in 1989, 1995, 1996–2001, 2002–2007, and 2008–2013. The most recent estimates (2008– 2013) are 89 600 animals in the Northeastern stock, and 11 000 animals for the Jan Mayen area, which is exploited by Norwegian whalers. The present (2016–2021) RMP quota of 880 animals annually is considered precautious, conservative, and protective for the minke whale population in the Northeast Atlantic. At present only Norway utilizes this quota.

Harp seal (*Pagophilus groenlandicus*)

Northeast Atlantic stocks of harp seals are assessed every second year by the ICES Working Group on Harp and Hooded Seals (WGHARP). The assessments are based on modelling, which provides ICES with sufficient information to give advice on both status and catch potential of the stocks. The applied population model estimates current total population size, incorporating historical catch data, estimates of pup production and historical values of reproductive rates. Modelled abundance is projected into the future to provide an estimate of future population size for which statistical uncertainty is provided for various sets of catch options. Russian aerial surveys of White Sea harp seal pup production conducted during the period 1998–2013 indicate a severe reduction in pup production after 2003. This could be due to changes in fecundity and/or changes in survival. The Barents Sea/White Sea population of harp seals is now considered data poor (available data for stock assessment older than 5 years). The population model provided a

poor fit to pup production survey data; primarily due to the abrupt reduction after 2003. Nevertheless, to the model results were used to provide advice in 2017 (ICES 2016d). The total size of the population was estimated to be 1 408 200 (95% C.I. 1 251 680–1 564 320). A catch of 10 090 age 1+ animals, or an equivalent number of pups (where one 1+ seal is balanced by 2 pups), per year would sustain the 1+ population at present level over the 15-year period (2017–2032). Catches in recent years have been much lower than the quotas. Particularly after 2008, the last year that Russia hunted this population.

3.9.4 Fishing activity

By Gro van der Meeren (IMR) and Alexey Russkikh (PINRO)

Fishing activity in the Barents Sea is tracked by the Vessel Monitoring System (VMS). Figure 3.9.4.1 show fishing activity in 2017 based on Russian and Norwegian data. VMS data offer valuable information about temporal and spatial changes in fishing activity. Figure 3.9.4.2 show the use of gear in 2017 and annual fishing intensity reported to the Norwegian fishery authorities in 2011-2017. The most widespread gear used in the Barents Sea is bottom trawl; but long lines, gillnets, Danish seines, and handlines are also used in demersal fisheries. Pelagic fisheries use purse seines and pelagic trawls. The shrimp fishery used special bottom trawls.

The fishing intensity west of Svalbard in the central to northern part of the Barents Sea has increased in the period from 2011 to 2017. Updates for 2018 is not available at the time of the WGIBAR meeting.
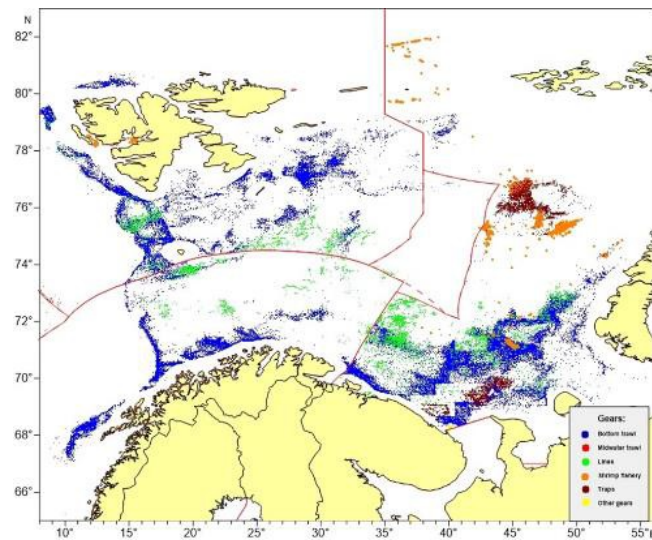
Figure 3.9.4.1. Location of Russian and foreign fishing activity from commercial fleets and fishing vessels used for research purposes in 2017 as reported (VMS) to Russian authorities. These are VMS data linked with logbook data (source: PINRO Fishery statistics database).
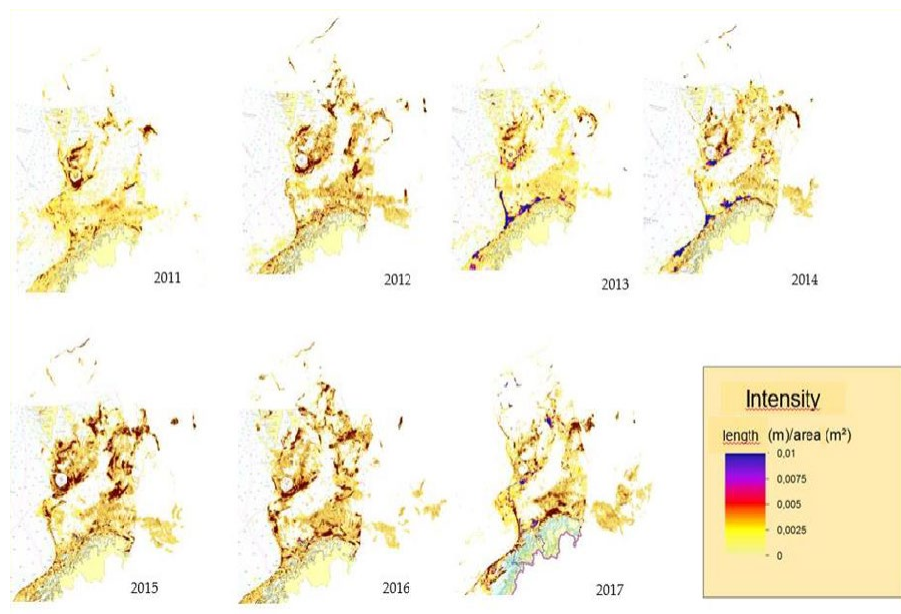

Figure 3.9.4.2 a) Type of gear used in 2017 and b) Location and intensity of Norwegian and foreign fishing activity from commercial fleets (larger than 15m) and fishing vessels used for research purposes in 2011; 2012; 2013; 2014; ; 2015; 2016; 2017 as reported (VMS) to Norwegian authorities. This is VMS data linked with logbook data. (source: Norwegian Directorate of Fisheries).

From 2011 onwards, minimum mesh size for bottom trawl fisheries for cod and haddock is 130 mm for the entire Barents Sea; previously the minimum mesh size was 135 mm in the Norwegian EEZ and 125 mm in the Russian EEZ. It is still mandatory to use sorting grids. Minimum legal catch size was harmonized at the same time: for cod from 47 cm (Norway) and 42 cm (Russia) to 44 cm for all, and for haddock from 44 cm (Nor- way) and 39 cm (Russia) to 40 cm for all.

3.9.5 Discards

The level of discarding in fisheries is not estimated, and discards are not accounted for in stock assessments. Both undersized fish and by-catch of other species can lead to discarding; fish of

legal size but low market value are also subject to discarding to fill the quota with larger and more valuable species (known as high-grading).

Discarding is known to be a (varying) problem, e.g., in haddock fisheries where discards are highly related to the abundance of haddock close to, but below, the minimum legal catch size. Dingsør (2001) estimated discards in the commercial trawl fishery for Northeast Arctic cod during 1946-1998, and the effects on the assessment. Sokolov (2004) estimated cod discard in the Russian bottom trawl fishery in the Barents Sea during 1983-2002. The lack of discard estimates leads to less precise and accurate stock assessments. The influence of the fishery on the ecosystem is, therefore, not fully understood. A possible way to estimate discard is through analysis of landing information (size/weight composition of landings relative to observations made onboard fishing vessels). In 1987 Norway launched a general discard ban, regulated by law in 2004 (Storting. Meld. 2003-2004 Havressursloven 2004).

Since 1984, documentation of redfish (mainly *S. mentella*) taken as bycatch and then discarded in the Norwegian shrimp fishery, shows that shrimp trawlers removed significant numbers of juvenile redfish during the early 1980's. This discarding peaked in 1984, when by-catch amounted to about 640 million individuals; a number comparable to a good year class in this stock (Figure 3.9.5.1). After sorting grids became mandatory in 1993, by-catch of redfish was reduced dramatically. It was also shown that areal closure are necessary to protect small juvenile redfish, since they are not sufficiently protected by sorting grids. The by-catch and discard of cod consists mainly of 1- and 2- year-olds, but is generally small compared to other reported sources of mortality like catches, discards in the demersal fisheries and cannibalism.
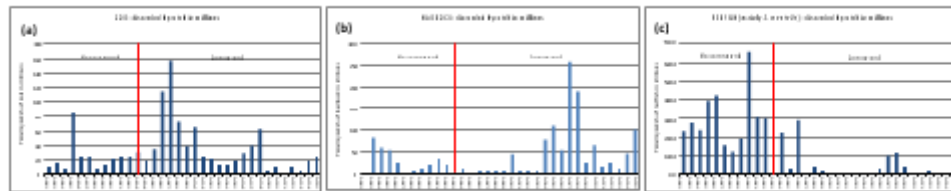

Figure 3.9.5.1. Revised bycatch (discards) estimates of small a) cod, b) haddock and c) redfish during the Barents Sea shrimp fishery 1982-2015 (ICES 2016c).

Noticeable discard of cod in the shrimp fishery occurred in 1985 and 1996-1998. The highest recorded number of discarded cod was 157 million in in 1997 and far less dis- card have been estimated since 2010 (ICES 2016c). Cod by-catch has declined in recent years (< 20 million). Discards of haddock in the Barents Sea shrimp fishery have been estimated for the period 2000-2005, and show the highest discard in 2007-2008 (about 200 millions). Discard of Greenland halibut in the Barents Sea shrimp fishery was estimated for the 2000-2005 period; highest discard occurred in 2002 and 2000 (approximately 13 million specimens).

Even if the sorting grid prevents discarding of fish larger than 18 cm, it becomes obvious that only effective surveillance and closing areas for shrimp fishing can prevent bycatch and discard of smaller specimens.

3.9.6 Shipping activity

The extent of the shipping activity is not obtained numerically. However, maps showing the AIS tracking of vessel in the Barents Sea in August, 2012 to 2018, confirms the increased fisheries effort east of Svalbard and also an increase in passenger vessels to the Svalbard area (Figure 3.9.6.1). Fisheries and passenger vessels dominates in the traffic in the western and northwestern Barents Sea. A notable increase in the traffic in the northeastern Barents Sea, between Europe and

Asia, by tankers and cargo vessels are also shown. The effect on the marine ecosystem of the increased tourist traffic is not known, but the possibility for more littering in a potential risk (Source: Havbase.no; the Norwegian Coastal Authorities).
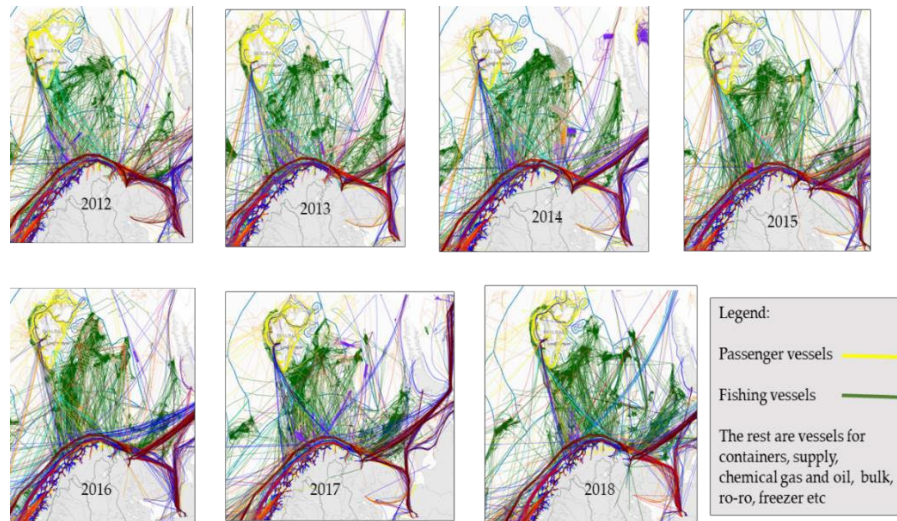

Figure 3.9.6.1. Maps showing all vessels in the Barents Sea during August, 2012 to 2018. Yellow (passenger ships) and green (fishing vessels) dominates at open sea while red (ro-ro), orange (bulk), purple (goods) and blue (gas) cross between Europe and Asia (Source: Havbase.no; the Norwegian Coastal Authorities, AIS tracking.

3.9.7 Marine litter

By Tatiana Prokhorova (PINRO), Bjørn Einar Grøsvik (IMR) and Elena Eriksen (IMR)

Marine litter is defined as "any persistent, manufactured or processed solid material discarded, disposed or abandoned in the marine and coastal environment".

Large-scale monitoring of marine litter was conducted by the BESS survey during the 2010–2017 period, and helped to document the extent of marine litter in the Barents Sea (the BESS survey reports, Grøsvik *et al.*, 2018). Distribution and abundance of marine litter were estimated using data from: pelagic trawling in upper 60 m; trawling close to the seabed; and visual observations of floating marine debris at surface.

The study, done by Grøsvik *et al.*, 2018, had comprehensive, with data collected from 2265 pelagic trawls and 1860 bottom trawls, and surface observations made between stations. Marine litter was recorded from 301 pelagic- and 624 bottom-trawl catches. In total, 784 visual observations of floating marine debris were recorded during the period. Marine litter was categorized according to volume or weight of material type: plastic; wood; metal; rubber; glass; paper; or textile. Marine litter is observed in the entire Barents Sea and distribution varied with material densities, ocean currents, and water depth. Plastic was the dominant type of marine litter observed at: 72% of surface observations; 94% of pelagic trawl stations; and 86% of bottom-trawl stations (Figure 3.9.6.1.1, Grøsvik *et al.*, 2018). Wood constituted 19% of marine litter observed at the surface, 1% in pelagic trawls, and 17% in bottom trawls. Materials from other categories — metal, rubber, paper, textile, and glass — were observed less frequently.

Floating marine debris was widely distributed; highest volume was observed in central, eastern, and northern areas (Figure 3.9.7.1). Wood dominated observations in this category (61.9 ±21.6% by volume), while plastic constituted 34.6 ±22.3% by volume. Metal, rubber, and paper were recorded less frequently.

Pelagic marine litter was observed in 13% of all pelagic trawls with a mean of 58 grammes per trawl catch, and was widely distributed (Figure 3.9.7.1). Plastic formed the bulk (85.1%) of pelagic marine litter observed with a mean of 0.011 mg m-3; paper formed 9.4%; textile formed 3.9%, and was more seldom observed; other materials were only observed sporadically. Pelagic plastic was significantly correlated with latitude and longitude during some years, and indicated northeastern distribution in 2010, and northern distribution in 2011 and 2014.

Marine litter as bycatch from bottom trawling was observed in 33.5% of all bottom- trawl hauls, with a mean of 772 g per haul. Marine litter from bottom trawls was distributed widely; highest levels were observed in western, southeastern, north eastern parts, and around Svalbard. Plastic was observed in the entire Barents Sea, processed wood in eastern and northern parts, and metal and rubber in the southeast (Figure 3.9.7.1 and 3.9.7.2). Processed wood dominated marine litter from bottom trawls, with 66% of mean weight in all catches with any type of marine litter. Plastic constituted 11.4% of the mean weight; but dominated in the number of observations. Metal and rubber constituted ~10% of the mean weight, but the number of observations was limited. On average, 26 kg km^{-2} of marine litter was observed in the Barents Sea; with an average of 2.9 kg km^{-2} of plastic litter alone (Grøsvik *et al.,* 2018).

Current situation and trends

The Russian Zone was not well covered during the 2018 BESS. As result, only maps of anthropogenic marine litter distribution in the observed area are presented without comparison to previous years or estimation of average weight of litter observed in trawls.

Plastic dominated types of anthropogenic litter observed at the water surface and in both pelagic and bottom trawls (Figure 3.9.7.1, 3.9.7.2).
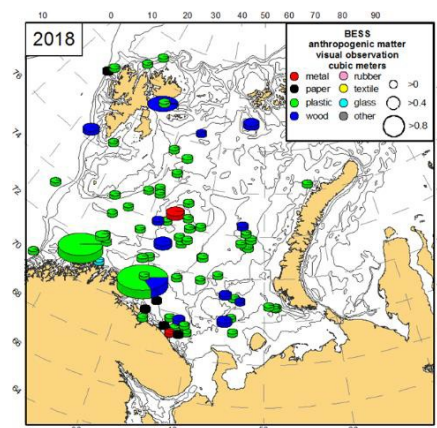
Figure 3.9.7.1 Types of anthropogenic marine litter (m3) observed at the surface during the 2018 BESS . From the 2018 BESS Report (Prokhorova and Grøsvik, 2019).
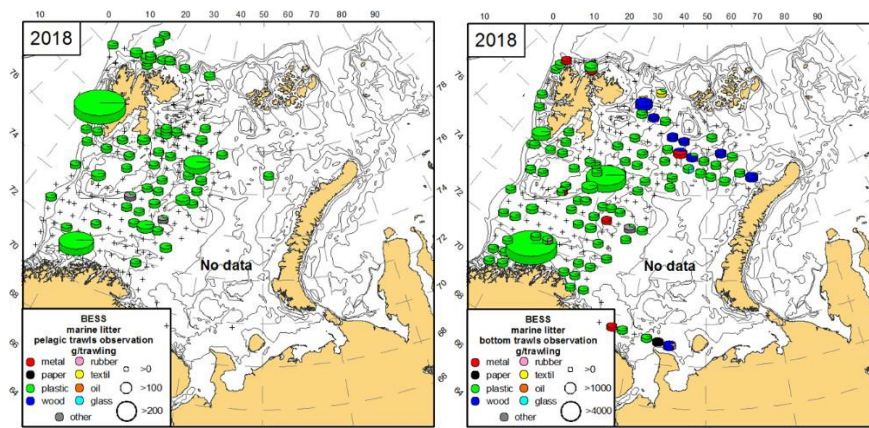

Figure 3.9.7.2 Types of anthropogenic marine litter collected in pelagic trawls (left) and bottom trawls (right). Size of circles indicate weight in the range of >0, >100g, and >200 g for pelagic trawls or in the range of >0, >1000 g and >4000 g for bottom trawls. Crosses indicate trawl stations. From the 2018 BESS Report (Prokhorova and Grøsvik, 2019).

The number of litter recordings from both pelagic and bottom stations has increased during the period since these recordings were initiated (2010) through 2018. In 2010, 6.6 % of pelagic trawls contained litter, 2.9 % in 2011, and 24.2 % in 2018 (Figure 3. 10.7.3). Litter recordings in bottom trawls were 10.9 % in 2010 and 54.0 % in 2018) (Figure 3.9.6.3).
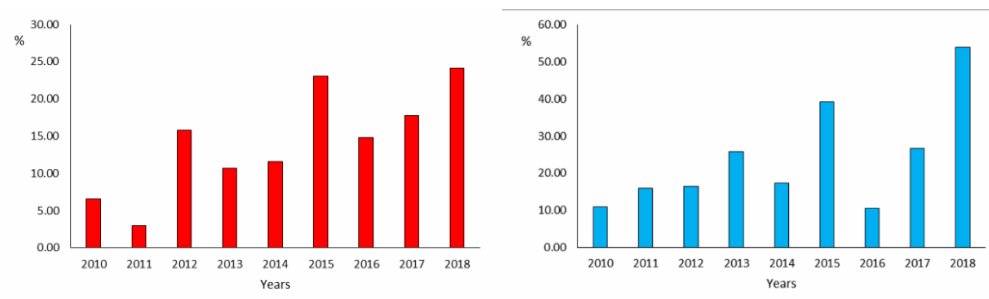

Figure 3.9.7.3 Number of stations (%) with anthropogenic litter collected in pelagic trawl stations (left) and bottom trawl stations (right) during the BESS from 2010 through 2018.

We observed distribution of different types of anthropogenic marine litter during the two periods: 2010-2013 and 2013-2018 (Figure 3.10.7.4). Plastics dominated all types of litter in pelagic and bottom trawl stations both during the 2010-2013 and 2014-2018 periods. Plastic constituted 94.7 % of marine litter content in pelagic trawls during the 2010-2013 period and 95.6 % during

2014-2018. For bottom trawls, 81.0 % of litter recorded was plastic during the 2010-2013 period, while 88.7 % of litter recorded contained plastic during 2014-2018. Litter from fisheries — ropes, strings and cords, pieces of nets, floats/buoys, etc. — dominated recordings of plastic litter. Wood was recorded as bycatch from bottom stations, mainly in northern and eastern regions of the Barents Sea. The number of bottom stations with wood was lower during the 2010-2013 period (11.3 % of stations) compared with the 2010-2013 period (19.0 % of stations). Metal, paper, rubber, glass, and textiles were all observed sporadically in both pelagic and bottom trawl catches.
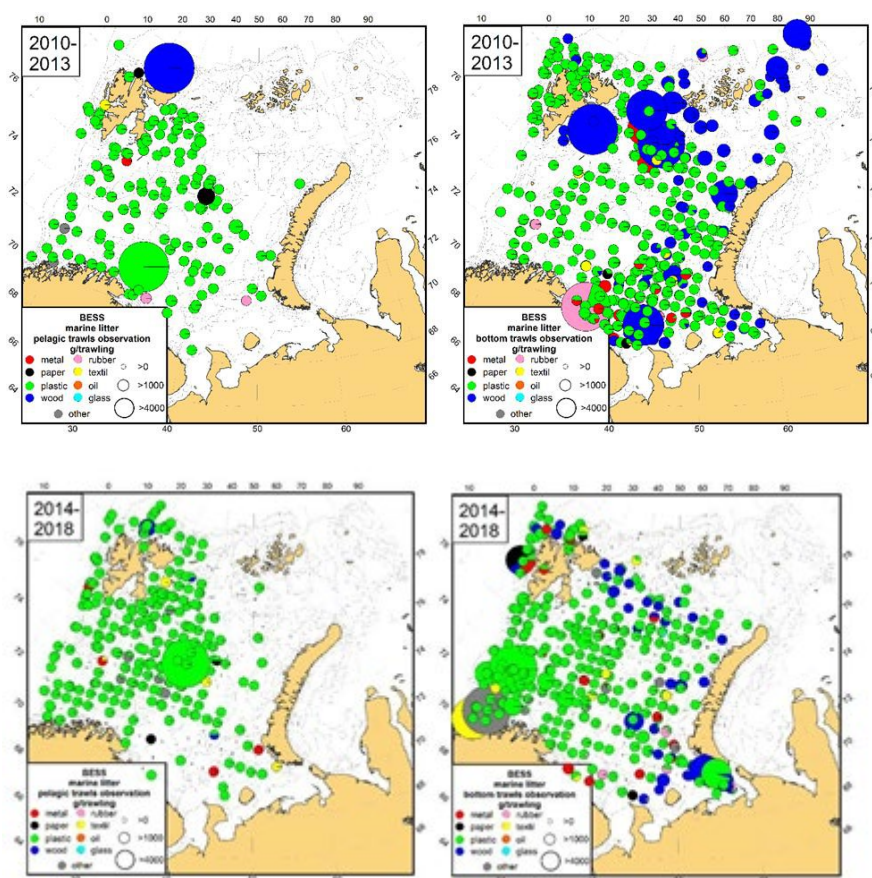

Figure 3.9.7.4 Types of anthropogenic marine litter collected in pelagic trawl stations (left) and bottom trawl stations (right) during the 2010-2013 period (upper) and the 2014-2018 period (lower).

References

Grøsvik BE, Prokhorova T, Eriksen E, Krivosheya P, Horneland PA, Prozorkevich D. 2018. Assessment of marine litter in the Barents Sea, a part of the joint Norwegian-Russian ecosystem survey. Front. Mar. Sci., 06 March 2018. https://doi.org/10.3389/fmars.2018.00072.

Prokhorova T. and Grøsvik B.E. 2019. Marine litter. In: Survey report from the joint Norwegian/Russian ecosystem survey in the Barents Sea and adjacent waters, August-October 2018 (eds by van der Meeren, G.I and Prozorkevich D.). IMR/PINRO Joint Report Series, No. 2/2019.

4 Interactions, drivers and pressures

By Bjarte Bogstad (IMR), Dmitri Prozorkevich (PINRO), Alexey Russkikh (PINRO), Andrey Dolgov (PINRO), Irina Prokopchuk (PINRO), Lis Lindal Jørgensen (IMR), Natalia Strelkova (PINRO) and Denis Zakharov (PINRO)

4.1 Feeding and growth of capelin and polar cod

Not updated as 2017 data for diet of capelin and polar cod were not yet available

Capelin

Eleven years (2006–2016) of capelin diet were examined from the Barents Sea where capelin is a key forage species, especially of cod. The PINRO/IMR mesozooplankton distribution shows low plankton biomass in the central Barents Sea, most likely due to predation pressure from capelin and other pelagic fish. This pattern was also observed in 2017. In the Barents Sea, a pronounced shift in the diet from smaller (<14 cm) to larger capelin (≥14 cm) is observed. With increasing size, capelin shift their diet from predominantly copepods to euphausiids, (mostly *Thysanoessa inermis* - not shown), with euphausiids being the largest contributor to the diet weight in most years (Figure 4.1.1). Hyperiid amphipods contributed a small amount to the diet of capelin.
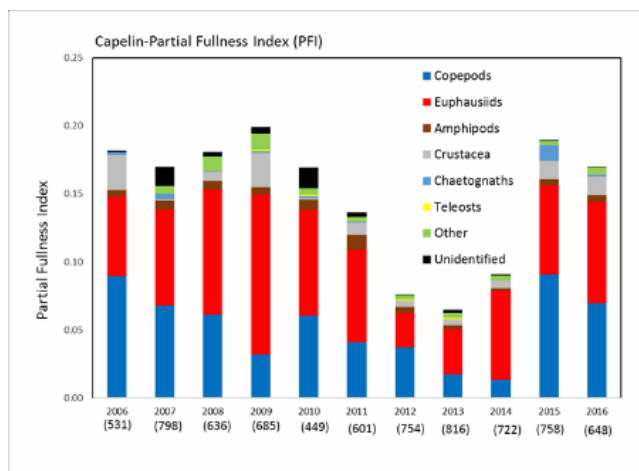

Figure 4.1.1. Stomach fullness of capelin during survey in August-September 2006-2016. Number of fish sampled each year in brackets.

Capelin growth decreased from 2009 onwards in a way similar to earlier periods of relatively high capelin abundance (1990–1992, 1998–2002) (Figure 4.1.2). There was a corresponding decrease in stomach fullness of capelin from 2009 onwards. These trends were reversed in 2014; both weight-at-age and stomach fullness are now at relatively high levels.

The decrease in individual growth rate and condition of capelin observed before 2014 for the large capelin stock may have been caused by reduced food availability linked to strong grazing on the largest planktonic organisms; as suggested by reduction of the largest size fraction (>2 mm) in the Norwegian zone during the autumn survey (see section 3.3). Plankton species composition in the northeastern area has changed; abun- dance and biomass of large copepod species (*Calanus finmarchicus* and *C. glacialis*) — which are important prey items for capelin — decreased in recent years. While the abundance of small copepods (*Pseudocalanus minutus*) — which are not important to the capelin diet — has increased. This change species composition of the plankton com-

munity is most likely caused by warming in the Barents Sea, and high grazing pressure from capelin and other species. Compared to 2015, the 2016 abundance of large cope- pods (*C. finmarchicus* and *C. glacialis*) increased, while that of the smaller copepod (*P. minutus*) decreased slightly. In 2016, increase biomass of *C. finmarchicus* was observed relative to 2015, while biomass of *C. glacialis* remained at the same level.
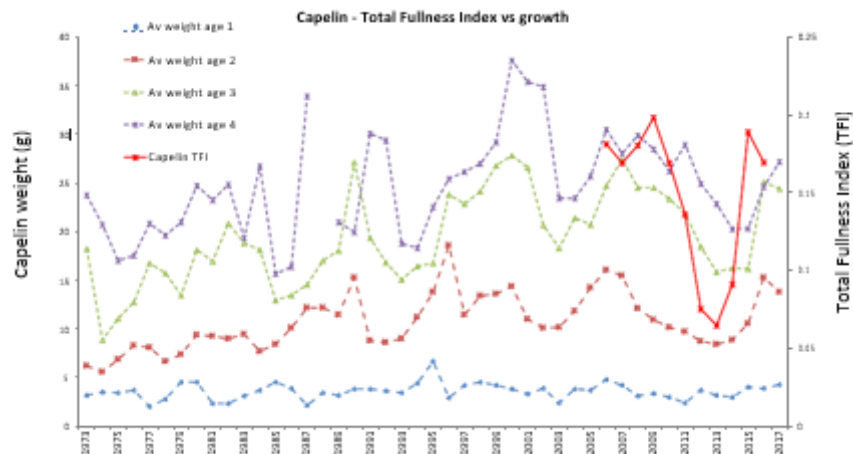

Figure 4.1.2 Growth (weight at age from ecosystem survey) and stomach fullness (TFI) of capelin in 1973–2017.

Capelin growth depends on the state of the plankton community (Skjoldal *et al.,* 1992; Dalpadado *et al.,* 2002; Orlova *et al.,* 2010). Capelin produces a strong feedback mechanism on zooplankton stock levels through predation (Figure 4.1.3, Dalpadado *et al.,* 2003; Stige *et al.,* 2014); has been found to be particularly pronounced for krill in the central Barents Sea (Dalpadado and Skjoldal, 1996).
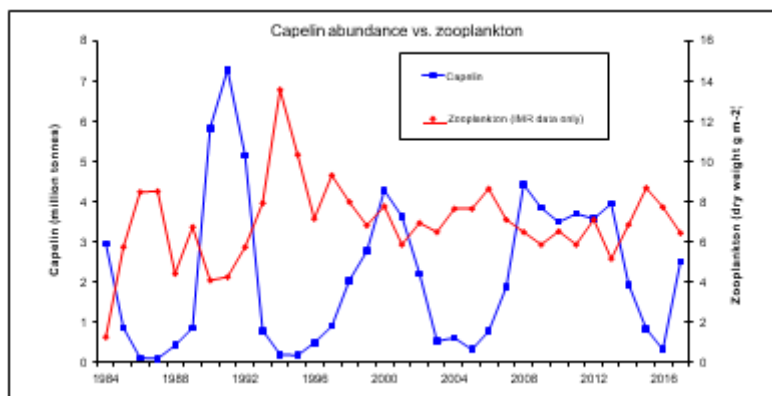

Figure 4.1.3. Fluctuation of capelin stock and zooplankton biomass in the Barents Sea in 1984–2017.

There is evidence of a density-dependent effect on capelin growth. This is reflected in decreasing length of individual (2- and 3-year old) capelin with increasing capelin abundance (Figure 4.1.4).
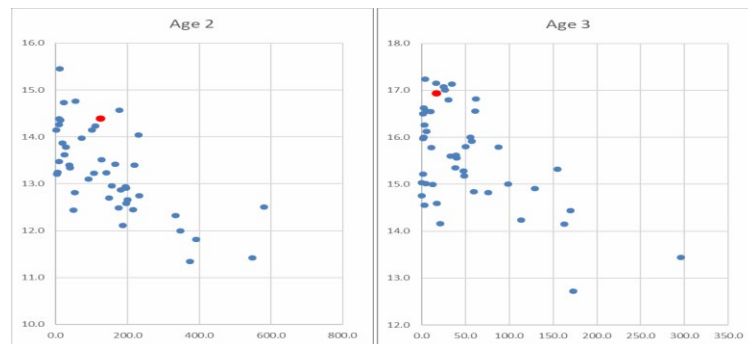
Figure 4.1.4. Average length as function of abundance for capelin at age 2 and 3. The data point from 2017 is marked in red.

Polar cod

Diet data from 2007–2016 indicate that polar cod mainly feed on copepods, amphipods (mainly hyperiids *Themisto libellula* and occasionally gammarids), euphausiids, and other invertebrates (to a lesser degree) (Figure 4.1.5). Large polar cod also prey on fish. The total stomach fullness index decreased after 2011, and was at a fairly low level in 2012–2015; the index increased again in 2016 to the highest level measured in this 10- year time-series (Figure 4.1.6). The growth rate of polar cod was low in 2016 and, thus, did thus not reflect the increased stomach fullness observed that year. It should be noted that spatial coverage for polar cod is incomplete during most years of the BESS; thus, growth and stomach fullness data may not reflect the status of the entire population.
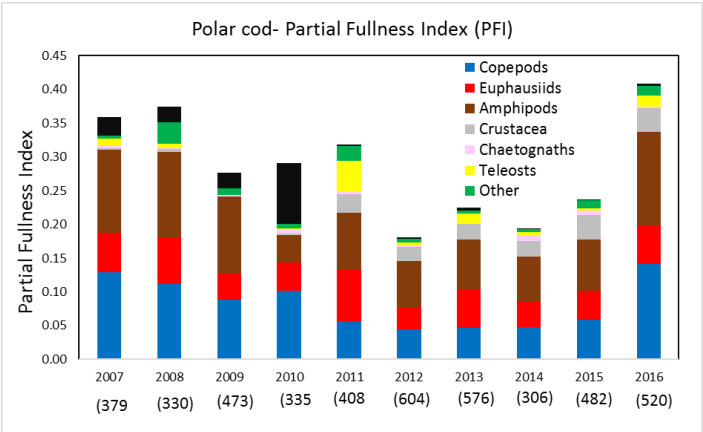
Figure 4.1.5. Stomach fullness of polar cod during survey in August–September 2007–2016. Number of fish sampled each year in brackets.
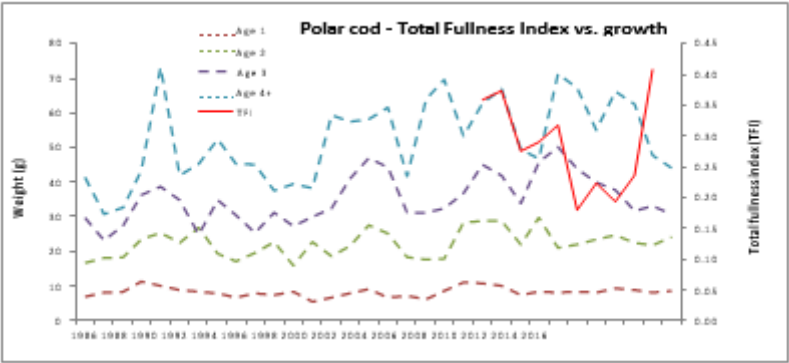

Figure 4.1.6 Growth (weight at age from ecosystem survey) and stomach fullness (TFI) of polar cod in 1986-2017.

4.2   Feeding, growth and maturation of cod

Feeding

Figures 4.2.1 and 4.2.2 show the consumption and diet composition of cod.
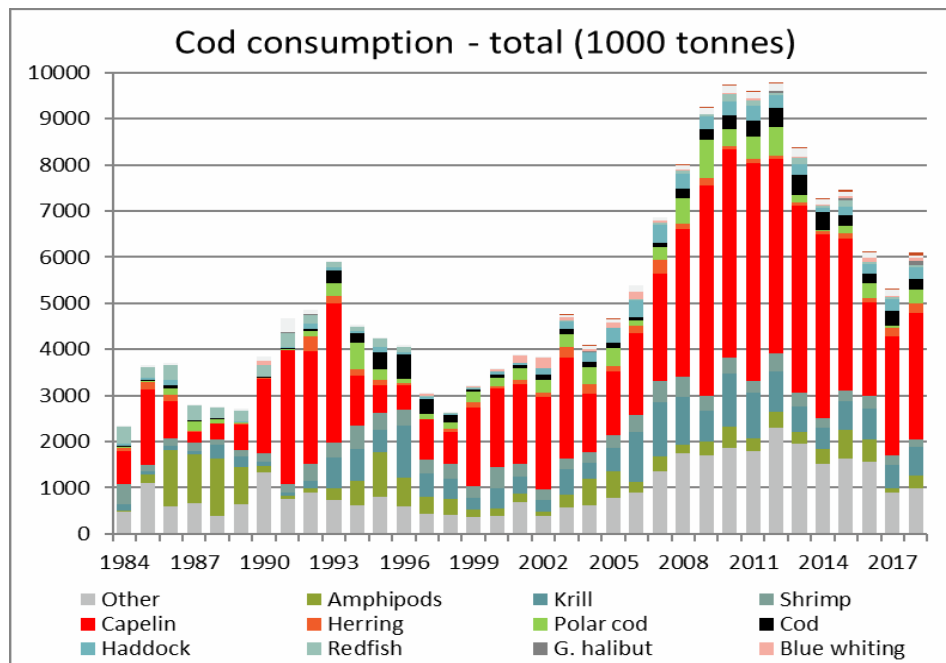
Figure 4.2.1 Cod consumption 1984–2018. Consumption by mature cod outside the Barents Sea (3 months during first half of year) not included. Norwegian calculations, preliminary figures, final numbers to be found in AFWG 2019.
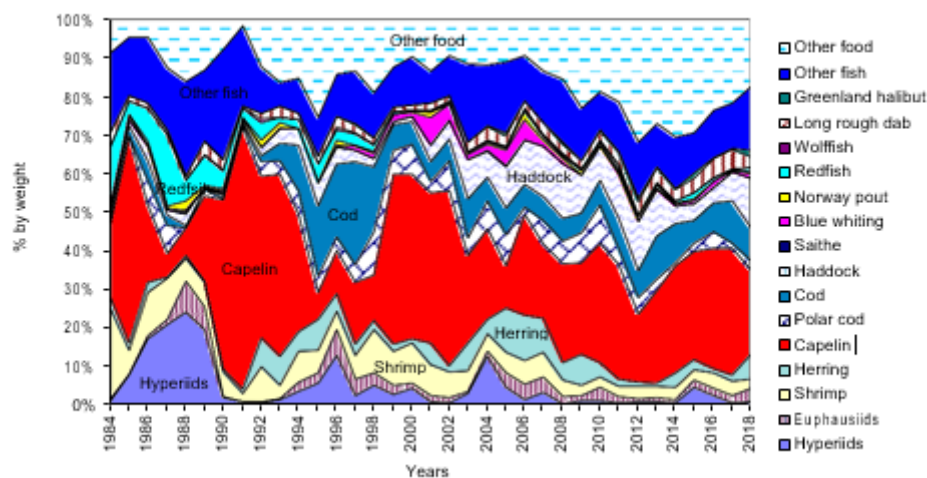
Figure 4.2.2. Cod diet composition in the Barents Sea in 1984–2018, by weight.

Cod is the major predator on capelin; although other fish species, seabirds and marine mammals are also important predators. In the last 6–7 years, cod stock levels have been extremely high in the Barents Sea. Estimated biomass of capelin consumed by cod in recent years has been close to the biomass of the entire capelin stock (Figure 4.2.3). Abundance levels of predators other than cod are also high and, to our knowledge, stable.
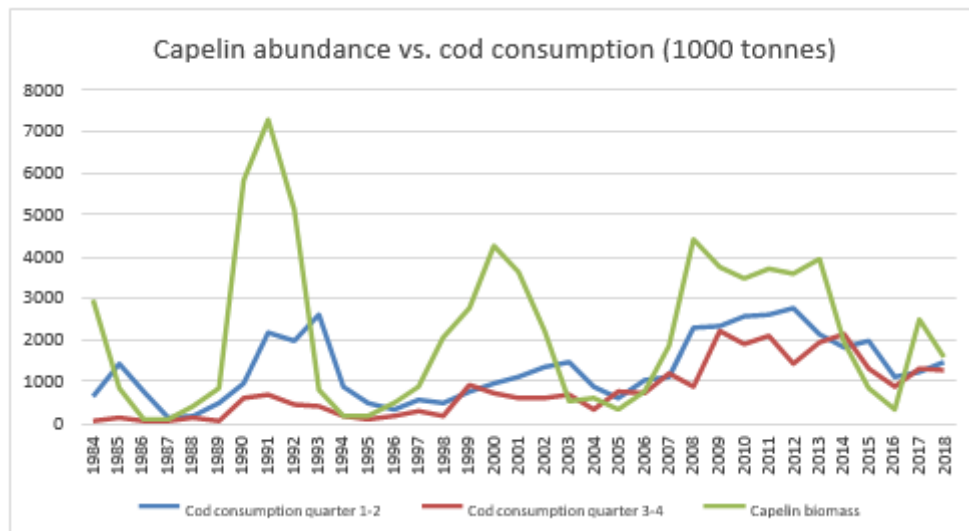
Figure 4.2.3 Size of the capelin stock and estimated consumption of capelin by cod.

Estimated consumption of capelin by cod during first and second parts of the year has indicated different temporal patterns. Consumption during the 1st and 2nd quarters has been high during earlier periods and includes consumption during the spawning period, and during spring and early summer prior to seasonal capelin feeding migrations. During the last decade, however, a major difference has been the pronounced increase to a much higher level of consumption in the 3rd and 4th quarters (Figure 4.2.3). This reflects the northward movement of cod stock, and a larger spatial overlap between cod and capelin under the recent warm conditions.

Figure 4.2.4 Acoustic estimates of polar cod compared to consumption of polar cod by cod and % of polar cod in cod diet, 1986-2017.

Figure 4.2.4 shows that there is a reasonable correspondence between the proportion of polar cod in the cod diet and acoustic estimates of polar cod.

Figure 4.2.5. Cod diet composition during the ecosystem survey in August–September 2011–2018. Red dots indicate capelin, and blue dots polar cod.

During the first capelin collapse (1985–1989) the importance of capelin in cod diet decreased from 53% in 1985 to 20–22% (m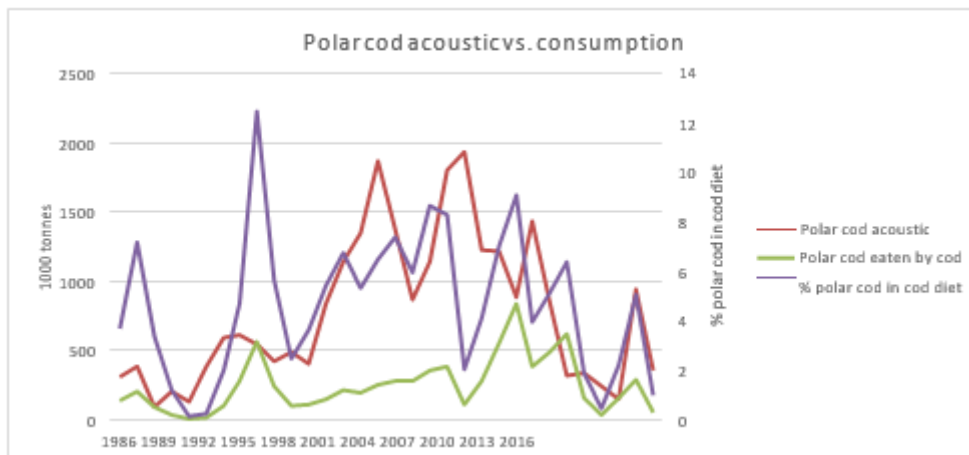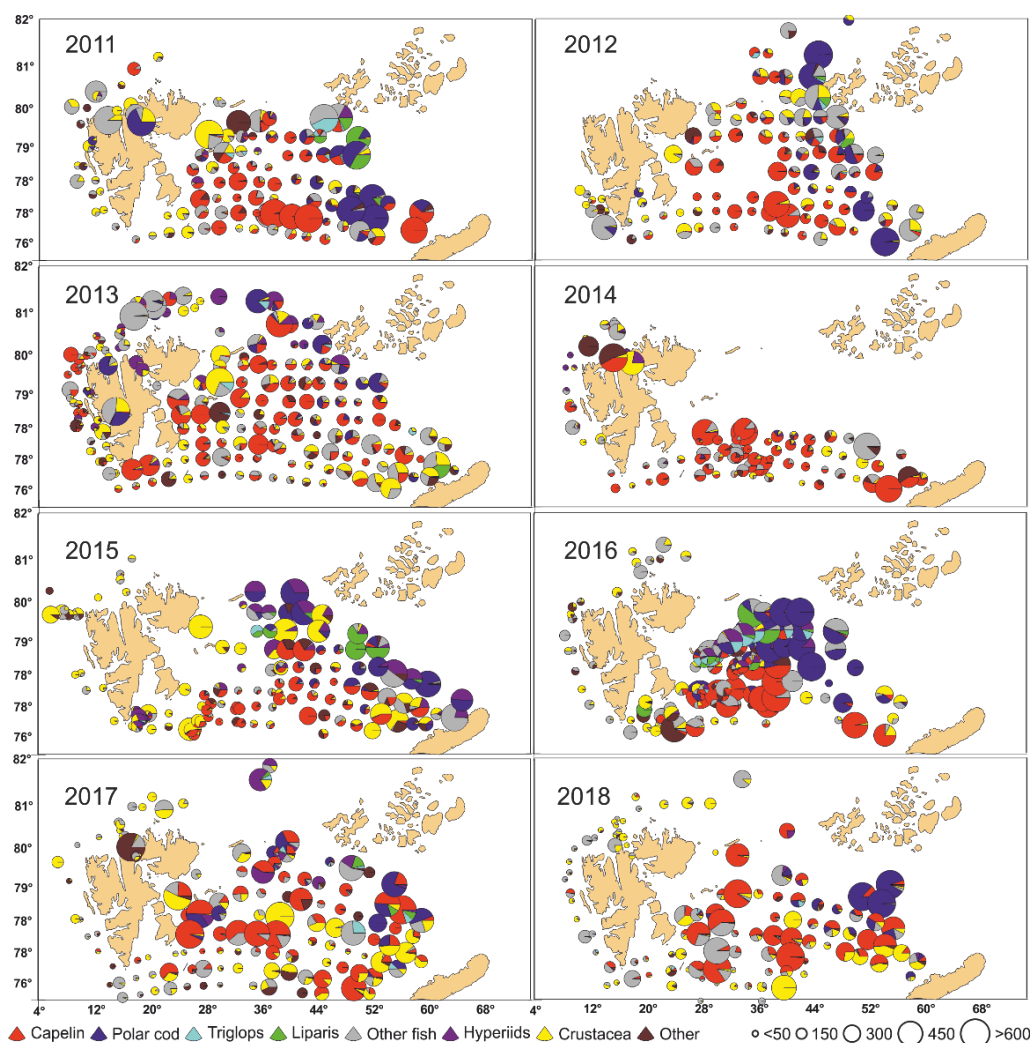aximum) for the remainder of the collapse period. During that period, an increase of other prey was observed; in particular, hyperiids which constituted 7–23% of the capelin diet and redfish which constituted 3–18%.

During the second capelin collapse (1993–1997), the proportion (by weight) of capelin in the cod diet was high during the first 2 years (47% and 30%), followed by a decreased to 6–16%. During this period, cannibalism in cod increased sharply from 4–11% to 18– 26% of the diet. In addition, more intensive consumption of hyperiids was observed (1–12%), but the proportion of hyperiids consumed was still much lower than during the first collapse.

During the third capelin collapse (2003–2006), consumption of capelin by cod was rather high (10–26%). Several alternative prey groups were present in the cod diet in similar quantities: juvenile haddock (6–11%) and cod (5–10%); herring (3–11%); blue whiting (1–5%); and hyperiids (1–12%). Consumption of capelin by cod during the most recent years has remained somewhat stable (17–31%), but has been much lower than during earlier periods of high capelin abundance (average 36–51%). In recent years, a relatively diverse cod diet has been recorded: with stable high consumption of juvenile cod and haddock (6–11 and 5–11%, respectively); other fish species (11–15%); and other food types (21–33%) (mainly ctenophores and crabs).

Investigations of cod diet in the area north of 76°N showed different types of feeding intensity in three different local areas (Dolgov and Benzik, 2014). Cod feeding intensity was low (149–169$^0/_{000}$) in areas near western and southern Spitsbergen — where cod feed on non-commercial fish. Other local areas were characterized by high feeding intensity (MFI 214-251-169 $^0/_{000}$) with capelin as dominant; non-target species (snailfish and sculpins), polar cod, and hyperiids were also consumed. These two are traditional areas of cod distribution during summer. The third area (Franz Josef Land, northern Novaya Zemlya, and adjacent areas) has become available habitat for cod only since 2008; in this area, cod (MFI 284-340 $^0/_{000}$) feed intensively on polar cod and capelin. Northward expansion of cod distribution, and their movement into northeastern Barents Sea results in better feeding conditions for cod under their high stock biomass and decreasing of main prey (capelin and polar cod).

In addition, some new prey items appeared in the cod diet. The non-indigenous snow crab (*Chionoecetes opilio*) has become a rather important prey items for cod, especially in eastern Barents Sea alongside Novaya Zemlya (Dolgov and Benzik, 2016). The percentage (by weight) of snow crab in the cod diet sharply increased from 2014 onwards (Figure 4.2.6). In contrast, two other non-indigenous crab species (red king crab and crab *Geryon sp.*) have not become more important in the cod diet. The difference is probably related to higher overlap between cod and snow crab, and more appropriate body shape and size of snow crab than the other crab species as prey for cod.
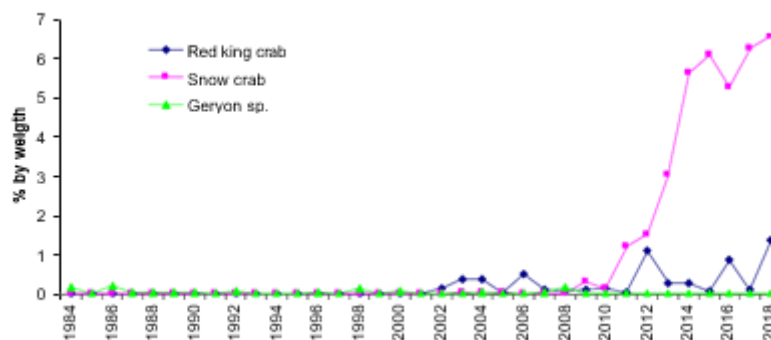
Figure 4.2.6. Importance of snow crab, red king crab and crab Geryon sp. in cod diet (% weight of total consumption) in 1984–2018.

Growth and maturation

Consumption and growth for young cod has been relatively stable in recent years (Fig- ure 4.2.7); there has been a slight decrease for older cod (Figure 4.2.8). Maturity-at-age for cod decreased considerably in 2015-2016, but did in 2019 increase to the level seen in the early 2000s recent years, particularly for ages 6-9. The changes in maturity ogives were considerably larger than indicated by recent changes in weight-at-age estimates (Figures 4.2.9 and 4.2.10).

Biomass of the main prey species, relative to the cod stock size, has decreased somewhat in recent years (Figure 4.2.11). However, no consequences of the 2015-2016 'mini-collapse' of the Barents Sea capelin stock on cod growth and condition have been observed. This may be related to on-going expansion of cod stock to the northern Barents Sea, making previously untapped food resources now available for cod consumption.

Figure 4.2.7 Cod growth and consumption at age 3 (ICES 2019).

Figure 4.2.8 Cod growth and consumption at age 6 (ICES 2019).

Figure 4.2.9 Maturity-at-age for cod ages 6-9 (ICES 2019).

Figure 4.2.10 Cod maturity and weight at age 7 (ICES 2019).

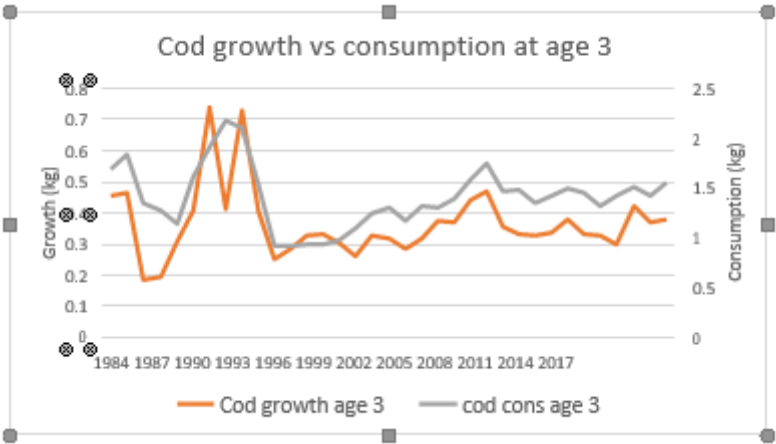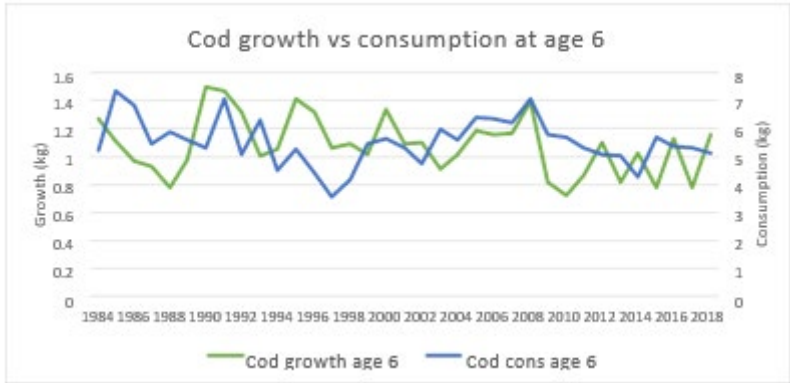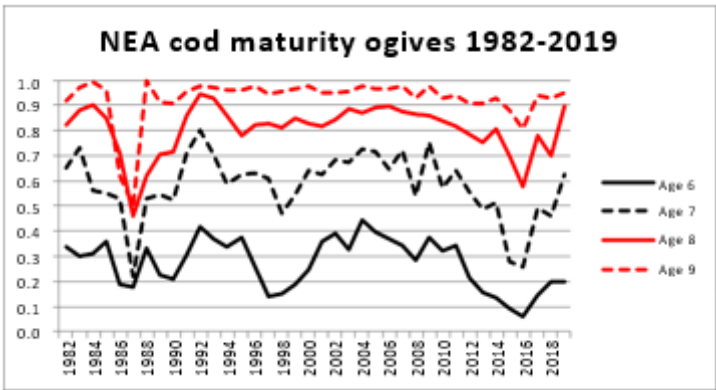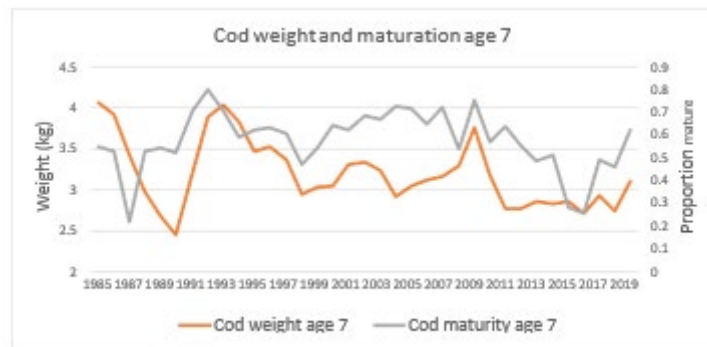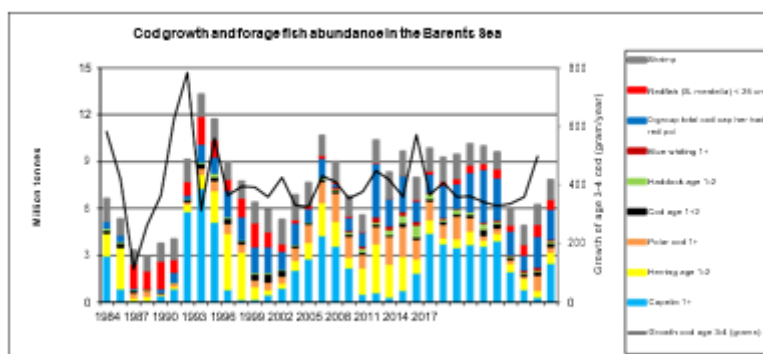**Figure 4.2.11. Abundance of major fish prey stocks and shrimp compared to cod growth. Not up- dated as some 2018 data still are missing.**

4.3 Causes of capelin fluctuations

Stock size fluctuations

The Barents Sea capelin has undergone dramatic changes in stock size over the last three decades. Three stock collapses (when abundance was low and fishing moratoriums imposed) occurred during 1985–1989, 1993–1997, and 2003–2006. A sharp reduction in stock size was also observed during 2014–2016; followed by an unexpectedly strong increase during 2016–2017. Observed stock biomass in 2015 and 2016 was below 1 million tonnes, which previously was defined as the threshold of collapse, while stock biomass increased to above 1 million tonnes in 2017-2018. Despite indications that capelin stock size was underestimated in 2016, at present 2015–2016 is recognized as a 'mini-collapse'.

Previous collapses have had serious effects both up and down the foodweb. Reduced predation pressure from capelin has led to increased amounts of zooplankton during periods of capelin collapse. When capelin biomass was drastically reduced, its predators were affected in various ways. Cannibalism became more frequent in the cod stock, cod growth was reduced, and maturation delayed. Seabirds experienced in- creased rates of mortality, and total recruitment failures; breeding colonies were abandoned for several years. Harp seals experienced food shortages, and recruitment failure, and increased mortality; partly because they invaded coastal areas, and were caught in fishing gear. The effects were most serious during the 1985–1989 collapse, whereas, the effects could hardly be traced during the third collapse. Gjøsæter *et al.* (2009) concluded that these differences in effect likely resulted from increased availability of alternative food sources during the two most recent collapses (1990s and 2000s).

These collapses were caused by poor recruitment, most likely in combination with low growth and increased predation pressure. It is likely that high levels of fishing pressure during 1985–1986 amplified and prolonged the first collapse. After each collapse, the fishery has been closed and the stock has recovered within a few years due to good recruitment. Several authors have suggested that predation by young herring has had a strong negative influence on capelin recruitment and, thus, has been a significant factor contributing to these capelin collapses (Gjøsæter *et al.*, 2016).

Recruitment

Capelin is a short-lived species and thus the stock size variation is strongly influenced by the annual recruitment variability. This may indicate that the main reason of capelin stock collapses is poor recruitment (Figure 4.3.1).
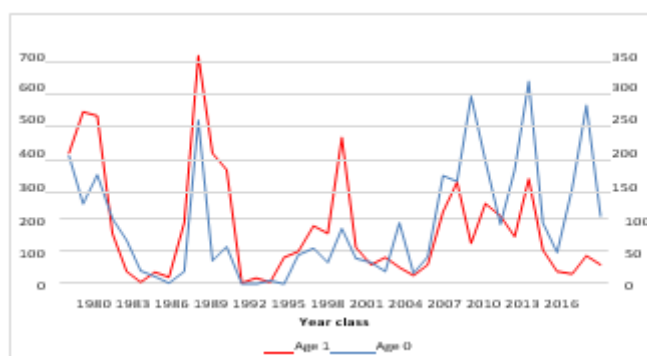
Figure 4.3.1. Fluctuation of capelin at age 0 (blue line) and 1 (red line) for the cohorts 1980–2017.

Mean length of 0-group capelin has varied somewhat during the data time-series. From a biological perspective, one may hypothesize that survival rates from age 0 to age 1 might be correlated with lengths-at-age 0. However, a plot of mean length-at-age 0 and total mortality, from age 0 to age 1, shows no such correlation; rather, this plot shows that 0-group and/or 1-group abundance estimates and, therefore also, mortality estimates from age 0 to age 1, are noisy; this could possibly mask possible relationships that might exist.

Figure 4.3.2 shows a stock–recruitment plot from Gjøsæter *et al.* (2016) going back to 1987. This plot shows that 1989 is still the strongest year class (age-1). An estimation of breakpoint from this plot could be attempted. This figure has not been updated since the 2016 report. Figure 4.3.3 shows an alternative approach where recruitment-at-age 0 is used, and SSB is estimated as the mature stock (>14 cm) in autumn (with fishery removals taken in January–March subtracted).
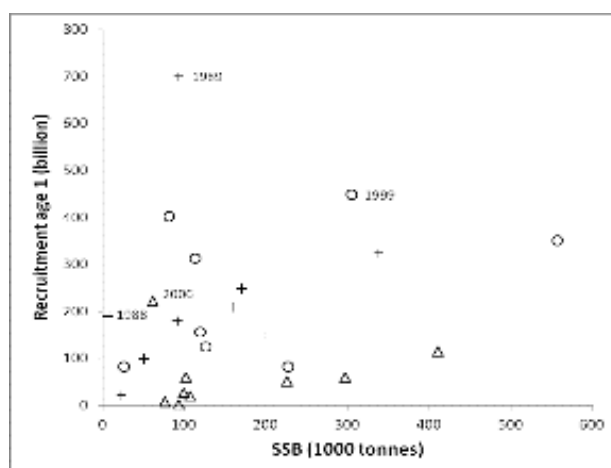
Figure 4.3.2. SSB/R plot for capelin. Cohorts 1987–2012. Points coded according to herring biomass age 1 + 2 in spawning year. Circles—herring biomass <450 000 tonnes, crosses—herring biomass between 450 000 tonnes and 1.3 million tonnes, triangles-herring biomass >1.3 million tonnes. (Figure 7 in Gjøsæter et al. 2016).
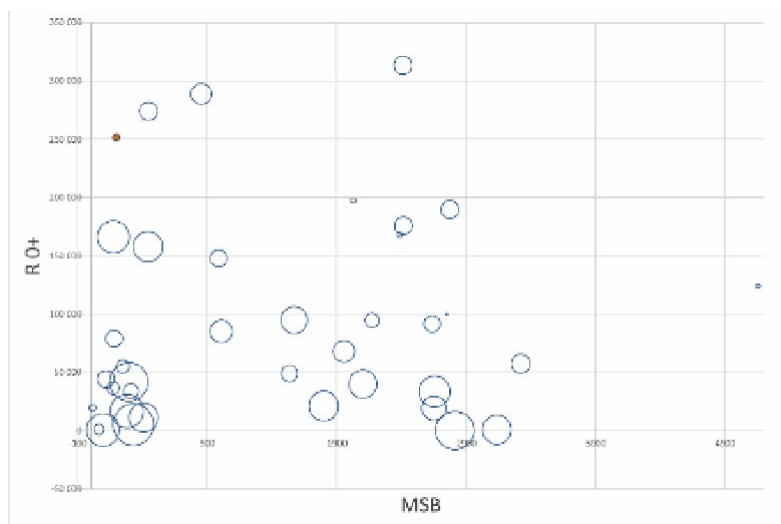
Figure 4.3.3. Relationship between mature stock biomass (>14 cm) with spring fishery subtracted (biomass at 1 Oct. Y, total landings from 1 January to 1 April.Y+1 are subtracted, 1000 tonnes) and 0-group index in billions (Y+1), covering the cohorts 1980–2017. The size of bubbles indicates the biomass of herring at age 1-3 (ICES WGIBAR data). Minimum diameter of bubble corresponds to 0.02 million tonnes of herring (1983), the maximum - 5.02 million tonnes. (1994). The red point is the 1989 cohort which is the basis for the current reference point (B_{lim}).

The Barents Sea polar cod stock also has had a declining trend in recent years (described in the next section). The decrease in polar cod abundance may have contributed to increased predation pressure on capelin since polar cod is also prey for cod. Predation pressure from seals and whales may also have changed, but data are limited. Assuming that the occurrence of predators, such as harp seal and minke whale, has been stable, their steady feeding on capelin would come in addition to the heavy predation by cod.

4.4 Causes of polar cod fluctuations

The Barents Sea polar cod stock was at a low level in 2017 and 2018. Norway conducted commercial fisheries on polar cod during the 1970s; Russia has fished this stock on more-or-less a regular basis since 1970. However, the fishery has for many years been so small that it is believed to have very little impact on stock dynamics. Stock size has been measured acoustically since 1986, and has fluctuated between 0.1–1.9 million tonnes. Stock size declined from 2010 to a very low level

in 2015, increased to 0.9 million tonnes in 2016, and again declined to 0.4 million tonnes in 2017. The rate of natural mortality for this stock appears to be quite high, relative to its importance as prey for cod and different stocks of seals.

It appears that polar cod mortality has increased in recent years. The recent warming in the Barents Sea has resulted in decreased sea ice distribution; several boreal species have moved northward, while the distribution area of Arctic species, such as polar cod, has decreased.

Since the mid-1990s, there has been a general trend of increase in both air and water temperature in the Barents Sea (See Section 3.1); record highs have been recorded during the 2000s. The areal extent of sea ice coverage has never lower, for both the Arctic and the Barents Sea, as in 2016. In the Barents Sea, the area of Arctic water decreased, while a larger portion has been dominated by warmer Atlantic water. These climatic changes have likely affected the distribution and abundance of Arctic species like polar cod.

The reduction of sea ice in winter reduces spawning habitat, leading to unfavourable conditions for polar cod spawning (Eriksen *et al.*, 2015c). The eggs have long incubation time and float near the surface where they may be exposed to unstable temperatures and increased water mixing due to lack of ice. Most of the juveniles are found in waters with temperatures below 5°C and reduction of cold-water masses in summer and autumn reduces the nursery area for 0-group polar cod. 0-group polar cod prey on small plankton organisms such as copepods and euphausiids, while adults feed mainly on large Arctic plankton organisms such as *Calanus hyperboreus* and *C. glacialis* and hyperiids. The biomass of Arctic forms of zooplankton decreased in recent years and most likely influenced negatively the feeding conditions for 0-group polar cod. However, no significant changes in the condition of adults were observed in recent years. This indicates a high degree of adaptability of this species to changes in the environment and enough available food resources.

The current fishing pressure is negligible now compared to the 1970s, when total catches were as high as 350 thousand tonnes. Thus, the total mortality is close to the natural mortality. Most likely predation by cod has contributed to the high natural mortality. Cod is a boreal species and associated with the temperate waters. The Barents Sea warming has been beneficial for cod and it has spread further north. In the northern areas cod overlapped with polar cod, and thus predation pressure on polar cod has increased, contributing to the declining stock trend in recent years. In the overlapping area cod feeds efficiently on polar cod (see Section 4.2).

4.5 Cod-capelin-polar cod interaction

The interaction cod-capelin-polar cod is one of the key factors regulating the state of these stocks. Cod prey on capelin and polar cod, and the availability of these species for cod varies. Cod can strongly influence on numbers of these species. In the years when the temperature was close to the long-term mean, the cod overlap with capelin and polar cod was lower than in the recent warm years. Cod typically consume most capelin during the capelin spawning migration in spring (quarters 1+2), but especially in recent years the consumption has been high also in autumn (quarters 3+4) in the northern areas (Figure 4.2.3). In 2017-2018 capelin consumption by cod was stable.

With the recent warming of the Barents Sea, the cod stock increased and became distributed over larger area, overlapping with capelin and especially polar cod to a higher degree than before. Cod can prey intensely on polar cod. The polar cod are most likely more available for cod than the capelin in mix concentration, because they possibly have a lower swimming speed (confirmed by trawl catch analyses) and are distributed closer to the bottom. However, capelin is a fatter and energetically more valuable prey item. It should be noted, that the polar cod biomass in the Barents Sea is substantially less than the capelin biomass, thus, the effect of cod consumption on the

stocks of these fish is different. Besides, that the length of the period with cod and polar cod overlap is much shorter (September-December) compared to the overlapping time of cod and capelin. Thus, interspecific interactions in this trophic system are very complex and require more detailed study.

4.6   Snow crab effect on benthos

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In most of the measured by BESS years, the biomass in the northeast part of the Barents Sea was above the total Barents Sea mean (Figure 4.6.1), but from 2013 and ongoing, the mean biomass was reducing, and was record low (<20 kg/nm) in 2016, and below the total Barents Sea mean. As one of the reasons of this decrease could be assumed develop of snow crab population and it predation on the benthos (including juvenile stages of the megabenthic animals. In 2017, the biomass extremely increased to 116 kg/nm, the highest value recorded over the entire period of BESS (Figure 4.6.1). But there are some reasons to assume in this year the benthic biomass overestimation due to changes in the trawl tuning. Lack of coverage of the snow crab area let not estimate mean biomass value in the 2018. Thus, the assumption about a decrease in the benthic biomass in the north-eastern part of the Barents Sea by the population of snow crabs, developing here, continues to remain in the hypothetical state.
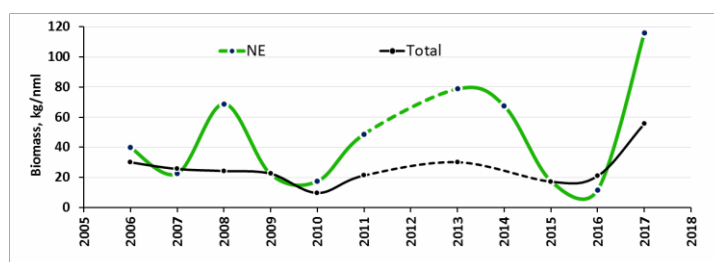

Figure 4.6.1 Inter-annual fluctuation of the mean megabenthos biomass (excluding *Pandalus borealis*) for the Barents Sea totally (black line,"Total") and for it north-eastern section (green line, NE). The years 2012 and 2014 are excluded from "Total" time-series, year 2012 – from NE time-series.

Current investigations show that the snow crab has very broad diet that includes almost all kinds of benthic invertebrates in the Barents Sea (Manushin *et al.* 2016). There is a difference in the diet of females and males, juveniles and adults. Juveniles and females prefer shallow areas with communities of bivalve molluscs, males live deeper on slopes and depressions where polychaetes and crustaceans are the most abundant group (Zakharov *et al.* 2018). Stomach contents are analysed to determine the species composition and the frequency of occurrence for various benthic taxa. Consumption of food was estimated and compared with data from the Russian seas of the Pacific region (Zakharov *et al.* 2018).

The total annual grazing of macro-zoobenthos by the snow crab is calculated for its current distribution in the Barents Sea. Snow crab consumes at least 30 thousand tons of benthos annually, which amounts to 0.1-0.2% of the total macrozoobenthos biomass of the investigated area. The snow crab population have the largest impact on the benthic communities in the north-eastern part of the Barents Sea and close to the south side of the Novaya Zemlya Archipelago (fig. 4.6.2). This is an area dominated by the polychaete *Spiochaetopterus typicus* (deeper areas with adult snow crabs) and the bivalve *Macoma calcarea* (shallower areas with juvenile snow crabs) (Zakharov *et al.* 2018).
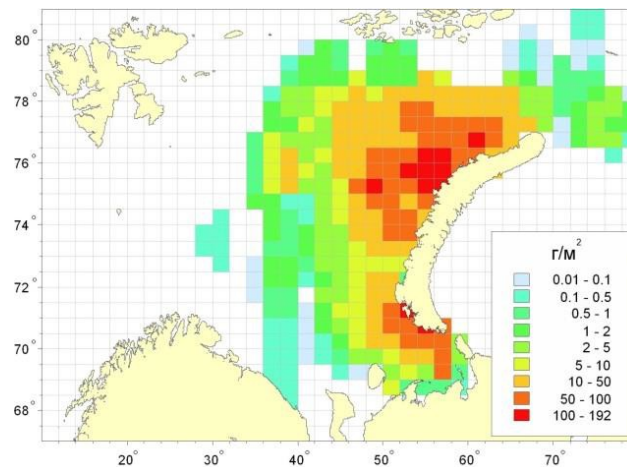
Figure 4.6.2. Total biomass (g/m2) of the benthos consumed/killed by the snow crab population during a nine-year period (2005–2017) (Zakharov et al. 2018).

4.7   Indirect effects of fisheries on the ecosystem

In order to conclude on the total impact of trawling, an extensive mapping of fishing effort and bottom habitat would be necessary. In general, the response of benthic organisms to disturbance differs with substrate, depth, gear, and type of organism (Collie et al. 2000). Seabed characteristics from the Barents Sea are only scarcely known (Klages *et al.* 2004) and the lack of high-resolution (100 m) maps of benthic habitats and biota is currently the most serious impediment to effective protection of vulnerable habitats from fishing activities (Hall 1999). An assessment of fishing intensity on fine spatial scales is critically important in evaluating the overall impact of fishing gear on different habitats and may be achieved, for example, by satellite tracking of fishing vessels (Jennings *et al.* 2001). The challenge for management is to determine levels of fishing that are sustainable and not degradable for benthic habitats in the long run.

The qualitative effects of trawling have been studied to some degree. The most serious effects of otter trawling have been demonstrated for hard-bottom habitats dominated by large sessile fauna, where erected organisms such as sponges, anthozoans and corals have been shown to decrease considerably in abundance in the pass of the ground gear. Barents Sea hard bottom substrata, with associated attached large epifauna should therefore be identified.

Effects on soft bottom have been less studied, and consequently there are large uncertainties associated with what any effects of fisheries on these habitats might be. Studies on impacts of shrimp trawling on clay-silt bottoms have not demonstrated clear and consistent effects, but potential changes may be masked by the more pronounced temporal variability in these habitats. The impacts of experimental trawling have been studied on a high seas fishing ground in the Barents Sea (Kutti *et al.* 2005.) Trawling seems to affect the benthic assemblage mainly through resuspension of surface sediment and through relocation of shallow burrowing infaunal species to the surface of the seafloor.

During 2009-2011 work between Norway and Russia was conducted to explore the possibility of using pelagic trawls when targeting demersal fish. The purpose with pelagic trawl is to avoid impact on bottom fauna and to reduce the mixture of other species. During the exploratory fishery it was mandatory to use sorting grids and/or a more stable four-panel trawl geometry with square mesh in the top panel of the cod-end to avoid catches of undersized fish. The efficiency of pelagic trawling was also tested in comparison with bottom trawling with regards to reduce the oil consumption per kilo of fish caught, i.e., to improve profitability and reduce NOx emissions.

After three years of exploratory fishing with pelagic trawls, pelagic trawling for cod, haddock and other demersal fishes are still not allowed, mainly due to on average a smaller size of the fish and too big catches which are difficult to handle. The experiment has, however, led to a further development of the bottom trawls, including bigger trawl openings, better size selection and es-capement windows to prevent too big catches.

Lost gears such as gillnets may continue to fish for a long time (ghost fishing). The catch effi-ciency of lost gillnets has been examined for some species and areas (but at present no estimate of the total effect is available. Ghost fishing in depths shallower than 200 m is usually not a sig-nificant problem because lost, discarded, and abandoned nets have a limited fishing life owing to their high rate of biofouling and, in some areas, their tangling by tidal scouring. Investigations made by the Norwegian Institute of Marine Research of Bergen in 1999 and 2000 showed that the amount of gillnets lost increases with depth and out of all the Norwegian gillnet fisheries, the Greenland halibut fishery is the metier where most nets are lost. The effect of ghost fishing in deeper water, e.g. for Greenland halibut, may be greater since such nets may continue to "fish" for periods of at least 2–3 years, and perhaps even longer (D. M. Furevik and J. E. Fosseidengen, unpublished data), largely because of lesser rates of biofouling and tidal scouring in deep water. The Norwegian Directorate of Fisheries has organised retrieval surveys annually since 1980. All together 10 784 gill nets of 30 meters standard length (approximately 320 km) have been removed from Norwegian fishing grounds during the period from 1983 to 2003. During the retrieval sur-vey in 2011 the following were retrieved and brought to land: more than 1100 gillnets, 54 red king crab traps, 13 km trawlwire, 12 km of ropes, 40 km longlines, trawl cod ends, 14 tonnes of fish and about 12000 crabs, mainly red king crab.

Other types of fishery-induced mortality include slipping (pelagic catch is released, but too late to survive), burst net, and mortality caused by contact with active fishing gear, such as escape mortality (Suuronen 2005). Some small-scale effects are demonstrated, but the population effect is not known.

The harbour porpoise (*Phocoena phocoena*) is common in the Barents Sea region south of the polar front and is most abundant in coastal waters. A new population estimate is in progress in Nor-way (Bjørge 2017). The harbour porpoise is subject to by-catches in gillnet fisheries, but testing sound scaring (pingers) show good effect on reduced bycatch of harbor porpoises (Bjørge 2017). Revised estimates of harbour porpoise by-catches in two Norwegian coastal gillnet fisheries sug-gest an annual bycatch of ~ up to 7 000 harbour porpoises along the entire Norwegian coast (Bjørge et al. 2013). This estimate will be updated 2019, and an advice is given to establish a surveillance and monitoring group to strengthen the advices for improved bycatch management (Bjørge 2017).

Fisheries impact seabird populations in two different ways: 1) Directly through by-catch of sea-birds in fishing equipment and 2) Indirectly through competition with fisheries for the same food sources.

Documentation of the scale of by-catch of seabirds in the Barents Sea is fragmentary. Special incidents like the by-catch of large numbers of guillemots during spring cod fisheries in Norwe-gian areas have been documented. Gillnet fishing affects primarily coastal and pelagic diving seabirds, while the surface-feeding species will be most affected by long-line fishing. The popu-lation impact of direct mortality through by-catch will vary with the time of year, the status of the affected population, and the sex and age structure of the birds killed. Even a numerically low by-catch may be a threat to red-listed species such as Common guillemot, White-billed diver and Steller's eider.

Several birds scaring devices has been tested for long-lining, and a simple one, the bird-scaring line, not only reduces significantly bird by-catch, but also increases fish catch, as bait loss is reduced. This way there is an economic incentive for the fishermen to use it, and where bird by-catch is a problem, the bird-scaring line is used without any forced regulation.

In 2009, the Norwegian Institute for Nature Research (NINA) and the Institute of Marine Research (IMR) in Norway started a cooperation to develop methods for estimation of bird by-catch. Estimates suggest that a total of 10 000 to 12 000 seabirds are killed by Norwegian fisheries in 2009 and 2010, where Fulmars, Cormorants, Puffins, Black Guillemot and Razorbills were particularly impacted, although for some local populations of Black Guillemot and Fulmars, the loss was concluded to be a small fraction of the populations (Fangel et al. 2011).

4.8 Benthic habitat integrity and benthos vulnerability

With retreating sea ice, new areas in the northern Barents Sea become available for fisheries, including bottom trawlers. Of special interest to WGIBAR is therefore the vulnerability analysis (Jørgensen *et al.*, 2015). Current knowledge of the response of benthic communities to the impact of trawling is still rudimentary. The benthos data from the ecosystem survey in 2011 have been used to assess the vulnerability of benthic species to trawling, based on the risk of being caught or damaged by a bottom trawl (WGIBAR report 2016). A clear decline in biomass was noted for all three categories when comparing trawled vs. untrawled areas. This suggests that trawling significantly affects the biomass of all species, but predominantly the "high-risk" taxa. Some Barents Sea regions were particularly susceptible to trawling (2016 WGIBAR Report).

4.9 Indirect impact of shipping on the ecosystem

Several sea birds species have had dramatic population declines and will be vulnerable for additional threats, like oil pollution (Fauchald *et al* 2019). Although the oil- and gas production in the Barents Sea is relatively small and in limited areas, the increase in ship traffic may add a risk for accidents leading to local oil spills. The increased traffic by cruise ships and fisheries activity in the Svalbard region add to the risk of local breeding populations.

References

Bjørge, A., Skern-Mauritzen, M, Rossman, M.C. 2013. Estimated bycatch of harbour porpoise (*Phocoena phocoena*) in two coastal gillnet fisheries in Norway, 2006–2008. Mitigation and implications for conservation. Biological Conservation 161: 164–173

Bjørge A. 2017. Status for bifangst av sjøpattedyr i Norge: Bestandsvurdering og rådgivning 2017. IMR, Norway 2017, 5pp. (in Norwegian: Status for bycatch of sea mammals in Norway: Stock assessments and advices 2017)

Fangel, K., Wold, L.C., Aas, Ø., Christensen-Dalsgaard, S., Qvenild, M., Anker-Nilssen, T. (2011) Bifangst av sjøfugl i norske kystfiskerier. Et kartleggings- og metodeutprøving- sprosjekt med fokus på fiske med garn og line - NINA Rapport 719. 72 pp. (in Norwegian: Bycatch of sea birds in Norwegian coastal fisheries)

Fauchald, P., Erikstad, K. E. & Reiersten, T. K. 2019. Seabird in the Barents Sea - an evaluation of vulnerable species, populations, areas and seasons based on new and updated data and knowledge. NINA Report 1616. Norwegian Institute for Nature Research.

Storting. Meld. 2003-2004 Havressursloven 2004 (White paper).

5 Expected changes in the coming years

5.1 Sea temperature

Oceanic systems have a "longer memory" than atmospheric ones. Thus, a priori, it seems feasible to predict oceanic temperatures realistically and much further ahead than weather predictions. However, the predicting is complicated due to variations being governed by processes originating both externally and locally, which operate at different time scales. Thus, both slow-moving advective propagation and rapid barotropic responses resulting from large-scale changes in air pressure must be considered.

According to the expert evaluation based on the analysis of the internal structure of the long-term variations in hydrometeorological parameters, over the next two years (2019–2020), the Atlantic water temperature in the Murman Current is expected to decline slightly but remain typical of warm years.

Due to high temperatures and low sea-ice extent in recent years, the ice coverage of the Barents Sea is expected to remain below normal.

5.2 Possible development of the stocks

Most of the commercial fish stocks found in the Barents Sea stocks are at or above the long-term level. The exceptions are polar cod and *Sebastes norvegicus*. In addition, the abundance of blue whiting in the Barents Sea is at present very low, but for this stock only a minor part of the younger age groups and negligible parts of the mature stock are found in the Barents Sea.

Concerning shellfish, the shrimp abundance is relatively stable and above the long- term meanwhile, the abundance and distribution area of snow crab is increasing.

Based on the current abundance and age structure of the main commercial stocks, the following lines of development are possible:

A new haddock outburst may take place, as the 2016 and 2017 year classes so far seem to be of the same order of magnitude as the strong 2004–2006 year classes.

The abundance of young herring is currently the highest since 2005, and this may affect the capelin recruitment in 2018–2019 negatively.

The westward expansion of snow crab leads to higher overlap between cod and snow crab and thus predation by cod on snow crab may slow down the rate of increase of the snow crab stock.

If the sea temperature increases further, this may allow further north and eastwards expansion of several stocks, while e.g. cod has almost reached it maximal distribution and polar cod will be negatively affected by other species moving into typical polar cod areas.

Annex 5: Time-series used in WGIBAR

Description of the time-series used in the integrated multivariate analysis, grouped into abiotic, biotic and pressures.

a. Abiotic

Winter (December–March) North Atlantic Oscillation (NAO) index (station-based). TaAnom_East and TaAnom_West - Air temperature anomalies in the eastern (69–77°N, 35–55°E) and western (70–76°N, 15–35°E) Barents Sea based on monthly data from the ERA Interim (ECMWF). Storms - Annual storm activity (number of days with wind 15 m/s and more) anomaly in the central Barents Sea.

Ice:

IceareamaxApril and IceareaminSept - Ice area in the Barents Sea (10–60oE, 72-82oN) at maximum (April) and minimum (September) ice coverage. Sea ice concentration was obtained from the National Snow and Ice Data Center (NSIDC)

Fluxes:

The Barents Sea is a through-flow system with Atlantic water entering from the Nor- wegian Sea in southwest and leaving modified between Novaya Zemlya and Franz Josef Land in northeast. Here, we use modelled volume transports from a 4 km resolu- tion model hindcast for the Barents Sea. BSO is the modelled net eastward volume transport between Norway and Bear Island (positive into the Barents Sea). BSX is the modelled net eastward volume transport between Franz Josefs land and Novaya Zem- lya (positive out of the Barents Sea). NBSO is the modelled net southward volume transport between Svalbard and Franz Josef Land (positive into the Barents Sea). SBSO is the modelled net eastward volume transport between Kola and Novaya Zem- lya (positive out of the Barents Sea).

Water masses:

Areas of Arctic Water (Area_ArW, T<0°C), Atlantic Water (Area_AW, T>3°C) and Mixed Water (Area_MW 0°C<T<3°C) were calculated based on the mean 50-200 tem- perature fields from temperature measurements taken during the BESS. To ensure complete data coverage each year, the area calculations were restricted to the area 72– 80°N, 20–50°E.

Ocean temperatures:

TempNE and TempNW - Average temperature in two boxes representing the northern and northeastern Barents Sea based on data from the BESS. FB-aug - The temperature averaged over the 50–200 meter depth range between 71.5°N and 73.5°N in the Barents Sea Opening in August. Kola_Temperature - The annual mean temperature averaged over the 50–200 meter depth range between 70.5°N and 72.5°N in the Kola Section.

Salinity:

Kola_Salinity - The annual mean salinity averaged over the 0-200 meter depth range between 70.5°N and 72.5°N in the Kola Section.

b. Biotic

Plankton

Meso-zooplankton – Biomass estimate (interpolated from catches by WP2 plankton nests) from survey in August-September, total and by three size fractions (Zoopl_Total, ZooplSmall, ZooplMedium, ZooplLarge). The mesozooplankton biomass data consist mainly of copepods.

Krill - There are four species of krill in the BS, our data are not separated by species. The krill series is from 0-group survey (now the BESS) covering most of the BS shelf in August-September. A pelagic trawl is used, and only larger (>15 mm) specimens are retained in the trawls.

Jellyfish (Jelly) - This is a biomass index based on data from 0-group survey (now the BESS) covering most of the BS shelf in August-September.

Benthic invertebrates - *Pandalus borealis* index (Shrimp) from stock assessment.

Pelagic fish

Mallotus villosus- Capelin is a key species in the BS, capelin total-stock biomass (age 1+) acoustic estimate from survey in August-September (Capelin_TSB), length growth from age 1 to 2 (Capelin_gr12), condition at age 2 (Capelin_cond), % mature age 2 (Cap- elin_Mat2). 0-group abundance and biomass is from the BESS/0-group survey, pelagic trawl (Capelin_0).

Boreogadus saida – Polar cod is a true arctic species. Polarcod_biom is acoustic estimate of biomass from the acoustic survey in August-September. The acoustic survey was originally targeted towards capelin, and the polar cod distribution area extends north- east outside the survey area, so the estimate of the polar cod is uncertain, especially before 2004. 0-group abundance and biomass is from the BESS/0-group survey, pelagic trawl (Polarcod_0).

Juvenile *Clupea harengus*. Juvenile herring is a key species in the BS, and strong year classes of herring are often associated with recruitment failure of capelin: VPA data age 1 and 2 on herring multiplied with individual weight by age (Herring1-2_biom). 0- group abundance is from the BESS/0-group survey, pelagic trawl (Herring_0).

Demersal fish

Gadus morhua – Cod is the most important piscovore in the BS and a very important commercial species. Cod total-stock biomass (Cod3+_biom), recruitment-at-age 3 (Cod_Rec3), weigth at age (Cod_w3y, Cod_w5y, Cod_w8y), weight at age 3, proportion mature at age 7 (Cod _mat7), all these series are obtained from assessment. 0-group abundance is from the BESS/0-group survey, pelagic trawl (Cod_0).

Melanogrammus aeglefinus – Haddock is an important commercial species, and is more benthivor than cod. Haddock total-stock biomass (Haddock3+_biom), spawning-stock biomass ages 6–8 (Haddock_SSB68), recruitment-at-age 3 (Haddcok_R3), and predation mortality age 3 from cod (Haddock_M_age3). Data from assessments (ICES 2016c) 0-group abundance is from the BESS/0-group survey, pelagic trawl (Haddock_0).

Hippoglossoides platessoides – long rough dab is of limited commercial importance but one of the most abundant and widespread fish in the BS. We used a cpue index from the Russain demersal survey in Nov-Dec (LRD) 0-group abundance is from the BESS/0- group survey, pelagic trawl (LRD_0).

c. Pressures

Fishing mortality of shrimp (Relative_F_Shrimp) is from the last shrimp assessment (ICES 2016a).

Fishing mortality and haddock (Cod_F510 and Haddock_F47) are from the last stock assessments (ICES 2016c).

Fishing Mortality of Capelin (Relative_F_Capelin) in year y was calculated as the sum of catches in autumn year y-1 and the next spring (year y) divided by biomass in autumn year y-1. This was shifted one year compared to the analyses done last year, to reflect that most of the catches are taken in spring.