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

22-26 February 2016

Murmansk, Russia



# International Council for the Exploration of the Sea Conseil International pour l'Exploration de la Mer

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# Contents

Exe	cutive	e summary1			
Adı	Administrative details2				
1	Terms of Reference a) – d)				
2	Sum	mary of Work plan4			
3	Sum	mary of Achievements of the WG during 3-year term5			
4	Fina	l report on ToRs6			
	4.1	Introduction			
	4.2	ToR a: Prepare an inventory of, and compile, relevant datasets (such as data from the joint IMR-PINRO surveys, and others) that can be used to describe and analyse fluctuations and changes in the Barents Sea ecosystem			
	4.3	ToR b: Perform integrated analyses of multivariate and multidisciplinary datasets (including pressures and drivers) to examine and document past and current changes in the ecosystem;7			
	4.4	ToR c: Prepare an annual status report of the Barents Sea ecosystem based on the integrated analysis of multivariate datasets from monitoring surveys and other relevant sources including three- dimensional physical and ecological modelling			
	4.5	ToR e Consider and suggest improvements to the monitoring activities and programs in the Barents Sea including survey design, observation and estimation methods and sampling that will improve the fundament for integrated ecosystem assessments			
	4.6	ToR d Identify knowledge gaps and priority research items that when addressed, can improve future integrated ecosystem assessments9			
5	Coop	peration15			
6	Sum	mary of Working Group self-evaluation and conclusions			
7	Refe	rences			
Anr	nex 1.	List of participants19			
Anr	nex 2.	Recommendations20			
Anr	nex 3.	WGIBAR new terms of reference21			
Anr	nex 4.	WGIBAR Self-evaluation24			
Anr	1ex 5.	WGIBAR State of the Barents Sea 201526			

### **Executive summary**

The third meeting of the Working Group on the Integrated Assessments of the Barents Sea (WGIBAR) was held in Murmansk on 22–25 February 2016. A report on the Barents Sea ecosystem state was prepared (Annex 5). Since the 1980s there has been a warming trend, reduced fishing pressure, and increased biomass of several mostly boreal species. The current situation is unprecedented. The main findings for 2015 are:

- The atmosphere and ocean temperature was higher than the long-term mean (1951–2010) and higher than 2013 or 2014. The ice coverage was lower than normal and lower than 2013 or 2014. The seasonal ice maximum was observed in February, two months earlier than usual.
- The mean biomass of mesozooplankton was somewhat higher than in 2014. Biomass was highest in the western Barents Sea (BS) in the area of inflowing Atlantic water, and was lower in the northeastern Barents Sea compared to 2013–2014.
- The biomass of krill, mostly found in warmer water remained higher than the long-term mean and was higher than in 2014. Hyperiid amphipods (colder water), are at low levels.
- The capelin biomass decreased to a low level. Causes of capelin decline are an increase in natural mortality (mainly due to high cod consumption), low growth, and relatively low recruitment.
- Polar cod is at its lowest level since 25 years. There is no fishing on polar cod, but natural mortality appear to be very high. Increased consumption of cod has contributed to increase the natural mortality. In the last three years the recruitment of polar cod has been very poor, possibly due to changes in spawning habitat.
- Cod stabilized at three million tonnes, well above the long-term mean (1946-). Haddock is declining slightly, but the stock size is at present about 1 million tonnes, twice the long-term mean (1950-).
- Related to the retreating sea ice, new areas of sea are open for human activity. A baseline mapping of benthic species vulnerable to trawling was published in 2015. This map should be of relevance to management of human activities.
- The distribution area of the invasive snow crabs continued to increase, but the impact and development of this stock in future are unknown.
- Due to the low levels of polar cod and capelin, cod and other piscivores have to compensate by feeding on other prey, which has potential large consequences for the foodweb.

Since most stocks have increased their distribution area during the last decade, an increase in days at sea is required to get complete coverage. The ecosystem survey is of particular value in the current situation since it covers the whole BS shelf, and allows the study of spatial overlap and interactions. WGIBAR recommends that annual monitoring of all ecosystem components should be kept at the same level as in the period up to 2016. Of particular concern in 2016 is the influence of the capelin collapse on the cod stock and the foodweb.

# Administrative details

### Working Group name

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

Year of Appointment within the current three-year cycle

3

Reporting year concluding the current three-year cycle

2016

Chair(s)

Yury Kovaljev, Russia

Edda Johannesen, Norway

Meeting venue(s) and dates

24-28 March 2014, Kirkenes, Norway (12 participants)

1-4 June 2015, Kirkenes, Norway (12 participants)

22–25 February 2016, Murmansk, Russia (12 participants)

1	Terms of Reference a) – d)	

ToR	DESCRIPTION	Background	Science Plan topics addressed	DURATION	Expected Deliverables
a	Prepare an inventory of, and compile, relevant datasets (such as data from the joint IMR-PINRO surveys, and others) that can be used to describe and analyse fluctuations and changes in the Barents Sea ecosystem	Science and advisory requirements		Year 1and 2	Year 2 Report on data inventory
b	Perform integrated analyses of multivariate and multidisciplinary datasets (including pressures and drivers) to examine and document past and current changes in the ecosystem	Science and advisory requirements		Year 1, 2 and 3	Annual reports on integrated analysis progress, papers as appropriate
с	Prepare an annual status report of the Barents Sea ecosystem based on the integrated analysis of multivariate datasets from monitoring surveys and other relevant sources including three- dimensional physical and ecological modelling	Science and advisory requirement		Year 1, 2 and 3	Annual status reports
d	Identify knowledge gaps and priority research items that when addressed, can improve future integrated ecosystem assessments	Science and advisory requirements		Year 1, 2, and 3	Updates in annual meeting reports
e	Consider and suggest improvements to the monitoring activities and programs in the Barents Sea including survey design, observation and estimation methods and sampling that will improve the fundament for integrated ecosystem assessments	Science and advisory requirements		Year 1, 2 and 3	Updates in annual meeting reports

# 2 Summary of Work plan

#### Year 1

Focus will be on preparation an inventory of, and compile, relevant datasets (such as data from the joint IMR-PINRO surveys (Annex 1), and others) that can be used to describe and analyse fluctuations and changes in the Barents Sea ecosystem. Consider how to achieve regular evaluation of monitoring program (surveys design and sampling, uncertainties in stocks estimations and observation methods) and make priorities for different tasks. Start work on integrated data analyses and prepare a first version of a status report of the Barents Sea ecosystem.

#### Year 2

Perform integrated analyses of multivariate and multidisciplinary datasets (including pressures and drivers) to examine and document past and current changes in the ecosystem. Identify knowledge gaps and priority research items that when addressed, can improve future integrated ecosystem assessments. Prepare an updated annual status report of the Barents Sea ecosystem based on the integrated analysis of multivariate datasets from monitoring surveys and other relevant sources including three-dimensional physical and ecological modelling.

#### Year 3

Consider and suggest improvements to the monitoring activities and programs in the Barents Sea including survey design, observation and estimation methods and sampling that will improve the fundament for integrated ecosystem assessments. Continue work to identify knowledge gaps and priority research items. Prepare updated integrated data analyses and annual status report of the Barents Sea ecosystem.

# 3 Summary of Achievements of the WG during 3-year term

- Barents Sea Ecoregion Ecosystem overview:
  <u>http://www.ices.dk/sites/pub/Publication%20Reports/Advice/2016/2016/Barents Sea Ecore-gion-Ecosystem overview.pdf</u>
- Spatial indicators and methods. Workshop Bergen May 2014.
- Exchange of knowledge for Integrated Ecosystem Assessment. Workshop Bergen February 2016. Supported by the ICES Science fund.
- "IEA Comparison: Norwegian waters" Oral presentation held by D, Howell at the ICES Annual Science Conference, 15–19 September 2015, A Coruña, Spain.
- "Integrated ecosystem assessment of the Barents Sea: recent findings and relevance to management" Oral presentation held by E. Johannesen at the 17<sup>th</sup> Russian-Norwegian Symposium: "Long-term sustainable management of living marine resources in the Northern Seas" 16–17 March 2016 Bergen, Norway.
- "Climate related changes and ICES activities on IEA for the Barents Sea and Norwegian Sea LMEs" and "Arctic Large Marine Ecosystems and the Ecosystem Approach to Management – work under the Arctic Council" Oral presentations held by H.R. Skjoldal at the South-Russia Science Center, Russian Academy of Sciences, Rostov-on-Don, Russia, 28–29 October 2015.
- "Integrated Ecosystem Assessment Work at IMR and ICES. Oral presentation held by H.R: Skjoldal: NOAA meeting on IEA, Boulder, USA. 1–3 March 2016

### 4 Final report on ToRs

#### 4.1 Introduction

WGIBAR was appointed in 2013 to perform Integrated Ecosystem Assessment of the Barents Sea (Figure 1) by compiling relevant data (ToR a), perfoming multivariate analysis (ToR b), and gathering new results from research and monitoring to prepare annual ecosystem status reports (ToR c). Furthermore, the connection between research, monitoring and ecosystem assessment (Figure 2) was addressed by defining priority research items (ToR d) and monitoring activities (ToR e) that could improve integrated ecosystem assessment.



Figure 1. The Barents Sea is a high latitude shelf sea shared between the Kingdom of Norway and the Russian Federation. The countries are parties to the 1982 Law of the Sea Convention and have implemented the provisions of that convention as regards sea boundaries. The continental shelf is divided between the two countries by a 1680 km boundary line that was agreed in cooperation agreement in 2010 (in force from 7 July 2011). An area of approximately 60 000 km<sup>2</sup> in the Barents Sea (the "loophole") is beyond the 200 mile zones of the two countries. The Norwegian EEZ was established from 1 January 1977, while the EEZ of the Soviet Union was established 22 March that year. Also, Norway established a non-discriminatory Fisheries Conservation Zone around Svalbard (Spitsbergen) the following year, on the grounds that expanding fisheries in the north threatened fish stocks there. Norway's rights to practise resource management in this area, through appropriate regulations, as well as necessary control and enforcement measures, has been disputed by some countries, including Russia. The exact geographic delineation of the Barents Sea varies, but the 500 m depth contour is commonly used to delimit the Barents Sea shelf towards the deeper basins to the west and north.

WGIBAR built on the framework provided by Skjoldal and Misund (2008) where Integrated (Ecosystem) Assessment is "building on new information from monitoring and research of the current situation, including the impacts of human activities". In this framework ecosystem assessment is one of five elements in the Ecosystem Approach to Ocean Management (Figure 2).



Figure 2. A framework for Ecosystem Approach to ocean management with main components shown in an iterative management decision cycle: *Objectives:* set for the overall condition in the ecosystem and translated into operational objectives or targets. *Monitoring and research:* to provide updated information on the status and trends and insight into the relationships and mechanisms in the ecosystem. *Assessement:* building on new information from monitoring and research of the current situation, including the impacts of human activities. *Advice:* translating the complexities of nature into a clear and transparent basis for decision-makers and the public. *Adaptive management:* where measures are tailored to the current situation in order to achieve the agreed objectives (from Skjoldal and Misund, 2008).

The Report of the Workshop on Benchmarking Integrated Ecosystem Assessments (ICES 2013) advised linkages between single-stock assessment groups and ecosystem assessment groups. This was taken into consideration when forming WGIBAR. WGIBAR had in the period 2014–2016 23 members, of which nine are members of the Arctic Fisheries Working Group (AFWG), the main single-stock assessment group for the Barents Sea stocks.

The members of WGIBAR have been from two institutions: the Institute of Marine Research Research (IMR), Norway and Knipovivh Polar Research Institute of Marine Fisheries and Oceanography (PINRO), Russia. These two institutions carry out the large-scale monitoring of the Barents Sea ecosystem and provide advice for the main stocks. In future, members from other institutions could be included in WGIBAR.

# 4.2 ToR a: Prepare an inventory of, and compile, relevant datasets (such as data from the joint IMR-PINRO surveys, and others) that can be used to describe and analyse fluctuations and changes in the Barents Sea ecosystem

WGIBAR compiled dataseries for the first WGIBAR interim report, updated and expanded these for the second report to include more than 100 time-series.

# 4.3 ToR b: Perform integrated analyses of multivariate and multidisciplinary datasets (including pressures and drivers) to examine and document past and current changes in the ecosystem;

Multivariate analyses were performed on time-series going back to 1986 or further. The time-series representing the main ecosystem components was included in the dataset

for the analysis. Both interim reports included Integrated Trend Analysis (ITA: Principal Component Analysis on time-series of the main ecosystem components). In this year's report ITA on data updated to 2015 can be found in Chapter 2.1 in Annex 5.

# 4.4 ToR c: Prepare an annual status report of the Barents Sea ecosystem based on the integrated analysis of multivariate datasets from monitoring surveys and other relevant sources including three-dimensional physical and ecological modelling.

A joint Norwegian-Russian report on the status of the Barents Sea ecosystem updated to 2013 is underway and will be published on the Barentsportal website (http://www.barentsportal.com/barentsportal/) this spring. This report will be approximately 400 pages (McBride *et al.*, 2016). Most of the WGIBAR members have contributed to this report.

In the two interim reports of WGIBAR annual ecosystem status reports have been provided as Annexes ("Report on the state of the Barents Sea ecosystem components 2013", 30 pages, Annex 4 to the WGIBAR report 2014 and "Barents Sea Ecosystem State 2014", 70 pages, Annex 5 to the WGIBAR report 2015). This year the annual status report is found in Annex 5.

# 4.5 ToR e Consider and suggest improvements to the monitoring activities and programs in the Barents Sea including survey design, observation and estimation methods and sampling that will improve the fundament for integrated ecosystem assessments.

Apart from smaller scaled, more targeted monitoring by other countries/institutions (e.g. around Svalbard/Spitsbergen) IMR and PINRO are currently responsible for the large-scale monitoring of the BS stocks and main ecosystem components, including oceanography and pollution.

An evaluation of the present monitoring and the development of a new strategy for surveying of the Barents Sea has started at IMR in 2012. It resulted in a report describing the present system for monitoring/surveying, a short historic account on how today's surveys developed from previous surveys/monitoring programs and recommendations for future development (Eriksen and Gjøsæter, 2013). The report was discussed with PINRO during the 2013 IMR-PINRO March meeting. The report suggested that the Joint IMR PINRO winter survey (January-March) should be strengthen through coordinating the effort with the cod spawning survey (April) and that the Joint IMR PINRO ecosystem survey in August-September should be strengthen by allocating effort from other surveys in the second half of the year.

Since this report came out (2013) the large-scaled monitoring activity in the Barents Sea has been reduced: the Russian groundfish survey in late autumn-early winter was stopped in 2016 and the plan for the Joint IMR-PINRO ecosystem survey as of March 2016 will result in major reduction in effort on this survey in 2016.

The reduction in days at sea is very unfortunate, since most stocks have increased their distribution areas during the last decade, so an increase in days at sea is required to get complete coverage. Furthermore, although the cod and haddock stocks in the Barents Sea are currently large, the situation in the Barents Sea is now changing rapidly, with unknown consequences for the stocks. The ecosystem survey is of particular value in the current situation since it covers the whole BS shelf, and allows the study of spatial overlap and interactions.

WGIBAR recommends that the annual monitoring of all ecosystem components should be kept at the same level as in the period up to 2016.

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

In the first WGIBAR interim report (2014) research questions relevant to the Barents Sea integrated assessment were formulated. These questions were addressed in working group documents and by group work during the meetings and intersessionally. Current state of knowledge pertaining to these questions is summarized and discussed below.

# Question 1. The last decade has been the warmest on record. During the last 30-40 years there has been a general warming in the BS whereas before this there was a general cooling. Will there be a long-term cooling trend in the BS soon, and how cold will the BS then become?

The question of climate predictability is very complicated. Prediction reliability of future climate change depends upon many factors, each of which provides some degree of uncertainty. The main sources of uncertainty are (Anon., 2008):

- there is a fundamental problem to forecast future technological development and energy use in the world for a long period. In turn, it causes uncertainty in future emissions of greenhouse gases and aerosols to the atmosphere;
- it is a priori impossible to take into account natural external forcing such as future volcanic eruptions and changes of solar flux at the top of the atmosphere;
- current models describe climatically significant processes and relevant feedbacks with some inaccuracy, which is caused by inadequate understanding of some physical processes.

There are two main opinions about the future climate changes. The first opinion is that human activity and greenhouse gases are responsible for climate changes, so the current warming will continue in future. Those who share this point of view believe that considerable reduction in ice covered area in the Arctic and warming of the global ocean will continue during the 21<sup>st</sup> century (Anon., 2008; IPCC, 2014). They expect that there will be no sea ice in the Arctic Ocean during summer by the middle of the twenty-first century (Tsaturov and Klepikov, 2012). The maximum sea ice extent, which is normally observed in March, will continue to decrease by 2% per decade, and the minimum ice extent, which normally happens in September, will be reduced by 7% per decade relative to ice extent for the period 1910–1959 with a faster reduction in the area of multiyear ice compared with the seasonal ice area (Anon, 2008).

The second opinion is that natural cyclic processes play a significant role in climate changes, so warming and cooling periods alternate and cooling must be expected in future. Recent predictions of global warming have projected a significant decrease of the ice-spreading area in the Arctic, prophesying its complete disappearance by the end of the 21<sup>st</sup> century. However, these forecasts are based on the significant decrease in the ice cover area in the Arctic Seas only over the last 15–20 years. Frolov *et al.* (2009, 2010, 2012) provide data from analyses of climatic changes in the Arctic and fluctuations of the sea-ice extent over an 80–100-year period, and show that there is no unambiguous proof of the future state of the ice cover in the Arctic. The authors examine spatial and temporal special features of the constituents of the Arctic climate system and discuss in detail the different parameters of the Arctic climate system. They prove

the importance of natural climatic changes induced by internal and external causes and demonstrate that the Arctic sea ice cover is unlikely to disappear during the next few decades. The authors also predict future changes of air temperature and ice covered area in the form of cyclic variations and refute predictions of progressive global warming due to anthropogenic causes of climatic changes. They expect that an oscillatory (rather than a unidirectional) background of ice area changes in the Arctic Seas will be preserved during the current century, with a gradual increase by the 2030s and a subsequent decrease by the 2060s. They also predict the decreasing of temperature by 2030–2040 and preservation of oscillations typical for the twentieth century.

The Barents Sea climate exhibits variability on time-scales from weeks to months and up to the decadal and multidecadal time-scales, as manifested in the Kola section temperature time-series. Depending on the underlying, governing processes, the Barents Sea climate may be predicted to a certain degree at various lead times.

Ottersen *et al.* (2000) gave predictions of temperature in the Arcto-boreal Barents Sea for many years. To evaluate an objective statistical forecasting system, they analysed time-series representing mechanisms previously proposed as influencing the temperature of the Barents Sea. These include components of suggested periodic nature, largescale advective effects, regional processes, and atmospheric teleconnections. The predictability of Barents Sea temperature based on the above mechanisms was evaluated through calculations of auto- and cross-correlations, linear regression, spectral analysis and autoregressive modelling. Forecasts based on periodic fluctuations in temperature performed poorly. Advection alone did not explain a major part of the variability. The precision of predictions six months ahead varied with season; forecasts from spring to autumn had least uncertainty. A first-order autoregressive model, including modelled atmospherically driven volume flux to the western Barents Sea during the preceding year and the position of the Gulf Stream off the east coast of the USA two years earlier, explained 50% of the total historical temperature variability.

According to the temperature prediction in the southern Barents Sea, made using a prediction model based on harmonic analysis of data time series (Boitsov and Karsakov, 2005) with use of background predictions of air temperature and ice extent, the Atlantic Water temperature in the Kola section (the Murman Current) is expected to remain typical of warm years over the next two years with a small decline in the mean annual temperature from 5.0°C in 2015 down to about 4.7°C in 2016 and about 4.6°C in 2017.

Årthun and Eldevik (2016) explore the propagation of ocean heat anomalies through the northeastern North Atlantic using a multi-century climate model simulation. They found a dominant mode of northern seas climate variability of 14 years, which includes observed SST, modelled OHC, air-sea heat flux and SAT. Furthermore, they found that ocean heat content anomalies are driven by poleward ocean heat transport owing to variable volume transport. This offers some predictability due to the approximatively 2 years propagation time from the upstream entrance to the Norwegian Sea to the entrance to the Barents Sea (e.g. Furevik, 2001). Observations from 2015 reveal decreasing warm anomalies upstream along the northward Atlantic Water pathway through the eastern Norwegian Sea. Thus, the Barents Sea temperature may be expected to drop from today's level in the coming few years.

On a larger scale, Drinkwater *et al.*, 2014, identified a pattern of a linear dependence between spatial and temporal scales in the log-log space. At the high end, they identified the AMO to vary at a spatial scale of about 10 000 km and a temporal scale of 60–

70 years. Moreover, they found a high correlation between the AMO and the temperature as observed in the Kola section. Based on historical variations in the AMO, the current high temperatures may be interpreted as a multidecadal maximum in the North Atlantic temperature, indicating that the temperature trend, excluding any anthropogenic warming, may turn negative over the next few decades. To what degree the anthropogenic warming trend may offset such a downtrend is still under debate.

# Question 3. Are there different optimal levels of exploitation of commercially important species in "cold" and "warm" periods / different productivity regimes?

In periods where the stocks has high surplus productivity larger catches can be taken without resulting in stock declines. Since boreal species are on the northern border of their distribution limit in the Barents Sea, they are expected to be more productive in warm periods. In a working document by Johannesen et al. (2016) assessment data by age on cod and haddock and biomass data on capelin were used to calculate surplus production by cod, haddock, and capelin using the method described in Dutil et al. (1999). The main findings were: *i*) The cold period in the late 1970s and early to mid-1980s coincided with small stocks of cod and haddock with low surplus productivity, whereas the recent warm period has had large and productive stocks of cod and haddock. ii) Negative density-dependence in surplus production is evident in the most recent years for both cod and haddock, but the results are based on assessment data, which are inheritably more uncertain in the most recent years *iii*) In the recent warm period, surplus production the way it is calculated here, has been low for capelin, due to high predation pressure from the large demersal stocks. There is no clear evidence of density-dependence in surplus production of capelin *iv*) Currently, we cannot answer the question on different optimal levels of exploitation for warm and cold periods and we lack empirical data on the surplus production under warm conditions for small demersal stocks, and surplus production under cold conditions for large demersal stocks. v) Most likely, a higher fishing pressure can be sustained in warmer periods in the Barents Sea. However, complex interactions and rapid and unprecedented changes in the Barents Sea calls for caution.

# Question 5. Most of the stocks in the BS are large and well managed, but could the management be further improved if we take ecosystem considerations more into account?

This is likely. There are three main issues:

- 1) Improve assessments of present stock size and stock history as well as short to medium-term predictions of stock development if more species interactions and other ecosystem interactions are taken into account (e.g. including predation by cod also in models for *Sebastes mentella*, herring and shrimp, as well as developing models predicting predation by cod on capelin, cod, and haddock). Cod growth could also be modelled as a function of prey abundance. Including predation by minke whales and harp seals is also an option although feeding data are limited. This approach of adding species interaction into existing single-species models has been termed 'Extended singlespecies Assessment Models' (Plaganyi, 2007).
- 2) Harvest control rules could be changed to give a higher yield for some stocks (and then probably yield of other stocks would be lower). In order to define whether this would improve management, one would need some quantity to define result of management (e.g. total economic yield). Total catch in biomass would not be a useful measure, as this would strongly favor harvesting at lower trophic levels.

3) In order to investigate the performance of various harvest control rules on the ecosystem appropriate models are needed. Over the last 25 years, several multispecies models for the Barents Sea have been developed (Bogstad *et al.*, 1997; Schweder *et al.*, 2000; Filin, 2005; Tjelmeland, 2005; Lindstrøm *et al.*, 2009; Howell and Bogstad, 2010) as well as some ecosystem models (Ecopath, Atlantis (Hansen *et al.*, 2016)). Even if we limit the models for such use to the main commercial species and the predators/prey/other effects most important for those, this is a formidable task – both considering selection of model structure and resolution level as well as estimation of parameters in the actual model. It would be advisable to focus on development of assemblage model that would be able to incorporate different models. See also model overview in AFWG section 1.4.1 (ICES 2015).

# Question 6. The cod stock is very large, if cod becomes food limited, should the fishing pressure on cod be increased (or decreased)?

This has been investigated by WKNEAMP-2 (ICES 2016) as well as by Filin (presentation). The background for these investigations was that several (no. 6-10) of the harvest control rules for cod suggested by the Joint Russian Norwegion Fisheries Commission (2015) which were tested by WKNEAMP-2 says that fishing mortality should be increased at high SSB levels (for some rules (no. 8-9) this takes place only when capelin stock size is low). The results indicate that increase of cod fishing mortality from F =0.40 to 0.60, when cod SSB is high and capelin is low, will not have negative long-term consequences for cod stock and cod fishery. This will not lead to major changes if constraint on interannual variations in cod Total Allowable Catch (TAC) is not be introduced. This will support increasing long-term mean of cod TAC and capelin stock, but will reduce stability of cod stock size and TAC if 20% constraint on interannual changes in TAC will be applied.

Question 8. The cod stock is one of the most profitable stocks in the BS and the current strategy is to aim for a maximum catch of cod and to take the catch of other fish as a "residual" after cod consumption

- What is the cost (loss of catch of other species) of having a large cod stock?

- How would alternative harvesting strategies of cod change the biomass of stocks of other commercial species and their MSY?

#### - How would different harvesting strategies affect the rest of the ecosystem?

Simple approach – estimate changes in consumption of prey based on scaling up or down consumption calculations (linear or not), and adjust prey stock levels and yield accordingly based on historical data.

As explained above, joint and evaluated models for investigating these issues are not available at present. Although there is likely to be a cost (loss of catch) to other species of having a large cod stock, the complicated nature of the ecosystem may result in unexpected effects. To illustrate this:

When comparing the results of Bogstad *et al.* (1997) and Schweder *et al.* (2000), it is seen that one model estimates that the indirect effects are stronger than the directed effects, while another and equally plausible model estimates the direct effects to be the strongest. To put it more clearly: In both models, minke whales prey on both capelin and cod (and herring), cod prey on both cod and capelin, and additionally cod growth depends on capelin abundance. Bogstad *et al.* (1997) found that increasing the whale stock led

to an increased capelin stock, while Schweder *et al.* (2000) found that increasing the whale stock led to a decreased capelin stock.

A large spawning stock of cod and other stocks may lead to high abundance of larvae and 0-group, which are prey for other organisms. Thus, a high spawning stock may also have a positive effect on the ecosystem although the gain in recruitment to the fishable stock is marginal when increasing the SSB above some threshold.

#### Question 9. Capelin is moving north-eastwards - is the movement driven by food limitations?

# Question 10. Why has the condition and weight-at-age of capelin decreased the last five years or so

The capelin weight-at-age dropped continuously from 2006–2007 to 2013 for all age groups. The uninterrupted 7-year decline stands out in the time-series of weight-atage, which typically has high interannual variability. The most dramatic decline was observed for the two-year-olds where average weight-at-age dropped almost 50% from 16.1 to 8.4 g from 2006 to 2013. The weight-at-age has stabilized or slightly increased after 2013. Also the condition factor declined markedly during the same period, around 30% for all age groups from 2006 to 2014, but with more annual variability than for the weight-at-age. The decline in capelin weight-at-age and condition factor correspond to a strong reduction in the estimated abundance of large copepods (> 2000  $\mu$ m), which has been below the long-term average (1988–2015) in all years after 2006, and was reduced by 75% from the peak year in 2004 to the low in 2013. The large copepods are important in the capelin diet. Amphipod/hyperiid abundance has also decreased noticeably. Krill, which is an important prey item for capelin, has not shown a similar decrease as large copepods and amphipods. From 2009 to 2013 there has been a decrease in stomach fullness of capelin (Dalpadado et al., 2015). The stomach content of capelin may reflect the low prey availability and that may have led to the decrease in capelin growth observed in the recent years.

In the years 2010–2013, the capelin distribution was further north than ever before monitored. It is likely that the warm Barents Sea in this period made more northerly areas adequate for food exploitation. However, it is important to note that extensive seasonal feeding migrations are costly in energy, and in principle they should be avoided unless the local feeding conditions further south are sufficiently poor. There is evidence to support that there was a marked reduction in abundance of large copepods in the Barents Sea during the years of long capelin migrations, and that food limitation could be a driver behind the migrations.

# Question 11. What is driving the variability of jellyfish biomass, and will the observed increase in jellyfish impact 0-group fish or other planktivores?

The biomass of jellyfish has increased in many marine ecosystems worldwide, and the response to this event has the potential to change the ecosystem. The Barents Sea jelly-fish populations appear to be oscillating, similar to most jellyfish populations (Condon *et al.*, 2012), and over the past 30 years, this population experienced a high interannual variability, from a few thousand tonnes to 5 million tonnes (Eriksen *et al.*, 2012).

During last three decades the climate changed from cold to warm in the Barents Sea, and jellyfish (mostly *Cyanea capillata*) biomasses were low during 1980s, increased during 1990s, and were highest in early 2000s. The jellyfish were present in the water volume in the temperature interval  $1^{\circ}C < T < 10^{\circ}C$ , with peak densities at ca. 5.5°C, and the greatest proportion of the jellyfish occurring between 4.0–7.0°C. It seems that the

ongoing warming trend may be favorable for Barents Sea jellyfish medusa (Eriksen *et al.,* 2012).

The bulk of the jellyfish were observed in the central parts of the Barents Sea, which is a core area for most 0-group fish. In years with moderate and high levels of jellyfish (> 1 million tonnes), the catches of 0-group of most species increased with the increased jellyfish catches, with a ten times increase in 0-group fish, and five times increase in pelagic fish with a hundred times increase in jellyfish catches. The co-occurrence of high concentrations of jellyfish and other pelagic components such as krill, 0-group fish (capelin, herring, cod, haddock, polar cod, and redfish), and pelagic fish stocks (older capelin, herring, blue whiting, and lumpfish) indicated a highly productive area in the central Barents Sea most likely defined by ocean. Scyphozoan jellyfish appear not to limit the habitat of other species in the Barents Sea during the late feeding period, but catches of certain species appear to level off or decrease for very high catches of jellyfish (Eriksen, 2015).

PINRO and IMR has agreed to make an effort to estimate the impact of jellyfish predation on recruitment of commercially important fish in the Barents Sea (eggs, larvae, and 0-groups). Diet composition, food intake and food biomass consumed by jellyfish should be investigated to try to predict possible changes in fish recruitment related to abundance and distribution of jellyfish (Anon, 2016).

#### Question 12 Will an increase in the invasive snow crab affect the shrimp stock or other species?

A working document (Anismova *et al.*, 2016) compared distribution, habitat and dietary preference of shrimp (*Pandalus borealis*) and snow crab (*Chionoecetes opilio*). There is a little spatial and dietary overlap between shrimp and snow crab, and no clear and apparent negative impact of the recent increase in abundance and distribution of snow crab on shrimp. It may be assumed that acclimatization of snow crab in the northern part of the Barents Sea will be without any dramatic consequences for the Barents Sea. At the same time the climax of the snow crab population growth in the Barents Sea has not yet been reached. However, it is not possible to make long-term predictions about the consequences of this species for the Barents Sea ecosystem.

# 5 Cooperation

## Cooperation with other WG

- Stock assessment groups in particular the Arctic Fisheries Working Group (AFWG)
- Other Integrated Assessment (IEA) groups in particular the Working Group on the Integrated Assessments of the Norwegian Sea (WGINOR) and the ICES/PAME Working Group on Integrated Ecosystem Assessment (IEA) for the Central Arctic Ocean (WGICA)
- Working Group on Multispecies Assessment Methods (WGSAM), Working Group on the Ecosystem Effects of Fishing Activities (WGECO)

#### Cooperation with Advisory structures

- The Joint Russian Norwegian Fisheries Commission
- The Joint Russian Norwegian Environmental Commission
- Delivery of results for the Norwegian holistic ecosystem-based management plan reports on state of the marine ecosystem for the Norwegian part of the Barents Sea.

### Cooperation with other IGOs

• Relevant groups within the Arctic Council

# 6 Summary of Working Group self-evaluation and conclusions

Integrated Ecosystem Assessment has a high priority within ICES and is a key element in the ecosystem approach to management. The Barents Sea is a high latitude ecosystem undergoing rapid changes affecting some of the largest stocks in the Northeast Atlantic. WGIBAR therefore has an important place within ICES and could play an important role in the management of the Barents Sea and should therefore continue for a new 3-year period.

## 7 References

- Anisimova, V., Pavlov, and LL Jørgensen 2016. Snow crab and northern shrimp. Working Document, ICES WGIBAR, Murmansk, Russia 22-25 February 2016. 6 pp.
- Anon 2016. Protocol of the Annual Meeting between Russian and Norwegian scientists Bergen, Norway 14-15 March 2016
- Anon 2008. Assessment report on climate change and its consequences in Russian Federation General summary / Federal Service for Hydrometeorology and Environmental Monitoring (Roshydromet). Moscow, 25 pp.
- Boitsov, V.D., and Karsakov, A.L. 2005. Long-term projection of water temperature to be used in the advance assessment of the Barents Sea productivity. In Ecosystem dynamics and optimal long-term harvest in the Barents Sea fisheries. Proceeding of the 11th Russian-Norwegian Symposium, 15–17 August 2005, IMR/PINRO Joint Report Series, 2005(2), 324–330.
- Bogstad, B., Hiis Hauge, K., and Ulltang, Ø. 1997. MULTSPEC A Multi-Species Model for Fish and Marine Mammals in the Barents Sea. J. Northw. Atl. Fish. Sci. 22: 317-341.
- Condon, R.H., Duarte, C.M., Pitt, K.A., Robinson, K.L., Lucas, C.H. et al. 2012. Recurrent jellyfish blooms are a consequence of global oscillations. PNAS. doi: 10.1073/pnas.1210920110.
- Dalpadado P, Prokopchuk I, Bogstad B, Gjøsæter H, Dolgov H, Rey A. Gordeeva A. 2015. Trophic studies of capelin and polar cod .Working Document, ICES WGIBAR, Kirkenes, Norway 1-4 June 2015. 6 pp.
- Drinkwater, K.F., Miles, M., Medhaug, I., Otterå, O.H., Kristiansen, T., Sundby, S. and Gao, Y. 2014. The Atlantic Multidecadal Oscillation: Its manifestations and impacts with special emphasis on the Atlantic region north of 60°N. Journal of Marine Systems, 133, 117–130.
- Dutil, J.D., Castonguay, M., Gilbert, D., Gascon, D. 1999. Growth, condition, and environmental relationships in Atlantic cod (Gadus morhua) in the northern Gulf of St. Lawrence and implications for management strategies in the Northwest Atlantic. Canadian Journal of Fisheries and Aquatic Sciences . 56(10): 1818-1831.
- Eriksen, E. and Gjøsæter, H. (eds) 2013. A monitoring strategy for the Barents Sea Report from project no. 14256 Survey strategy for the Barents Sea. Bergen: Havforskningsinstituttet, 73 pp.
- Eriksen, E. 2015. Do scyphozoan jellyfish limit the habitat of pelagic species in the Barents Sea during the late feeding period? ICES J Mar Sci ICES, doi: 10.1093/icesjms/fsv183
- Eriksen E, Prozorkevich D, Trofimov A, Howell D 2012. Biomass of Scyphozoan Jellyfish, and Its Spatial Association with 0-Group Fish in the Barents Sea. PLoS ONE 7(3): e33050.
- Filin AA. 2005. STOCOBAR model for simulation of the cod stock dynamics in the Barents Sea considering the influence of ecosystem factors. In: Ecosystem Dynamics and Optimal Long-Term Harvest in the Barents Sea Fisheries. Proceedings of the 11th Russian-Norwegian Symposium, Murmansk, 15- 17 August 2005. Murmansk: PINRO, p 236-247.
- Frolov, I.E., Gudkovich, Z.M., Karklin, V.P. and Smoljanickij, V.M. 2010. Climate changes in the Arctic and Antarctic – a result of acting natural causes. Problemy Arktiki i Antarktiki, 2(85), 52–61. (in Russian)
- Frolov, I.E., Gudkovich, Z.M., Karklin, V.P., Kovalev, E.G. and Smolyanitsky V.M. 2009. Climate Change in Eurasian Arctic Shelf Seas: Centennial Ice Cover Observations. Springer Praxis Books, 224 pp.
- Frolov, I.E., Gudkovich, Z.M., Karklin, V.P., Smoljanickij, V.P., Kljachkin, S.V. and Frolov, S.V. 2012. Methods for assessing the effects of climate change on physical and biological systems. Rosgidromet, Moscow, 400–429. (in Russian)
- Furevik, T. 2001. Annual and interannual variability of Atlantic Water temperatures in the Norwegian and Barents Seas: 1980–1996. Deep-Sea Research Part I, 48, 383–404.

- Hansen, C. Skern-Mauritzen, M., v.d. Meeren, G.I., Jähkel, A and Drinkwater, K, 2016: 'Set up of the Nordic and Barents Seas (NoBa) Atlantis model'. Fisken og havet 2-2016. 97 pp.
- Howell, D., and Bogstad, B. 2010. A combined Gadget/FLR model for management strategy evaluations of the Barents Sea fisheries. ICES Journal of Marine Science 67:1998-2004.
- ICES. 2013. Report of the Workshop on Benchmarking Integrated Ecosystem Assessments (WKBEMIA), 27–29 November 2012, ICES Headquarters, Copenhagen, Denmark. ICES CM 2012/SSGRSP:08. 27pp.
- ICES 2015. Report of the Arctic Fisheries Working Group, Hamburg, 23-29 April 2015. ICES C.M. 2015/ACOM:05, 590 pp.
- ICES 2016. Report of the second Workshop on Management Plan Evaluation on Northeast Arctic cod and haddock and Barents Sea capelin, 25-28 January 2016, Kirkenes, Norway. ICES CM 2016/ACOM:47, 76 pp.
- IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.
- Johannesen E, Nash RDM, Dingsør G, Skjoldal HR and Skaret G. 2016. Surplus production of cod, haddock and capelin in the Barents Sea. Working Document, ICES WGIBAR, Murmansk, Russia 22-25 February 2016. 12 pp.
- Lindstrøm, U., Smout, S., Howell, D., and Bogstad, B. 2009. Modelling multispecies interactions in the Barents Sea ecosystem with special emphasis on minke whales, cod, herring and capelin. Deep Sea Research Part II: Topological Studies in Oceanography 56: 2068-2079.
- McBride, M.M., Hansen, J.R., Korneev, O., Titov, O. (Eds.) Stiansen, J.E., Tchernova, J., Filin, A., Ovsyannikov A. (Co-eds.) 2016. Joint Norwegian - Russian environmental status 2013. Report on the Barents Sea Ecosystem. Part II - Complete report. IMR/PINRO Joint Report Series, 2016 (1). ISSN 1502-8828.
- Ottersen, G., Ådlandsvik, B. and Loeng, H. 2000. Predicting the temperature of the Barents Sea. Fisheries Oceanography, 9: 121–135. doi: 10.1046/j.1365-2419.2000.00127.x
- Plagányi, É.E. 2007. Models for an Ecosystem Approach to Fisheries. FAO Fisheries Technical Paper No. 477. Rome, FAO. 2007. 108p. ISBN 978-92-5-105734-6.
- Schweder, T., Hagen, G. S. and Hatlebakk, E. 2000.Direct and indirect effects of minke whale abundance on cod and herring fisheries. A scenario experiment for the Barents Sea. NAM-MCO Scientific Publications 2:120-133.
- Skjoldal HR and Misund OA 2008. Ecosystem Approach to management: definitions, principles and experiences from Implimentation in the North Sea pp 209-227. In Bianchi G and Skjoldal HR (eds) The Ecosystem Approach to Fisheries. CABI Wallingford UK and FAO Rome, Italy.
- Tjelmeland, S. 2005. Evaluation of long-term optimal exploitation of cod and capelin in the Barents Sea using the Bifrost model. Pp. 112-129 in: Shibanov, V. (ed.). "Ecosystem Dynamics and Optimal Long-Term Harvest in the Barents Sea Fisheries". Proceedings of the 11th Russian-Norwegian Symposium, Murmansk, Russia, 15-17 August 2005. IMR/PINRO Joint Report Series No 2/2005. 331 pp.
- Tsaturov, Yu.S., Klepikov, A.V. 2012. Present climate changes in the Arctic: results from a new assessment report of the Arctic Council. Arctic: ecology and economics, 4(8), 76–81. (in Russian)
- Årthun, M. and Eldevik, T. 2016. On anomalous ocean heat transport toward the Arctic and associated climate predictability. Journal of Climate, 29(2), 689–704

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# Annex 2. Recommendations

	ADRESSED
RECOMMENDATION	то
Attending members of the WGIBAR meeting in Murmansk 22–25 February 2016 recommended that the WG should continue for another 3-year period within the	SCICOM and ACOM
ICES system. Anatoly Filin (Russia) and Elena Eriksen (Norway) have agreed to co-	
chair the group for that period. New ToRs are proposed in Annex 3.	

# Annex 3. WGIBAR new terms of reference

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			COMMENTS (CHANGE IN	
	DATES	VENUE	REPORTING DETAILS	CHAIR, ETC.)
Year 2017	Early March	Russia	Interim report by 30 April 2017	
Year 2018	Early March	Norway	Interim report by end of April 2018	
Year 2019	Early March	Russia	Interim report by end of April 2019	

## **ToR descriptors**

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		Year 1,2 and 3	Updated multivariate datasets (Year 1,2 and 3). Develop new spatially disaggregated time-series (Year 1 and 2)
В	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		Year 1, 2 and 3	Annual reports of the status, drivers, pressures, trophic interactions and expected changes
С	Identify knowledge gaps and priority research items that when addressed, can improve future integrated ecosystem assessments	Science and advisory requirement		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		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		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	SSGRSP, 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. WGIBAR Self-evaluation

- 4) ICES Working Group on the Integrated Assessments of the Barents Sea (WGIBAR)
- 5) Year of appointment: 2013
- 6) Co-chairs: Yury Kovaljev, Russia and Edda Johannesen, Norway
- 7) Dates, venues and number of participants: March 24–28 2014, Kirkenes Norway, 12 participants, June 1–4 2015, Kirkenes Norway, 12 participants, February 22–25 2016, Murmansk Russia, 12 participants.

### WG Evaluation

8) If applicable, please indicate the research priorities (and sub priorities) of the Science Plan to which the WG make a significant contribution.

WGIBAR contributes to the first two goals of the ICES strategic plan 2014–2018.

- 9) In bullet form, list the main outcomes and achievements of the WG since their last evaluation. Outcomes including publications, advisory products, modelling outputs, methodological developments, etc.
  - Compilation and evaluation of relevant datasets
  - Reports of the state of the Barents Sea in 2013, 2014 and 2015.
  - Knowledge gaps identified and addressed
  - Ecosystem overview for the Barents Sea following the template provided by ICES

#### 10) Has the WG contributed to Advisory needs?

WGIBAR provided text to the first chapter in the AFWG report in 2014 and 2016, and ecosystem overview of the Barents Sea ecoregion.

<u>http://www.ices.dk/sites/pub/Publication%20Reports/Advice/2016/2016/Barents\_Sea\_Ecoregion-Ecosystem\_over-</u> <u>view.pdf</u>

11 ) Please list any specific outreach activities of the WG outside the ICES network

Presentations at the annual IMR PINRO March meetings in 2014, 2015 and 2016.

See also "3. Summary of Achievements of the WG during 3-year term" in the 2016 WGIBAR report.

### Please indicate what difficulties, if any, have been encountered in achieving the work plan.

Lack of resources (manpower, and funding) to do intersessional work and limited resources for meeting participation.

### Future plans

12) Does the group think that a continuation of the WG beyond its current term is required?

- 13 ) If you are not requesting an extension, does the group consider that a new WG is required to further develop the science previously addressed by the existing WG.
  - Not relevant
- 14) What additional expertise would improve the ability of the existing WG to fulfil its ToR?

The report of the status and changes of the Barents Sea ecosystem should include pollution, thus additional expertise of chemical pollution would improve the WG to fulfil its ToR. WGIBAR also lacks experts on seabirds.

15) Which conclusions/or knowledge acquired of the WG do you think should be used in the Advisory process, if not already used? (please be specific)

There was a benchmark of the harvest control rules of the haddock, cod andcapelin stocks in the Barents Sea in early 2016 and these were approved by ICES. At the 17th Russian-Norwegian Symposium: "Long-term sustainable management of living marine resources in the Northern Seas" harvest control rules of the BS stocks were discussed and it was a general consensus that these should be kept simple. IEAs could however, allow the design of appropriate modelling studies to evaluate HCRs in future.

WGIBAR could inform relevant stock assessment groups on recent developments in the ecosystem that could affect growth, mortality or recruitment of the stocks.

Furthermore WWGIBAR could develop mapping of biodiversity and address spatial changes in biodiversity, spatial distributions and interactions for area based management.

# Annex 5 WGIBAR State of the Barents Sea 2015

#### **Contributing Authors (Alphabetic):**

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The remote sensing data to WGIBAR (Chapter 3.2) is a contribution from the TIBIA project at IMR, Bergen, Norway. The work done here is in collaboration with Professor Kevin Arrigo and Gert van Dijken from Stanford University, USA.



# Contents

An	nex 5	WGIBAR State of the Barents Sea 2015	26			
Coi	ntents		27			
1	Sun	nmary	28			
2	Tom					
2	2 1	1980s to present: Integrated Trend Analysis	30			
	2.1	2004-2015: The Joint IMR PINRO ecosystem survey				
3	Cur	rent state of the Barents Sea				
	3.1	Oceanographic and climatic conditions				
	3.2	Phytoplankton and primary production				
	3.3	Zooplankton	59			
	3.4	Benthos and shellfish	71			
	3.5	Pelagic fish	76			
	3.6	Demersal fish	84			
	3.7	Marine mammals	93			
	3.8	Fisheries	94			
4	Inte	ractions, drivers, and pressures	100			
	4.1	Causes of capelin decline	100			
	4.2	Causes of polar cod decline	108			
	4.3	Cod-capelin-polar cod interaction	110			
	4.4	Benthic habitat integrity and benthos vulnerability	111			
5	Exp	Expected changes in the coming years11				
	5.1	Sea temperature	114			
	5.2	Possible development of the stocks	114			
6	Refe	erences	118			
7	App	endix. Time-series used in Integrated Trend Analysis	121			
	7.1	Abiotic	121			
	7.2	Biotic	122			
	7.3	Pressures	123			

#### 1 Summary

Since the 1980s, the Barents Sea has gone from a situation with high fishing pressure, cold conditions and low demersal stock levels to the current situation with high levels of demersal stocks, reduced fishing pressure, and warm conditions. The current situation is unprecedented and the Barents Sea appears to be changing rapidly. The main points for 2015 are listed below:

- The atmosphere and ocean temperature was higher than the long-term mean (1951–2010) and higher compared to 2013 and 2014.
- The area covered by Atlantic water was larger than the previous two years, and the area of Arctic water was smaller than the previous two years.
- The ice coverage was lower than normal and lower than 2013 and 2014. The seasonal maximum was observed in February, two months earlier than usual.
- Analyses of updated satellite data 1998–2015 show significant interannual variation in net primary production, and an increasing general trend.
- Mean biomass of mesozooplankton in 2015 was somewhat higher than in 2014. Biomass was highest in western Barents Sea in the area of inflowing Atlantic water mainly due to the medium sized zooplankton, and was lower in north eastern Barents Sea compared to 2013–2014. Note, however, some differences between years regarding the extents of the sampling areas these averages are based on. '.
- The main groups of macrozooplankton, krill, found mainly in warm water, and hyperiid amhipods, found mainly in cold water, show different trends. Biomass of krill remained higher than the long-term mean and was higher than in 2014. Hyperiids are at a low level, but in 2015 high concentrations were recorded east of Svalbard, possibly due to reduced predation pressures.
- Jellyfish biomass was estimated to be lower in 2015 than in 2014, although still markedly higher than the long-term mean (1980-).
- The capelin biomass decreased to a low level in 2015 and was less than half than in 2014 and <sup>1</sup>/<sub>3</sub> of the stock size in 2013. The capelin growth in 2015 was higher than in 2014 but still below mean level for the last 30 years. Causes of capelin decline are increase in natural mortality (mainly due to high cod consumption), low growth and relatively low recruitment.
- The polar cod is at the lowest level of abundance since the last 25 years. There is no fishing on polar cod but the natural mortality is very high. Increased overlap with and consumption by cod has contributed to the increased natural mortality. The last three years the recruitment of polar cod has been very poor possibly due to changes in spawning habitat.
- The cumulative biomass of demersal fish was highest in 2012–2013, and now tends to decrease. Numbers are going down faster than the biomass due to dominance of older individuals. Cod biomass stabilized at about 3 million tonnes, well above the long-term mean (1946-). Haddock abundance reached record levels in 2009–2012, declined from 2013, but is still at a high level. The biomass is at about 1 million tonnes, twice the long-term mean (1950-).

- Related to the retreating sea ice, new areas of seabed are open for human activity. A baseline mapping benthic species vulnerable to trawling was published in 2015. This map might be of relevance to management of human activities.
- The distribution area of the invasive snow crab continued to increase in 2015, but the consequences and future development of this stock are unknown.
- Due to the low levels of polar cod and capelin, cod and other piscivores have to compensate by feeding on other prey or survival, growth and reproduction will decrease.
- Increased predation pressure on alternative prey by the large cod stock has potential large, but unknown consequences for the Barents Sea foodweb dynamics.

#### 2 Temporal development

### 2.1 1980s to present: Integrated Trend Analysis

The temporal development of the Barents Sea ecosystem was characterized using Integrated Trend Analysis, which is a PCA run on time-series of the main ecosystem components. The year 1986 was selected as starting point, since this is the first year of the time-series on polar cod (*Boreogadus saida*) one of the most abundant pelagic fish in the Barents Sea. The dataset included 54 time-series on oceanographic conditions, zooplankton, shrimp (*Pandalus borealis*), the main fish stocks (biomass and demographic parameters), and fishing pressure (see the Appendix 1 for description of the time-series).

The Barents Sea is a very large area (approximately 1.4–1.8 million km<sup>2</sup> depending on how it is delimited) with substantial spatial heterogeneity in abiotic conditions, species composition and interactions. By using spatial averaged time-series, spatial variation in dynamics (demonstrated by e.g. Stige et al., 2014 for the interaction between pelagic fish and zooplankton) are blurred. It is not however, possible to obtain consistent spatially resolved time-series for the whole Barents Sea shelf before the onset of the Barents Sea ecosystem survey (2004-). Lagged effects and changes in correlations cannot be detected using PCA. Such changes are very important to detect in order to evaluate predictability. For instance, whereas there was previously a strong relationship between temperature and recruitment of haddock (Melanogrammus aeglefinus), cod (Gadus morhua), and herring (Clupea harengus) in the Barents Sea, this relationship has recently weakened (Bogstad et al., 2013), and whereas the 1980s collapse of the capelin (Mallotus villosus) stock had a strong negative impact on cod, the collapse in the early 2000s had no detectable consequence on the cod stock (Gjøsæter et al., 2009; Johannesen et al., 2016). Despite these limitations, PCA can be used to characterize main trends and development in the ecosystem.

The overall change in the Barents Sea has been from cold conditions, low demersal stocks levels and high fishing pressure in the 1980s to warm conditions (Chapter 3.1), large demersal stocks (Chapter 3.6) and lowered fishing pressure (Chapter 3.8), in recent years (Figure 2. 1.1).

The result of a PCA run on the abiotic time-series is shown in Figure 2.1.2. The positive values for the first PCA axis were associated with high temperatures and large areas of Atlantic and Mixed waters, negative values were associated with area of Arctic water, and ice covered area in April and September. Positive values for the second PCA axis were associated with the modelled net southward volume transport into the Barents Sea between Svalbard and Franz Josef Land (NBSO), and salinity in the Kola Section, whereas negative values were associated with the winter NAO index, and the modelled eastward volume transport between Franz Josefs Land and Novaya Zemlya (BSX), between Kola and Novaya Zemlya (SBSO), and between Bear Island and Norway (BSO). The PC1 is a thus gradient from cold to warm, whereas PC2 is a contrast between eastward and southward inflows and a gradient from high to low winter NAO index. The years after 2004 have all been warm and have positive PC1 scores and PC1 separates the last 10–15 years from the previous years. The year 2015 groups with the other years from 2004 to 2014 along the PC1 axis. Except for the outlier year 2010 with the lowest winter NAO index since 1899, the years before 2004 have more variation along the second PC axis compared to the last period. The year 2015 is similar to 2012 with respect to the second PC axis. The first two axes account for more than 60% of the variation in the abiotic 17 time-series.

The result of a PCA run on 31 biotic time-series is shown in Figure 2.1.3. The first two axes accounted for almost 40% of the variation in the variables.



Figure 2.1.1 Color matrix of 54 time-series (y-axis) 1985–2014 (x-axis). The time-series were standardized to zero mean and unit variance. Negative values are shown as blue and positive as red. A PCA was run on the time-series, and the time trajectory of the first axis is shown as a black line. The time-series as sorted according their scores along the first PC axis. The time-series are described in the appendix to this report.





Figure 2.1.2 Result of PCA run on a) 17 abiotic time-series 1982–2015. A) Biplot of the variables and B) the time trajectory plot with the years from 1982- The years 2004–2015 are shown in red.




Figure 2.1.3 Results of PCA run on 31 biotic time-series 1986–2015. A) Biplot of the variables and B) the time trajectory plot with the years from 1986- The years 2004–2015 are shown in red. Krill (Russian data) and shrimp are not yet updated and therefore no included.

Several of the variables had scores of similar magnitude along both the first and the second axes (Figure 2.1.3). The variables with the largest absolute value of the scores along the first axis (all negative) were biomasses of cod, haddock, and long rough dab (*Hippolglossoides platessoides*) and 0-group indices of cod and haddock. Positive values for the second PC axis were associated with weight-at-age 3 and age 5 for cod, weight-at-age 5 for haddock, and total-stock biomass of capelin. Negative scores for PC2 were associated with krill, biomass of mesozooplankton (total and 1000 mu) and mortality of haddock at age 3. Variables with negative scores along both PCA1 and PCA2 were biomass and recruitment of the demersal stocks, mortality-at-age 3 of haddock and the index of krill biomass. Positive scores of PC1 and PC2 were found for haddock weight-at-age 5. The gradient from negative PC1 scores/positive PC2 scores to positive PC1/negative PC2 scores is a gradient from high capelin biomass to high growth and maturation of capelin and high mesozooplankton biomass, consistent a grazing effect of capelin on mesozooplankton, and density-dependent growth and maturity of capelin (see also 4.1). The years from 2017 to 2015 all have negative scores for PC1 and PC2 and are different from earlier years.

# 2.2 2004-2015: The Joint IMR PINRO ecosystem survey

The ecosystem survey is a cooperation between IMR and PINRO and has been run annually in August-October since 2004. The survey was established by combining several earlier surveys, including the acoustics survey for pelagic fish providing basis for the stock assessment of capelin. Indices based on ecosystem survey data are also used e.g. in the assessment of shrimp, haddock, and Greenland halibut (*Reinhardtius hippoglossoides*) and cod stomach data sampled on the survey are used in haddock, cod, and capelin assessments. The ecosystem survey covers the whole Barents Sea shelf and samples all main ecosystem components allowing the study of spatial overlaps and interactions (see section 4.2 for an example). The recent warming has lead to ice-free conditions in August-September opening new areas to investigations, including the northern Arctic part of the Barents Sea.

During the relatively short period the ecosystem survey has been run many changes in the ecosystem has been documented. These include changes in fish community structure (Fossheim *et al.*, 2015) and functional diversity of fish (Wiedmann *et al.*, 2014), influencing foodweb structure (Korstch *et al.*, 2015). The changes are mainly associated with the expansion of boreal fish into the northern, Arctic Barents Sea. This expansion has been particularly pronounced for cod for which warming together with reduced fishing pressure has lead to stock level increase and more old and large individuals in the stock (Kjesbu *et al.*, 2014). The expansion of cod is much faster than predicted by niche-based and climate projection models (Ingvaldsen *et al.*, 2015). Other ecosystem components including shrimp has also shifted distribution towards the northeast during the survey period from 2004 (Figure 2.2.1). This has lead to a spatial shift in the shrimp fishery activity (ICES 2015a). During the period the ecosystem survey has been run, a rapid westwards expansion of the invasive snow crab (*Chionoecetes opilio*) has been documented (see chapter 3.4).

Parts of the text in this report are modified from the latest ecosystem survey report (Prozorkevich, 2015) and most of the maps shown are based on data from the ecosystem survey. In future, more work could be done to develop consistent, unified methods to quantify overlaps and spatial distributions for all components sampled at the ecosystem survey.



Figure 2.2.1 Shrimp densities interpolated from shrimp catches taken at ecosystem survey (from ICES 2015a)

# 3 Current state of the Barents Sea

## 3.1 Oceanographic and climatic conditions

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 oceanographic conditions both in the Barents Sea and in the Arctic Ocean and are related to large-scale atmospheric pressure systems.



Figures 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 2015, winter (December–March) NAO index changed to the third highest positive value of 1.88 since 1899 (0.92 in 2014). In the first half of the year, south-easterly winds prevailed over the Barents Sea; in the second half – northerly winds. In 2015, the number of days with winds more than 15 m/s was larger than usual most of the year. In November, the storm activity in the western Barents Sea was record high (since 1981). It was less or close to normal only in January in the eastern part of the sea and in April, August, and October in the western and central parts.

Air temperature 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 prevailed over the sea during 2015 (Figure 3.1.2). The largest positive anomalies (3.0°C in the west, 5.6°C in the east) were found in March. Small negative anomalies were only observed in July in the western part of the sea and in January and July in the eastern part.



Figure 3.1.2. Air temperature anomalies in the western (upper) and eastern (lower) Barents Sea in 1985–2015. The red line shows monthly values, the black one – 11-month running means.

#### Ice conditions

There has been a general decreasing trend in ice area in the Barents Sea in the last 4 decades, in particular during winter (Figure 3.1.3). In 2015, the seasonal maximum of ice coverage took place in February (two months earlier than usual) (Figure 3.1.4). Melting started in March. In April, the ice coverage of the Barents Sea (expressed as a percentage of the sea area) was 25% lower than normal and 14% lower than in 2014 (Figure 3.1.3). From August to October, there was no ice in the Barents Sea. In autumn, freezing started in the northern Barents Sea at the end of October, when ice appeared around the Franz Josef Land Archipelago. In October, the ice coverage was 1% that was 14% less than usual and 12% less than in 2014. In November and December, the ice coverage was less than both the average and that in 2014 by more than 20%. Overall, the 2015 annual mean ice coverage of the Barents Sea was lower than normal and compared to 2014.



Figure 3.1.3. Ice coverage anomalies in the Barents Sea in 1985–2015. The green line shows monthly values, the black one – 11-month running means.



Figure 3.1.4. Ice concentrations in February, April, and September 2015

#### 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. In 2006, the volume flux was at a maximum during winter and very low during fall. After 2006, the inflow has been relatively low. During fall 2014, the inflow was lower than average, whereas at the start of 2015, the inflow increased to 1.5 Sv above the long-term average for the season (Figure 3.1.5a). The dataseries currently stops in spring 2015, thus no information about the summer, fall and early winter 2015 is yet available.

Complementing the observed volume flux, numerical modelling suggests that the volume flux into the Barents Sea through the BSO (between Norway and Bear Island) was above average during the first half of the year, with January as the only exception. In the months July through September, the eastward volume transport was between 0.5 and 1.5 Sv below average, with the lowest value reached during July with only  $\frac{1}{3}$  of the normal transport. In October, the transport was 20% above normal. Modelled transports are as of yet not available for November or December. Similar to the inflow to the western Barents Sea, the modelled outflow through the northeastern Barents Sea (BSX) was substantially higher than normal during the first half of the year, while lower in the second half, especially during July. The exception was an uptick again in October. Also in the SBSO, between the Kola Section and Novaya Zemlya, the eastward volume transport was generally above average during the first half of the year and lower than normal during the second half. In the NBSO, between Svalbard and Franz Josef Land, the volume transport (positive southward) was exceptionally high in January, but then below average during the rest of winter. During the rest of the year, it was more variable. In terms of model evaluation, it has been found to be accurate for annual mean and standard deviation, but not for monthly variability (Lien et al., 2013; Figure 3.1.6).



Figure 3.1.5a. Volume flux anomalies through the Fugløya-Bear Island Section.



Figure 3.1.5b. Temperature anomalies in the 50-200 m layer in the Fugløya-Bear Island Section.



Figure 3.1.6. Modelled fluxes plotted against observed fluxes (From Lien et al., 2013).

#### 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 southeastern 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 2015, the temperature of the Atlantic Water flowing into the Barents Sea through the Fugløya–Bear Island Section (50–200 m) was 0.8°C above the long-term average and 0.5°C above the 2014 temperature, with some fluctuations throughout the year (Figure 3.1.5b). Atlantic and coastal waters in the Kola Section (0–200 m) had positive temperature anomalies increasing during the first half of the year from 0.4-0.8°C in January-February to 1.1-1.3°C in May-June (Figure 3.1.7). During the second half of the year, the anomalies remained high and were close to or more than 1°C. Some increase in temperature anomalies took place in autumn due to westerly winds in September-October. Compared to 2014, the Atlantic and coastal waters were warmer from April–May until the end of 2015. It should be mentioned that, in some months, the coastal (June-September and November) and Atlantic (September–December) waters had the highest positive anomalies since 1951. The 2015 annual mean temperature of Atlantic waters in the 0–200 m layer in the Kola Section was typical of anomalously warm years and 0.2–0.3°C higher than in 2014 (Figure 3.1.8). Overall, both these sections showed a temperature increase compared to 2014.



Figure 3.1.7. Monthly mean temperature (left) and salinity (right) anomalies in the 0–200 m layer in the Kola Section in 2014 and 2015. St. 1–3 – Coastal waters, St. 3–7 – Murman Current, St. 8–10 – Central branch of the North Cape Current.

In 2015, salinity in the coastal and Atlantic waters in the Kola Section was lower than in 2014. The coastal waters were much fresher than normal with negative salinity anomalies increasing over the year up to -0.2 in December. Throughout 2015, the Atlantic water salinity was lower than the average in the central part of the section but close to normal in the outer part of it (Figure 3.1.7). The 2015 annual mean salinity of Atlantic waters in the 0–200 m layer in the Kola Section was 0.03–0.05 lower compared to 2014; it was 0.07 lower than normal in the Murman Current and close to the average in the outer part of the section (Figure 3.1.8).

In the northern Barents Sea (NW) there was a temperature increase in 2015 compared with the year before, with the temperature anomaly increasing from 0.22°C in 2014 to 0.58°C in 2015. In the northeastern Barents Sea, the temperature increased by about 1.1°C, with a temperature anomaly of 0.36°C in 2015 compared with -0.73°C in 2014.



Figure 3.1.8. Annual mean temperature (upper) and salinity (lower) anomalies in the 0–200 m layer in the Kola Section in 1951–2015. Coastal waters – St. 1–3, Murman Current – St. 3–7, Central branch of the North Cape Current – St. 8–10.

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

During 2015, positive sea surface temperature (SST) anomalies prevailed in the Barents Sea. In the western part of the sea, the positive anomalies were not high (0.1– 0.7°C), whereas in the eastern Barents Sea, they were higher (0.8–2.2°C) with the largest values (2.0–2.2°C) in summer. Only in January and February, the SST in the east was close to the average.

In August–September 2015, during the joint Norwegian-Russian ecosystem survey carried out in the Barents Sea, the surface temperature was on average 1.2°C higher than the long-term mean for the period 1931–2010 almost all over the Barents Sea (Figure 3.1.9). Overall, positive temperature anomalies increased from west to east. Negative anomalies (-0.4°C on average) occupied under 10% of the surveyed area and were mostly found south and southeast of the Spitsbergen Archipelago. Compared to 2014, the surface temperature was much higher (by 1.3°C on average) in most of the Barents Sea (about three quarters of the surveyed area), especially in the north-eastern part of the sea. The surface waters were on average 1.0°C colder than in 2014 only in some places in the southeastern and western Barents Sea, especially south of the Spitsbergen Archipelago.





Figure 3.1.9. Surface temperatures (upper, °C) and their differences between 2015 and 2014 (lower left, °C) and anomalies (lower right, °C), August–September 2015.

The surface salinity was on average 0.4 higher than both the long-term mean and that in the previous year in most of the Barents Sea with the largest positive anomalies (> 0.5) mainly north of 76°N (Figure 3.1.10). The largest positive differences (> 1.5) in salinity between 2015 and 2014 took place north of 77°N and resulted from different ice conditions in these two years: in summer 2014, drift ice was located much further south compared to 2015 and resulted in much fresher surface waters in this area. Negative anomalies were found in the southwestern and southeastern parts of the sea as well as south and southwest of the Spitsbergen Archipelago. In August–September 2015, the surface waters were fresher compared to 2014 west and southwest of the Novaya Zemlya Archipelago as well as in the western Barents Sea, especially south and southwest of the Spitsbergen Archipelago.



46 |



Figure 3.1.10. Surface salinities (upper) and their differences between 2015 and 2014 (lower left) and anomalies (lower right), August–September 2015.

Arctic waters were, as usual, most dominant in the 50–100 m layer north of 77°N. The temperatures at depths of 50 and 100 m were mainly higher than the long-term mean (on average, by 1.2 and 1.0°C respectively) nearly all over the Barents Sea (Figure 3.1.11).





Figure 3.1.11. 100 m temperatures (upper, °C) and their differences between 2015 and 2014 (lower left, °C) and anomalies (lower right, °C), August–September 2015.

Small negative anomalies (-0.3°C on average) were found in some small areas in the northern part of the sea, especially right south and east of the Spitsbergen Archipelago. Compared to 2014, the 50 and 100 m temperatures were higher (on average, by 0.8 and 0.6°C respectively) in most of the Barents Sea (three quarters of the surveyed area). Negative differences in temperature between 2015 and 2014, changing with depth, on average, from -0.6°C at 50 m to -0.3°C at 100 m, took place in some areas in the central, south-eastern and north-western Barents Sea, especially south and south-east of the Spitsbergen Archipelago.

The salinity at depths of 50 and 100 m was higher than the long-term mean (on average, by 0.1) in more than 80% of the surveyed area (Figure 3.1.12). Small negative anomalies were only observed in some areas in the southern and southwestern Barents Sea. Positive and negative differences in salinity between 2015 and 2014 covered almost equal areas at these depths. The largest differences were at 50 m, and they decreased with depth down to negligible values at 200 m.





Figure 3.1.12. 100 m salinities (upper) and their differences between 2015 and 2014 (lower left) and anomalies (lower right), August–September 2015.

The bottom temperature was in general 0.9°C above the average throughout the Barents Sea (Figure 3.1.13). Negative anomalies (-0.6°C on average) occupied under 10% of the surveyed area and were mainly found in the north-western part of the sea, especially south and east of the Spitsbergen Archipelago. Compared to 2014, the bottom temperature was in general 0.5°C higher in most of the Barents Sea (two thirds of the surveyed area). Negative differences in temperature between 2015 and 2014 were on average -0.4°C and took place in some small areas of the sea, especially south and southeast of the Spitsbergen Archipelago.





Figure 3.1.13. Bottom temperatures (upper, °C) and their differences between 2015 and 2014 (lower left, °C) and anomalies (lower right, °C), August–September 2015.

The bottom salinity was close to that in 2014 and slightly higher (by up to 0.1) than the long-term mean in more than three quarters of the surveyed area (Figure 3.1.14). Negative anomalies were mainly found in some areas in the southwestern and southeastern Barents Sea as well as in shallow waters in the north-western part of the sea. Relatively large differences in salinity between 2015 and 2014 were only found in shallow waters between Bear and Hopen Islands (negative values) and in the southeastern Barents Sea (positive values).





Figure 3.1.14. Bottom salinities (upper) and their differences between 2015 and 2014 (lower left) and anomalies (lower right), August–September 2015.

### Area of water masses

In the past decades, the area of Atlantic Water and mixed waters has increased, whereas that of Arctic Water has decreased (Figure 3.1.15). In 2015, both the areas covered by Atlantic Water and mixed waters increased, whereas the area covered by Arctic Water decreased.



Figure 3.1.15. Area of water masses.

According to the data obtained from the joint Russian-Norwegian autumn surveys (now the ecosystem survey) in the Barents Sea, the largest area covered by water above 3°C was observed in 2012, that was higher than a previous maximum of 2006 (Figure 3.1.16). Since 2000, the area covered by cold bottom water was the largest in 2003 and the smallest in 2007, 2008, and 2012. In 2012, it reached a record low value since 1965 – the year when the joint Russian-Norwegian autumn surveys started. In 2015, the area covered by water above 3°C increased whereas the area covered by water below 0°C decreased compared to the previous year.



Figure 3.1.16 Areas covered by water with different temperatures in August–September 2000–2015 (69–80°N, 20–60°E) a) top at 50 m, b) middle at 100m, c) bottom near bottom

# 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 (January-March), phytoplankton biomass and productivity are quite low. The spring bloom takes place some time from mid-April to June or even later, dependent on physical conditions, and can 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 grazing by zooplankton and the exhaustion of nutrients. Later in autumn 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. For instance 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 product of the ice melting.

Dalpadado *et al.* (2014) reported an increase in net primary productivity in the Barents Sea based on satellite data. The time-series has now been updated including 2015 (Figure 3.2.1). Published and ongoing work has shown that about 50% of the annual production occurs during the spring bloom and it is fuelled by winter nutrients. Satellite based estimates of Net Primary Production (NPP) show that though there is significant interannual variability of the period 1998–2015, the general trend is that it has increased over the years in the Barents Sea. The increase is mainly due to the fact that the ice coverage has been reduced, leading to larger ice-free areas and longer growth period. Note that NASA has done reprocessing of remote sensing data and hence the whole satellite series has been updated.



Figure 3.2.1 Annual net primary production (NPP- satellite based) in the Barents Sea.

# 3.3 Zooplankton

### Mesozooplankton biomasses

Zooplankton plays a key role in the Barents Sea Ecosystem by channelling food from primary producers to animals higher in the foodweb. Zooplankton monitoring in the Barents Sea (BS) coordinated by the Institute of Marine Research (IMR, Norway) and Polar Research Institute of Marine Fisheries and Oceanography (PINRO, Russia) shows that there is a large interannual variability of the mesozooplankton biomass in the ecosystem. Updated information on the state of the zooplankton communities in the Barents Sea is presented below.

The geographical distributions of mesozooplankton biomass in the Barents Sea based on the PINRO/IMR joint ecosystem surveys during autumn in 2013, 2014, and 2015 are visualized in Figure 3.3.1.



Figure 3.3.1. Distribution of zooplankton biomass (dry weight, g m<sup>-2</sup>) from bottom-0 m in 2015 (upper panel). Databased on samples obtained during the joint Norwegian-Russian (IMR/PINRO) ecosystem survey in autumn (late August – early October). Corresponding zooplankton biomass distributions from the ecosystem surveys in 2013 (lower left panel) and 2014 (lower right panel) are shown for comparison.

The average biomass value for 2015 (7.3 g  $m^{-2}$  dry weight) is not directly comparable with that for 2014 (6.7 g m<sup>-2</sup>) as the area coverage differed for the two years, especially since the northernmost area between Spitsbergen and Franz Josef Land was not monitored in 2014 due to extensive ice cover. The general biomass distribution pattern, however, shows similarities for the two years, with high biomasses in the west and low biomasses in the central Barents Sea. The region with high biomasses (> 8 g  $m^{-2}$ ) area in the west was much larger in 2015 compared to 2014, spreading northwards to the west of Spitsbergen. In contrast, the biomasses in the eastern region were reduced in 2015 (3–10 g m<sup>-2</sup>) as compared to in 2014 (> 10 g m<sup>-2</sup>). Furthermore, the area south of the Spitsbergen Archipelago showed a significant increase in biomass, from 1–5 g m<sup>-2</sup> in 2014 to 5–10 g m<sup>-2</sup> in 2015, spreading northwards to the west of Spitsbergen region. The area with low biomasses in the central and southern parts of the Barents Sea was reduced in 2015 compared to the two previous years. This could be due to several reasons, among others, a lower predation pressure from the capelin stock, which was high (> 3 million tonnes) during 2008–2013, but has become drastically reduced over the last two years (ca. 1.95 and 0.85 million tonnes in 2014 and 2015, respectively).

The average mesozooplankton biomass within the Norwegian sector, which has the longer time-series, showed a clear increase in 2015 (8.7 g dry-weight m<sup>-2</sup>) compared to 2014 (6.9 g m<sup>-2</sup>), and the biomass in 2015 was much higher than the long-term mean of  $\sim 7.0$  g m<sup>-2</sup> (for the years 1990–2015). The time-series for average zooplankton biomasses in autumn is given in Figure 3.3.2. The increase in biomass was especially notable in the Atlantic, Arctic and in the Polar Front water masses. Zooplankton biomass can vary considerably between years and appears to be controlled largely by predation pressure, e.g. from capelin, although its yearly impact could also vary between regions. The capelin stock size has been relatively high during 2008–2013, exerting a high predation pressure on zooplankton, but has decreased to rather low levels during the last 2 years, likely easing the pressure on their prey.



Figure 3.3.2. Time-series of mean zooplankton biomass from bottom – 0m (dry-weight, g m<sup>-2</sup>) for the western and central Barents Sea for the Norwegian part of the autumn ecosystem-survey, 1988–2015. Data are shown for the three size-fractions (0.18–1 mm, 1–2 mm, > 2 mm) based on wet sieving.

In addition, processes such as transport of plankton from the Norwegian Sea into the Barents Sea, primary production (see section above), and local production of zoo-plankton, are likely to contribute to the observed variability of the zooplankton bio-mass in the Barents Sea.

#### Mesozooplankton species-composition

The Russian investigation along the Kola section in June 2015 showed that copepods were the dominant group of zooplankton at this time. Total abundance of copepods was much lower (5592 ind. m<sup>-3</sup>) in 2015 compared to 8275 ind. m<sup>-3</sup> in 2014. Still, their biomass was only slightly lower in 2015 than in 2014 – 724 and 798 mg wet weight m<sup>-3</sup>, respectively. This was probably caused by a later sampling period – sampling in 2015 was approximately 2 weeks later compared to 2014, so that older copepodites provided a relatively high biomass despite their lesser abundance. The numbers of the most abundant copepod *Calanus finmarchicus* in 2015 was less than half of that in 2014 – 2608 and 5878 ind. m<sup>-3</sup>, and much lower than the mean long-term level (7879 ind. m<sup>-3</sup>). Their biomass was lower too – 634 mg m<sup>-3</sup> in 2015 vs. 712 mg m<sup>-3</sup> in 2014, as compared to the mean long-term level (528 mg m<sup>-3</sup>).

Russian investigations of mesozooplankton communities in the northern Barents Sea (northwards of approximately 75°N) in the joint ecosystem survey in August-September 2014 showed continued tendencies revealed in previous years. Copepods were the most abundant group of zooplankton (95% of total zooplankton numbers), the second most abundant group were pteropods (3%). Pseudocalanus minutus was the most abundant species among copepods (73% of total abundance of copepods) in the northern Barents Sea, while other species (Metridia longa, Calanus glacialis, and C. finmarchicus) consisted only of 6-12% (Figure 3.3.3). Copepods dominated also in biomass (75% of total biomass of zooplankton). But biomass of other groups was also relatively high - pteropods, hyperiids, euphausiids, and hydromedusae consisted of 2.0-3.7%. C. glacialis was the dominant species among copepods in biomass (57% of total biomass of copepods) (Figure 3.3.4). Other copepods (P. minutus, M. longa, C. finmarchicus, and C. hyperboreus) consisted of 7-15%. In 2015, decreases of total abundance and biomass of zooplankton as well as of most copepods were observed when compared to 2014, excluding M. longa (abundance was increased) and C. glacialis (biomass remained the same as in 2014).



Figure 3.3.3. Abundance (ind. m<sup>-3</sup>) of the most abundant copepod species (bottom-0m) in the eastern Barents Sea (based on the PINRO samples from the PINRO/IMR ecosystem survey in August-September 2014).

Generally, like in previous years in the northern Barents Sea, small copepod species (*P. minutus*) were dominant in zooplankton communities in abundance, while larger species (*C. glacialis*) formed the biomass of copepods. In the southern Barents Sea, copepods were also the dominant group in both abundance and biomass (94% and 68% respectively). In addition, abundance of meroplankton was rather high (2.1%) as well as biomass of chaetognaths (15%) and euphausiids (4%). Among copepods, *P. minutus* and *C. finmarchicus* were the most abundant species (47% and 40% of total abundance of copepods) as well as *M. longa* (13%) (Figure 3.3.3). However, the biomass of copepods was mainly formed by *C. finmarchicus* (75% of total copepod biomass) while biomasses of *M. longa* and *P. minutus* were much lower (15% and 7% respectively) (Figure 3.3.4).



Figure 3.3.4. Biomass (mg wet-weight m<sup>3</sup>) of the most abundant copepod species (bottom-0m) in the eastern Barents Sea (based on the PINRO samples from the PINRO/IMR ecosystem survey in August-September 2014).

A time-series for abundance of copepodites of Calanus finmarchicus along the Fugløya-Bjørnøya transect across the southwestern opening of the Barents Sea exists for the period 1995-2015 (not shown). The information on Calanus abundances at the Fugløya-Bjørnøya transect presented below is modified from Dalpadado (2016, Havforskningsrapporten, IMR). The abundance of C. finmarchicus along the FBtransect has not changed much over the years 1995–2015. The average level for the period 1995-2015 has been about 30 000 ind. m<sup>-2</sup> when including samples representing the whole seasonal cycle. However, clearly increased abundances were observed in 2014 and 2015 (average values of about 59 000 and 61 000 ind. m<sup>-2</sup>, respectively) compared to in 2013 (about 7900 ind. m<sup>-2</sup>). Note that the numbers here presented represent annual means of 6 cruises in both 2014 and 2015, whereas that the average for 2013 only represented 3 cruises, which of none were made during November-February, a period with particularly little plankton. Hence, the average for 2013 would most likely have been even lower if data from the November-February period had been included. The 2013-level presented above may therefore not be directly comparable with those for 2014 and 2015.

### Krill

Krill (euphausiids) is the most important group of macrozooplankton in the Barents Sea, followed by hyperiid amphipods. Krill plays significant roles in the Barents Sea ecosystem, facilitating transport of energy between different trophic levels. There are mainly three species of krill in the Barents Sea; *Thysanoessa inermis* associated with Atlantic water in the western and central Barents Sea, *Thysanoessa raschii* found mainly in the shallow waters in the southeastern Barents Sea, and *Meganyctiphanes norvegica* associated with the inflowing Atlantic water, particularly in warm periods.

Meganyctiphanes norvegica is the largest species reaching a maximum length of about 4.5 cm, while Thysanoessa inermis and T. raschii reach about 3 cm in length. Samples of krill were collected in the Barents Sea during the PINRO winter survey with a zooplankton net attached to the bottom trawl. The Russian investigation of euphausiids during the Russian winter survey in October-December 2014 showed a continued rather high abundance of euphausiids (Figure 3.3.5). Abundance of euphausiids in the Barents Sea in 2014 increased - from 675 to 1637 ind. 1000 m<sup>-3</sup> in the southern part and from 640 to 1656 ind. 1000 m<sup>-3</sup> in the northwestern part. These estimates are much higher than the long-term mean values - 568 and 939 ind. 1000 m<sup>-3</sup>, respectively. The distribution of euphausiid species was typical for warm years (Figure 3.3.6). Thysanoessa inermis (most areas) and T. raschii (southeastern areas) were typically the most abundant species, T. longicaudata occurred mainly in the southwestern areas and Meganyctiphanes norvegica was distributed widely in the Barents Sea. However, it should be mentioned that the euphausiid abundance in the southern Barents Sea was increased due to a high abundance of 0-group T. inermis and T. raschii in eastern areas, which were not covered in 2013.



Southern Barents Sea



Northwestern Barents Sea

Figure 3.3.5 Abundance indices of euphausiids (log10 of number of individuals per 1000 m<sup>3</sup>) in the near –bottom layer of the Barents Sea based on data from the Russian winter survey in October-December 1959-2014. Based on trawlnet catches in bottom layer. a) Southern Barents Sea. b) Northwestern Barents Sea.



Figure 3.3.6 Distribution of euphausiids (ind. per 1000 m<sup>3</sup>) in the near-bottom layer in the Barents Sea based on data from the Russian winter survey in October-December 2014.

The following information on krill is modified from Eriksen *et al.* (2015a). The biomass values given in the survey report are in g wet-weight m<sup>-2</sup>. In 2013, the highest catches were mostly distributed in the central area, while in 2014 in the western area, and in 2015 the krill were distributed mainly in the south and southeast of Svalbard/Spitsbergen. The night catches in 2015, a mean of ca. 14.2 gramme per m<sup>2</sup>, were higher than in 2014 (ca. 4.9 gramme per m<sup>2</sup>) and the long-term mean (ca. 7.3 gramme per m<sup>2</sup>) (Figure 3.3.7).



Fig 3.3.7. Mean biomass of krill (g wet-weight m<sup>-2</sup>) sampled with pelagic 0-group fish-trawl within the 60-0m layer in the Barents Sea (based on night catches) from 1991 to 2015. Based on data from the joint autumn ecosystem-survey.



Figure 3.3.8. Krill distribution based on sampling with pelagic 0-group fish trawl in the 60-0m layer during the joint ecosystem survey in August – September 2015. The unit is g wet-weight m<sup>-2</sup>.

In 2015, krill were distributed in the western, central, eastern Barents Sea and around Svalbard/Spitsbergen (Figure 3.3.8).

# Hyperiid amphipods

Hyperiid amphipods are the second most important group of macrozooplankton in the Barents Sea. During the Russian winter survey in the Barents Sea, the abundance of hyperiids continued to decrease from 23 ind. 1000 m<sup>-3</sup> in 2012, to 13 and 12 ind. 1000 m<sup>-3</sup> in 2013 and 2014, respectively. As in previous years, *Themisto abyssorum* was the dominant species. The distribution in the PINRO winter survey in 2014 is shown in Figure 3.3.9.



Figure 3.3.9. Distribution of hyperiids (ind. per 1000 m<sup>3</sup>) in the near bottom layer in the Barents Sea based on data from the Russian winter survey in October-December 2014.

The following information on amphipods is modified from Eriksen *et al.* (2015a). In 2015, amphipods were found north, south and east for Svalbard/Spitsbergen and in the eastern area (Figure 3.3.10). The highest catches were made east of Svalbard/Spitsbergen, and were mostly represented by the Arctic *Themisto libellula*. In 2015, the mean catches taken during day were higher than during night, 3.6 and 2.7 gramme per m<sup>2</sup>, respectively. In 2012 and 2013 no catches of amphipods were made, while in 2014 some restricted catches of amphipods of occurred north of Svalbard/Spitsbergen and in the western area. In 2015, the estimated biomass of amphipods was 566 thousand tonnes for the covered area.



Figure 3.3.10. Hyperiid amphipods distribution, based on trawl stations covering the upper water layers (60-0 m), in the Barents Sea in August-September 2015.

### Chaetognaths

During the Russian winter surveys, the abundance of chaetognaths had increased from 734 ind. 1000 m<sup>-3</sup> in 2012 to 1022 ind. 1000 m<sup>-3</sup> in 2013, and further to 1198 ind. 1000 m<sup>-3</sup> in 2014. Such high abundances of predatory chaetognaths can impact the abundance and biomass of mesozooplankton. Distribution of chaetognates in late 2014 is shown in Figure 3.3.11.


Figure 3.3.11. Distribution of chaetognaths (ind. per 1000 m<sup>3</sup>) in the near bottom layer in the Barents Sea based on data from the Russian winter survey in October-December 2014.

## Jellyfish

The following information on jellyfish is modified from Eriksen et al. (2015b). In August-September 2015, jellyfish were encountered over the entire study-area of the Barents Sea. The lion's mane jellyfish (Cyanea capillata) was the most common species. The number of sampling stations in 2015 with no jellyfish in the catches was similar to in 2014, 30 vs. 28 stations respectively. The covered area was larger in 2015 than 2014, since the Barents Sea was ice-free during the survey period in 2015, while the area north and east of Svalbard was covered with ice in 2014. Jellyfish biomasses in 2015 were low in all western areas from the Norwegian coast to Spitsbergen, and increased from the southwest to northeast and southeast. The highest catches were made in the central, southern and eastern areas. These are the areas with the highest concentrations of 0-group fish, krill and pelagic gish (Eriksen et al., 2015c). The number of stations with high jellyfish biomass (> 10 000 kg per sq nm) was lower in 2015 than in 2014, 71 vs. 131 stations respectively. The total jellyfish biomass estimated from pelagic trawl catches in upper water layers (60-0 m) was 2.6 million tonnes in the Barents Sea in August-October 2015 (Figure 3.3.12). During the 5 last years (2011-2015), the estimated total biomass of jellyfish has been higher than the long-term mean (1.2 million tonnes). Small and fragile gelatinous plankton are easily destroyed by other organisms (such as larger fish or/and invertebrates) in the trawl codend, which will contribute to an underestimation of the abundance of gelatinous zooplankton. See the survey report (Eriksen et al., 2015b) for more details.



Figure 3.3.12. Estimated jellyfish biomass for the Barents Sea, in million tonnes with 95% confidence interval (grey line) for the period 1980–2015. Estimates based on autumn trawl-catches (mainly *Cyanea capillata*) covering the upper layer (60-0 m).

# 3.4 Benthos and shellfish

#### Benthos

There are more than 3000 species of benthic invertebrates registered in the Barents Sea (Sirenko, 2001). Bycatch of benthos in the standard demersal trawl hauls at the ecosystem surveys have been registered annually in 2005-2015 on board Russian vessels, while annually 2007-2013 and in 2015 on board Norwegian vessels. Benthic taxonomic specialists have been identifying benthos bycatch to the lowest possible taxonomic level. During this 11-year period (2005–2015) the abundance and biomass of 423 species in addition to 220 taxa (genera or families) have been registered. These are from 15 phyla. In the case when no specialist have been available on board (2007-2008 in northern Barents Sea in Norwegian sector), the benthos bycatch has been identified to 33 main groups (Porifera, Hydroidea, Alcyoniidae, Actiniaria, Madreporia, Polychaeta, Sipunculida, Priapulida, Nemertini, Echiura, Pycnogonida, Cirripedia, Mysida, Cumacea, Isopoda, Amphipoda, Euphausiidae, Natantia, Brachyura, Anomura, Polyplacophora, Bivalvia, Scaphopoda, Gastropoda, Cephalopoda, Brachiopoda, Bryozoa, Crinoidea, Asteroidea, Ophiuroidea, Echinoidea, Holothuroidea, Ascidiacea). There is ongoing work between IMR and PINRO to harmonize and improve species identification among the specialists and to calibrate benthos catchability in the trawl between the different research vessels. Several publications have been made on the basis of the fine taxonomic resolution data (Anisimova et al., 2011; Jørgensen et al., 2015a; Jørgensen et al., 2015b).

Benthos is one of the main components of marine ecosystems. It can be stable in time, characterizing the local situation, and can show the ecosystem dynamics in retrospective. It is also dynamic and shows pulses of new species such as the snow crab and the king crab (*Paralithodes camtschaticus*) and changes in migrating benthic species (sea stars, brittlestars etc.). The changes in community structure and composition reflect natural and anthropogenic factors. In the joint Russian-Norwegian Monitoring Report (2015) the State of the benthic communities are based on data on benthos diversity, abundance and biomass (by species and total) from trawl samples, video and photographs) (Ljubin *et al.*, 2015). The monitoring show that there are four dis-

tinct groups of benthos in the Barents Sea and a baseline map was made for the 2011 distribution (Jørgensen *et al.*, 2015a; Figure 3.4.1). These four main groups are the temperate species and groups in the southwestern part, cold-water species and groups in the eastern part, arctic species and groups in the northern and northeastern part, and an increasing area in the eastern Barents Sea where the snow crab are expanding as a new, large benthic species. The period with warmer water in the Barents Sea has led to eastwards and northwards migrations of temperate species and groups (Jørgensen *et al.*, 2015a). The retreating ice front opens for new areas for human impact as well as imposing changes in the planktonic production and annual cycles, with possible impact on the benthic communities.



Figure 3.4.1. Baseline map of the Barents Sea mega-benthic communities in 2011, based on fauna similarity (modified from Figure 5 in Jørgensen *et al.*, 2015a). The northern (green and blue) and southern (yellow and red) region are separated by the black line illustrating the "benthic polar front" in 2011. The grey line is the approximately oceanographic Polar Front. Dotted line: partly illustrating a west-east division. Red: South West sub-region (SW) Yellow: Southeast, banks and Svalbard coast (SEW). Green: Northwest and Svalbard fjords (NW). Blue: Northeast (NE). See Jørgensen *et al.* (2015a) for details, methodology and discussion).

On a long time-scale, there was a decline in the total biomass of benthos from 1924– 1935 to 1968–1970 (Antipova, 1975b). This happened almost throughout the Barents Sea, and has been attributed to climate change by many investigators. The mechanism behind this biomass reduction is not clear, however. Some studies suggest that it is due to a change in faunal distribution during the cold period between the 1960s and 1980s (Bryazgin, 1973; Antipova, 1975b; Bochkov and Kudlo, 1973), while others invoke declining biomass of resident boreal-arctic species during the 1930s–1960 warm period (Galkin, 1987; Kiyko and Pogrebov, 1997; Kiyko and Pogrebov, 1998). The dominant boreal-arctic species have an optimum temperature range within the long-term temperature mean of the region. According to this, any deviation from the long-term mean temperature has a negative impact on boreal-arctic species reproduction, abundance, and biomass (see references in Anisimova *et al.*, 2011).

## Snow crab

The snow crab is a new species that has spread into the Barents Sea.



Figure 3.4.2 Maps of snow crab distribution from the ecosystem survey reports for selected years.

It is found mainly in the eastern part of the sea, west of Novaya Zemlya (Figure 3.4.2). It is currently spreading further west in the Barents Sea and the size of the population has increased from 2004 with a peak in 2012–2013. The size of the snow crab populations was at the peak estimated to be ten times larger than the king crab stock and half of that of the shrimp stock. The results from the survey in 2015 show that despite that the area of snow crab distribution in the Barents Sea increased compared with the previous years, all quantitative parameters indicated a reduction of the snow crab population to half of the size compared to the peak years (Anisimova

and Jørgensen, 2015). However, this species lives seasonally patchy, often in dense pods, making the stock size assessment difficult. Furthermore, the Campelen trawl demersal trawl used at the ecosystem survey is not optimal for snow crab capture. Work is underway to modify the trawl used at the ecosystem survey to increase the catchability of snow crab.

## Northern shrimp

After a minimum shrimp stock size in the 1980s, the size of stock has increased but is fluctuating (NAFO/ICES Pandalus Assessment Group report 2015: ICES 2015a, Figure 3.4.3). The assessment and estimate for 2015 is not ready yet (meeting is due September 2016). The results from the ecosystem survey in 2015 suggest a slight increase in the stock compared to 2014 and an estimate slightly above the average for the ecosystem survey period (2004–2015).



Figure 3.4.3 The temporal development in the shrimp stock 1970–2014 (relative abundance estimates from assessment model, provided by C. Hvingel), in ICES SA I and II.

Northern shrimp is widely distributed in the Barents Sea (Figure 3.4.4). The highest densities are recorded on silty grounds on the slopes of banks, troughs and the continental slope. Usually, highest densities are found in relation to the frontal zones Arctic and boreal waters, but has in the recent years shifted easterwards (ICES 2015a). The optimum bottom temperatures for the densest concentration of the northern shrimp are in the range of  $0-2^{\circ}$ C. (Berenboym, 1992).



Figure 3.4.4 Shrimp catches at the ecosystem survey 2015

#### **Red king Crab**

The king crab, intentionally released in the Barents Sea in the 1960s, is still expanding west- and eastwards along the coast of the southern Barents Sea, but the stock seems to have stabilized, with lower recruitment and females reaching maturity at smaller size that during the early expanding phase (Ljubin *et al.*, 2015).

# 3.5 Pelagic fish

#### Young of the year combined biomass

Zero group fish are important consumers on plankton and prey of other predators and therefore an important element in the transfer of energy between trophic levels in the ecosystem.

The total biomass of 0-group (cod, haddock, herring, and capelin), was 678 thousand tonnes in August-October 2015, which is lower than the long-term mean of 1.5 million tonnes. In 2015, 0-group redfish and polar cod biomass time-series for the period 1993–2015 were calculated for the first time (Eriksen *et al.*, 2015c; Figure 3.5.1). Capelin biomass was higher than the other 0-group species and contributed 29.5% of the total 0-group fish biomass. Low 0-group fish biomasses were as consequence of the poor year classes of herring, cod, and polar cod in 2015. Most of the biomass distributes in the central and northern-central part of the Barents Sea.



Figure 3.5.1. Biomass of 0-group fish species in the Barents Sea, August-October 1993-2015.

Capelin, young herring and polar cod constitute the bulk of pelagic fish biomass in the Barents Sea. In some years (e.g. 2004–2007), blue whiting (*Micromesistius poutassou*) also has a significant biomass but only in the western, deeper part of the sea. The total biomass of the main pelagic species in the Barents Sea in 1986–2015 has fluctuated between about 0.5 and 9 million tonnes. The main driver of this variation has been fluctuations of the capelin stock. In 2015 the cumulative biomass of capelin, herring, and polar cod was only half of the long-term mean (Figure 3.5.2).



Figure 3.5.2 Biomass of main pelagic fish species (excluding 0-group stage) in the Barents Sea, August-October 1980–2015.

### Capelin

## Young of the year

The 0-group capelin was distributed widely in the Barents Sea with more dense concentrations in the north-central Barents Sea. Most of the 0-group capelin likely originates from spring-spawning, however some were most likely from summer spawning. The average fish length was 5.0 cm which is larger than in 2013–2014 (4.7 cm) and the long-term mean (4.8 cm). The large size of 0-group capelin may most likely indicate suitable living conditions during summer and increases the chance to survive through winter. The capelin length varied from 1.5 to 7.0 cm, however the length of most of the fish (77%) was between 4 and 6 cm. The abundance index of 0group capelin in 2015 was 2.8 times higher than in 2014 and 1.5 times higher than the long-term mean (Figure 3.5.3). The 2015 year class is above average at the 0-group stage.



Figure 3.5.3. 0-group capelin abundance in the Barents Sea 1980–2015. Red line shows long-term mean for the period 1980–2015, while blue line indicate 0-group abundance fluctuation.

## Older capelin

The total capelin stock in 2015 is estimated at about 0.8 million tonnes, which is well below the long-term mean level (about 3 million tonnes), only about 21% of the stock size estimated for 2013, and about 43% of the 2014 stock size estimate. This can be characterized as a stock collapse and is the fourth collapse in the last 30 years (Figure 3.5.4).



Figure 3.5.4. Capelin biomass 1972–2015. The mature stock biomass (1 October) is the blue part of the column (million tonnes).

About 45% (0.37 million tonnes) of the 2015 stock has length above 14 cm and is considered to be maturing. The biomass of 1 year old (the 2014 year class) is about 0.15 million tonnes and well below the long-term mean. However, 1-year group estimate might be more uncertain than that for older capelin. The distribution in 2015 was more southerly and also more concentrated than what was found in the previous years (Figure 3.5.5).



Figure 3.5.5. Estimated total density distribution of capelin (t/sq nautical mile), August-October 2015.

#### Herring

#### Young of the year

0-group herring were distributed in the central and northwestern area in 2015. The length of 0-group herring varied between 3.0 and 11.5 cm, and most of the fish (77%) were 6.0–7.5 cm long. In 2015, the mean length of 0-group herring was 6.6 cm, which is lower than the long-term mean of 7.1 cm. The 2015 year class of herring is close to the 2011 level and is below the long-term mean, and can therefore be characterized as weak (Figure 3.5.6).



Figure 3.5.6. 0-group herring abundance in the Barents Sea 1980–2015. Red line shows long-term mean for the period 1980–2015, while the blue line indicates 0-group abundance fluctuation.

## Herring age 1, 2, and 3

Methodologically, estimation of the number of herring in the Barents Sea is more difficult than for most other stocks. Herring in the Barents Sea are monitored on two separate surveys in May (IESNS) and August-September (ecosystem survey). Both surveys have methodological problems. The horizontal and vertical distribution of herring is very variable from year to year. Nevertheless, both survey indices indicate the year-class strength of young herring and are used by the ICES Working Group on Widely Distributed Stocks (WGWIDE) for estimation of recruitment-at-age 3 (Figure 3.5.7). There has recently been a low abundance of juvenile herring in the Barents Sea.

Based on the ecosystem survey data in 2010–2011, herring were practically absent in the eastern and central parts of the Barents Sea and the level of the juvenile stock was less then 10% of the annual average. From 2012 numbers of young herring began to increase slowly. This is a positive signal with regards to the herring recruitment. In 2015 the number of herring was the highest since 2005, and found in the southern Barents Sea (Figure 3.5.8).



Figure 3.5.7. Juvenile herring in the Barents Sea – WGWIDE VPA estimates (ICES 2015b)



Figure 3.5.8. Estimated total density distribution of young herring (t/sq nautical mile), August-October 2015.

# Polar cod

Polar cod is a true Arctic species found in the whole circumpolar region. Traditionally, the world's largest population(s) of this species has been found in the Barents Sea.

#### Young of the year

As in previous years, the distribution of 0-group polar cod in 2015 was split into two components: western (around the Svalbard/Spitsbergen Archipelago) and eastern (off the western coast of Novaya Zemlya). The length of polar cod varied between 2.0 and 8.0 cm, and most of the fish were between 3.0 and 4.0 cm long. The mean length of 0-group polar cod (3.9 cm) was lower than in 2013 (5.0 cm) and was approximately equal to the long-term mean of 4.0 cm. The abundance index of 0-group polar cod in 2015 was twice that of 2014, but well below long time average level and the 2015 year class of polar cod was very weak (Figure 3.5.9). The abundance indices of 0-group polar cod have been extremely low for several years, indicating the reduction of the spawning stock and lack of spawning success.



Figure 3.5.9. 0-group polar cod abundance in the Barents Sea 1980–2015. Red line shows long-term mean for the period 1980–2015, while the blue line indicates 0-group abundance fluctuation.

### Older Polar cod

In 2015, the numbers of all age groups except 1+ was significantly reduced compared to the previous year. The number of polar cod aged 1+ was higher than in 2014, but low compared to the long-term level. It should be noted that the 2015 survey included more northerly areas than the 2014 survey, an area with much juvenile polar cod, and this could be the reason for the increased abundance of 1+ polar cod in 2015. No significant prespawning migration of polar cod was found in the traditional locations along Novaya Zemlya. Only small and scattered schools were recorded. Thus, the abundance of polar cod in the Barents Sea continues to decline. The total stock in 2015 amounted to only 148 thousand tonnes (Figure 3.5.10). This is the lowest level of abundance during the last 25 years. Since 2010, there has been an increase in natural mortality calculated from ecosystem survey data and there has been an almost complete recruitment failure since 2012. The polar cod distribution area was wider than last year, and particularly stretched further to the west. No high-density regions were recorded (Figure 3.5.11).



Figure 3.5.10. Polar cod biomass and recruitment in the Barents Sea, August-September 1986–2015. (2003 numbers based on VPA due to poor coverage survey).



Figure 3.5.11. Estimated total density distribution of polar cod (t/sq nautical mile), August-October 2015.

#### **Blue whiting**

Acoustic estimates of blue whiting in the Barents Sea have been made since 2004, but the target strength used here is different from what is used on other surveys on blue whiting so the estimates are only indicative. In 2004–2005 estimated biomass of blue whiting in the Barents Sea was higher than 1 million tonnes (Figure 3.5.12). The estimate dropped abruptly in 2008. In 2015 blue whiting biomass was about 535 000 tonnes which is the highest since 2007 (Figure 3.5.12). Blue whiting penetrates from the Norwegian Sea into the deeper parts of the Barents Sea (Figure 3.5.13) when the stock is large and when sea temperatures are high.



Figure 3.5.12. Blue whiting biomass in the Barents Sea, August-September 2004–2015.



Figure 3.5.13. Estimated total density distribution of Blue Whiting (t/sq nautical mile), August-October 2015.

## 3.6 Demersal fish

Most of the fish in the Barents Sea are demersal (Dolgov *et al.*, 2011). The demersal fish community consists of about 70–90 regularly occurring species. These have been classified into zoogeographical groups. About 25% are Arctic or mainly Arctic species. The commercial species are all boreal or mainly boreal (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 Chernova, 1995).

Distribution maps for cod, haddock, long rough dab, Greenland halibut, redfish, and six other demersal fish species based on data from the ecosystem survey in August-September can be found at:

http://www.imr.no/tokt/okosystemtokt\_i\_barentshavet/utbredelseskart/en

Abundance estimates are available for the commercial species that are assessed Figure 3.6.1 shows the biomass of cod, haddock, and saithe (*Pollachius virens*) from the assessments made in 2015. Saithe is mainly found along the Norwegian coast and off the coast south of the Barents Sea – little in the Barents Sea itself. The total biomass of these three species is close to the highest recorded (time-series starts in 1960). Greenland halibut and redfish, in particular *S. mentella*, are important commercial species with a large part of their distribution within the BS: Time-series of biomass estimates of *S. mentella* and Greenland halibut are much shorter than those of haddock, cod, and saithe. Apart from these main commercial stocks, long rough dab is the demersal stock with the highest biomass. Overall, cod is the dominant demersal species.



Figure 3.6.1 Biomass estimates of cod, haddock and saithe 1960–2015. Please note that saithe is only partly distributed in the Barents Sea.

## Cod

# Young of the year

Cod were widely distributed in 2015, and the densest concentrations were found in the north-central part of the sea, close to the Finnmark coast (Northern Norway) and west of Svalbard/Spitsbergen Archipelago. The cod 0-group biomass (130 thousand tonnes) is 7.4 times lower than in 2014 and 4.8 times lower than the long-term mean, and the abundance index of 2015 year class is 3.1 times lower than long-term mean (Figure 3.6.2). The 2015 year class may be characterized as weak. The lengths of 0-group cod varied between 2.0 and 13.5 cm, with a mean length of 7.5 cm, which is higher than in 2013–2014 and at the same level as the long-term mean of 7.5 cm.



Figure 3.6 2. 0-group cod abundance in the Barents Sea 1980–2015. Red line shows long-term mean for the period 1980–2015, while the blue line indicates 0-group abundance fluctuation.

## Older cod

The northeast Arctic cod stock is currently in a good shape, with high total stock size, and spawning-stock biomass (Figure 3.6.3). The 2004 and 2005 year classes were very strong, but after that recruitment-at-age 3 has returned to an average level (Figure 3.6.4). 0-group abundance has been very high in recent years (2011–2014), but this does so far not seem to result in strong year classes later on. Cod cannibalism is at a normal level given the high abundance of large, cannibalistic cod (Figure 3.6.5).



Figure 3.6.3. Cod total stock and spawning stock development – from AFWG 2015 (ICES 2015c)



Figure 3.6.4. Cod recruitment-at-age 3 from AFWG 2015 (ICES 2015c).



Figure 3.6.5 Cod consumption 1984–2014. Consumption by mature cod outside the Barents Sea (3 months during first half of year) not included. From AFWG 2015 (ICES 2015c).

The strong 2004 and 2005 year classes have, together with a low fishing mortality, led to a rebuilding of the cod age structure to that seen in the late 1940s (Figure 3.6.6).



Figure 3.6.6. Cod age distribution (biomass). Updated by AFWG 2015 data (ICES 2015c).

Consumption per cod and growth rates for older cod (7+) have decreased somewhat in the last years, but the weight at age for immature cod has been stable despite the large stock size (Figures 3.6.7 and 3.6.8). Proportion mature at age 7 decreased considerably from 2014 to 2015.



Figure 3.6.7 Cod stock weight at age 4(from AFWG 2015)





Figure 3.6.8 Cod stock weight and % mature fish at age 7. From AFWG 2015.

### NEA haddock

### Young of the year

Haddock was relatively widely distributed in the central part of the survey area in 2015. The haddock biomass was 178 thousand tonnes and it is 1.8 times higher than in 2014 and at the long-term mean (for the period 1993–2015). The number of fish belonging to the 2015 year class is higher than in 2014 and the long-term mean and can be characterized as an above average year class (Figure 3.6.9). The length of 0-group haddock varied between 2.5 and 16.5 cm, with mean length of 10.1 cm, which is higher than in 2014 and the long-term mean (9.1 cm). The high 0-group haddock abundance may indicate suitable living conditions for young haddock in 2015.



Figure 3.6 9. 0-group haddock abundance in the Barents Sea 1980–2015. Red line shows long-term mean for the period 1980–2015, while the blue line indicates 0-group abundance fluctuation.

## Older haddock

The Northeast Arctic haddock stock reached record levels in 2009–2013, due to the very strong 2004–2006 year classes. After that, recruitment has normalized, and the stock has declined in recent years but is still at a high level (Figures 3.6.10 and 3.6.11).



Figure 3.6.10. Carches and biomass of haddock 1930-2014.

A slight decrease in weight/maturity-at-age has been observed in the last decade, but it looks like these trends are being reversed now (Figure 3.6.12).



Figure 3.6.11 Recruitment of haddock. Updated with data from 2015.



Figure 3.6.12 Weight and maturation of haddock age 6.

1985 1988 1991 1994 1997 2000 2003 2006 2009 2012 2015

#### Long rough dab

### Young of the year

Long rough dab were widely distributed in the survey area. 0-group of long rough dab was observed both in pelagic and bottom catches indicating start of settlement to the bottom. Settlement was more widespread in the southwest area due to late coverage (second part of September) of that area. Thus, the abundance indices were likely underestimated in 2015. The long rough dab index in 2015 was the highest since 2009 and close to the long-term mean (Figure 3.6.13). Fish length varied between 1.0 and 5.5 cm with a mean length of 3.2 cm, which is approximately the same in 2012–2014 and the long-term average (3.4 cm).



Figure 3.6.13. 0-group long rough dab abundance in the Barents Sea 1980–2015. Red line shows long-term mean for the period 1980–2015, while the blue line indicates 0-group abundance fluctuation.

#### Older long rough dab

As in the previous years, older long rough dab (age 1+) were widely distributed in the Barents Sea, and denser concentrations of long rough dab were observed in the central-northern and eastern areas. Long rough dab, as in the previous years, were dominant by numbers in bottom-trawl catches in surveys. In 2015, long rough dab catch per unit of effort at the Russian winter survey was similar to the previous two years (Figure 3.6.14). Many small fish were observed in trawl catches especially in the eastern areas at the ecosystem survey in 2015.



Figure 3.6.14. Catch per unit of effort of long rough dab at the Russian winter survey.

### **Greenland halibut**

#### Young of the year

Since 2005 only low concentrations of 0-group Greenland halibut were found. Greenland halibut were mostly observed around Svalbard/Spitsbergen. The survey did not cover the numerous Svalbard/Spitsbergen fjords, where 0-group Greenland halibut are abundant, and therefore this index does not give the real recruitment (at age 0) to the stock, although it may reflect the minimum abundance index of the year-class strength in the standard long-term surveyed area. In 2012–2014, the abundance of Greenland halibut continuously decreased, while 2015 year-class index is close to the long-term mean. Fish length varied between 1.5 and 9.5 cm, with a mean length of 7.5 cm, which is higher than in 2007–2014 and the long-term mean (6.2 cm). The large 0group fish may most likely indicate suitable living conditions for 0-group Greenland halibut in 2015.

#### Older Greenland halibut

The distribution of Greenland halibut has been wide over the last five years, and specimens were captured in 41% of the bottom-trawl hauls in the ecosystem survey 2015. Greenland halibut were distributed along the shelf slope in the western Barents Sea and north of Svalbard/Spitsbergen, and large numbers of small individuals were

found between Svalbard and Franz Joseph land, which was not trawled in 2014 due to ice cover. The total biomass on Greenland halibut within the coverage area was the lowest since 2005, and mainly young age groups of Greenland halibut were observed. The adult part of the stock was as usual, distributed outside the survey area. On the other hand, in recent years an increasing number of large Greenland halibut has been captured in the deeper-waters in the surveyed area.

### Deep-water redfish

### Young of the year

Redfish, mostly *Sebastes mentella*, was widely distributed in the western part of the Barents Sea: from the north western part of the Svalbard/Spitsbergen Archipelago to the coast of Norway and between 70°N and 81 N. The densest concentrations were located west of the Svalbard/Spitsbergen Archipelago. 0-group redfish biomass in 2015 was 1.1 times higher than in 2014 and 1.3 times higher than the long-term mean. The abundance of 0-group redfish is highest since 2008 and 1.6 times higher than the long-term mean, thus the 2015 year class can be characterized as above average. 0-group redfish were found west of Svalbard in the deeper area of continental edge in 2014. The index of 0-group redfish in the Barents Sea is an unknown proportion of the total 0-group abundance, and therefore representative only for the shelf area of the Barents Sea.

## Older redfish

Deep-water redfish were widely distributed in the Barents Sea. At the ecosystem survey, the main concentrations of deep-water redfish were found, as usual, in the western and north-western parts of the Barents Sea. West and east of Svalbard/Spitsbergen the abundance of younger individuals are high, which is similar to what was found in previous years. The biomass of deep-water redfish in the Barents Sea decreased somewhat from 2013 to 2014, which was thought to be partly explained by limited coverage in the northern and northeastern Barents Sea, but the level in 2015 increased only slightly despite an increased coverage Over the last, at least, five years, deep-water redfish was observed along the shelf slope north and west of Svalbard/Spitsbergen, and the distribution area in the southern Barents Sea has increased in recent years.

# 3.7 Marine mammals

Polar bears, seven pinniped species, and five cetacean species reside year-round in the Barents Sea region. Eight additional whale species are regular seasonal migrants that come into the Barents Sea to take advantage of the seasonal, summer-time peak in productivity as the ice retreats northward (Kovacs *et al.*, 2009).

Sea mammal observers have been present on the Joint IMR PINRO Ecosystem survey most years. In 2015 two species of pinnipeds, fours species of toothed whales, and five species of baleen whales were observed (Figure 3.7.1), often associated with high concentrations of pelagic fish (Klepikovskiy and Øien, 2015).



Figure 3.7.1. Distribution of baleen whales observed at the ecosystem survey in August-October 2015

Minke whales (*Balaenoptera acutorostrata*) and the harp seal (*Pagophilus groenlandicus*) are currently commercially exploited in Barents Sea. Abundance of minke whales is estimated as part of a six year monitoring cycle aiming to estimate the total summer estimate of minke whales in the Norwegian and Barents Sea, and Jan Mayen. Harp seals are assessed in ICES/NAFO WGHARP. The latest report is from 2013 (ICES 2013).

# 3.8 Fisheries

## **Total catches**

Fishing is the largest human impact on the fish stocks in the Barents Sea, and thereby on the functioning of the whole ecosystem. However, the observed variation in both fish species and ecosystem is also strongly affected by as climate and trophic interactions. 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 tended to decrease the last years (Figure 3.8.1).



\* 2015 preliminary data

Figure 3.8.1 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 area 2a, i.e. along the Norwegian coast south to 62°N) in 1965–2015. Catches of Norwegian spring-spawning herring outside ICES area 2a are also included. Also minor catches of other stocks are taken in the Barents Sea (see ICES website).

Variation of catches in the region depends both on stock dynamics of species and management considerations. For all main species it is applied harvesting strategies which lead year-to-year deviation of catches.

## Fishing activity

The fishing activity in the Barents Sea is among other monitored by Vessel Monitoring System (VMS) data. Figures 3.8.2-3.8.3 show fishing activity in 2015 from Russian and Norwegian data. VMS data might give us valuable information about temporal and spatial changes in fishing activity. The most widespread gear used in the Barents Sea is bottom trawl, but also longline, gillnets, Danish seine, and handline are used in the demersal fisheries. The pelagic fisheries use purse-seine and pelagic trawl.



Figure 3.8.2. Location of Russian and foreign fishing activity from commercial fleets and fishing vessels used for research purposes in 2015 as reported (VMS) to Russian authorities. This is VMS data linked with logbook data (source: PINRO Fishery statistics database).



Figure 3.8.3 Location of Norwegian and foreign fishing activity from commercial fleets (larger than 15 m) and fishing vessels used for research purposes in 2015 as reported (VMS) to Norwegian authorities. This is VMS data linked with logbook data. Surrounding nets = Danish seine (source: Norwegian Directorate of Fisheries).

In addition, small catches of minke whales and harp seals are taken in the Barents Sea. From 2011 onwards, the 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. A change/harmonization from 2011 onwards of the minimum legal catch size for cod from 47 cm (Norway) and 42 cm (Russia) to 44 cm for all, and for haddock from 44 cm (Norway) and 39 cm (Russia) to 40 cm for all may lead to more fishing in areas that previously would be closed.

#### Fishing mortalities and harvesting strategies

Cod, haddock, saithe, and herring have F-based management plans which are largely followed by managers when setting TACs. All of these stocks are currently harvested close to or below MSY (Figure 3.8.4), and, except herring, all of them are above B<sub>pa</sub> at present. Several variants of harvest control rules for cod, haddock, and capelin have been tested and have been approved by ICES. The harvest control rules will be decided by the joint Russian-Norwegian Fisheries commission the autumn 2016.



Figure 3.8.4. Ratio between F and FMP (F currently used in the management plan) for cod, haddock, and saithe. For all these stocks, FMP gives a yield at or close to MSY (from ICES 2015). 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.

Capelin is managed by a target escapement strategy. MSY for capelin will depend strongly on the cod stock and gives little meaning in a single-species context.

The current large cod stock has caused some concerns about it being 'too large' as compared to food availability/carrying capacity. So far, the population dynamics of the stock has been little affected by the stock size, but the question is certainly valid. However, the concept of a stock being 'too large' is not at present incorporated in the ICES advice framework, although such issues are well known e.g. in management of freshwater fisheries and wildlife.

Recent catch levels for S. mentella and G. halibut are considered sustainable.

#### **Environmental impact of fisheries**

The impact of fisheries on the ecosystem is summarized in the chapter on Ecosystem considerations in the AFWG report (ICES 2015), and some of the points are:

- The demersal fisheries are mixed, and currently have largest effect on coastal cod and *Sebastes norvegicus* (Golden redfish) due to the poor condition of these stocks.
- The most widespread gear is bottom trawl. Trawling has largest effect on hard bottom habitats, whereas the effects on other habitats are not clear and consistent.

- Currently the possibility of using pelagic trawls when targeting demersal fish is explored, to avoid impact on bottom fauna and to reduce the mixture with other species. It will be mandatory to use sorting grids to avoid catches of undersized fish.
- Fishery induced mortality (lost gillnets, contact with active fishing gears, etc.) on fish is a potential problem but not quantified at present.

# 4 Interactions, drivers, and pressures

# 4.1 Causes of capelin decline

The Barents Sea capelin stock has undergone drastic changes in size during the last three decades. Three stock collapses (when the abundance was low and fishing has been stopped) occurred in 1985–1989, 1993–1997, and 2003–2006. A significant reduction in stock size was also observed in 2014–2015, and the stock biomass in 2015 again fell below 1 million tonnes. The previous collapses have caused evident effects both downwards and upwards in the foodweb. The reduced predation pressure from capelin has led to increased amounts of zooplankton during the collapse periods. When capelin biomass was drastically reduced, its predators were affected in various ways. Cannibalism became more frequent in the cod stock and cod growth was reduced and maturation delayed. Seabirds experienced increased rates of mortality and total recruitment failures, and breeding colonies were abandoned for several years. Harp seals experienced food shortage, increased mortality partly because they invaded the coastal areas and were caught in fishing gears, and recruitment failures. The effects were most serious during the 1985–1989 collapse, whereas they 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 last periods of collapse (1990s and 2000s).

The last collapses were caused by poor recruitment, most likely in combination with low growth and increased predation pressure. High level of fishing pressure in 1985–1986 also probably amplified and prolonged the first collapse. After each strong stock decline the fishery has been stopped and the stock has recovered in few years due to good recruitment. Predation by young herring has been suggested by several authors to have strong negative influence on capelin recruitment and thus to be a significant factor in capelin collapses (Gjøsæter *et al.*, 2016).

The strong decline in the capelin stock in the last two years appears to be caused by a combination of the same factors as in the previous capelin collapses but with different relative contributions. We have witnessed a decrease in individual growth rate (reflected in size-at-age) of capelin, increased mortality caused by heavy predation from the large cod stock, and lower recruitment. This is detailed in the subsections below. The estimated annual consumption of capelin by cod has been around 4 million tonnes since 2009, which is of the same magnitude as the stock size.

A possible explanation for the current capelin collapse is as follows. Heavy predation by cod is likely to have played a major role. A question is why the stock did not collapse earlier. Exceptionally good recruitment-at-age 0 from 2006 gave high abundance of juveniles and probably made the capelin stock more resilient against the effect of high predation in the first years when high cod and capelin stocks cooccurred. Good feeding conditions with a large proportion of krill in the capelin diet also contributed to high growth and production in the stock. When recruitment went down and also the feeding conditions and growth rate declined, the capelin stock became more sensitive to the heavy predation, moved away from the relatively steady state and started declining. Once the decline started, the effect of predation became relatively stronger and accelerated the decline.

#### Stock development

The capelin stock was at a high level for several years from 2008 to 2013 despite the increased predation pressure from a record high cod stock with an increased overlap in distribution compared to previous years.

The age composition of the capelin stock has varied considerably between years but has generally been dominated by age groups 1 and 2. The observed increase in older fish (age 3) and relatively high abundance of capelin of age 2 during the period 2008–2013 have contributed to keep the stock at a relatively high level reflecting good recruitment. A severe decrease in abundance of the age groups 1, 2, and 3 in 2014 and 2015 was associated with the present capelin stock collapse. The large numbers of one-year old capelin of the 2012 cohort in 2013 was strongly reduced as 2- and 3-year-old individuals in 2014 and 2015 indicating high mortality. The stock in 2015 was composed of relatively low abundances of 1- and 2-year-old individuals from the 2013 and 2014 cohorts (when recruitment was low) and also relatively small numbers of 3- and 4-year-old.

#### 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 a poor recruitment (Figure 4.1.1). Recruitment went down in 2013 and 2014, not to a very low level but substantially lower than in the period 2006–2012 (Figure 4.1.1). This was reflected also in lesser abundance of these cohorts as 1-year olds.



Figure 4.1.1. Fluctuation of capelin at age 0 (blue line) and 1 (red line) for the cohorts1980-2015.

Recruitment of capelin measured as 0-group during the ecosystem survey has been at a high level from 2006 to 2012 except for a dip in 2010 (which was a cold year in midst of a warm period) (Figure 4.1.1). The recruitment these years were exceptional with similar high 0-group values only seen a few times in previous years (1980–82 and 1989). 0-group abundance gives a first indication of spawning success, while abundance of age 1 indicates recruitment to the adult stock. Recruitment as 1-year olds was also good in these years although survival 0-group and 1-group was relatively low (Figure 34.1.1). Still their numbers were generally high (150–300 billion individuals) as were the estimated numbers of 2-year olds from 2008 to 2013 (Figure 4.1.2).



Figure 4.1.2. The capelin stock age composition during 1972–2015.

Most of the 0-group capelin originates from the spawning in spring. The 0-group from summer spawners is distributed mostly in the southern Barents Sea. Abundance of this portion (3 cm body length or less in August-September) has been relatively low compared with the total abundance of 0-group, and was estimated to make up 15% in 2013, 10% in 2014 and 2% in 2015. These small 0-group capelin likely are less able to survive the first overwintering since they have less time to grow during the first-feeding season.

The capelin stock age composition has varied considerably between years but has generally been dominated by age groups 1 and 2 (Figure 4.1.2). The observed increase in older fish (age 3) and relatively high abundance of capelin of age 2 during the period 2008–2013 have contributed in keeping the stock at a relatively high level and provide a good recruitment. A severe decrease in abundance of the age groups 1, 2, and 3 in 2014 and 2015 preceded the present capelin stock collapse.

Figure 4.1.3 shows stock-recruitment plot from Gjøsæter *et al.* (2016), going back to 1987. This plot shows that 1989 is still the strongest year class at age 1. An estimation of breakpoint from this plot could be attempted. Figure 4.1.4 shows an alternative approach where recruitment-at-age 0 is used and SSB is calculated as mature stock (> 14 cm) in autumn (with fishery in take January-March subtracted).



Figure 4.1.3. 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 4.1.4. Relationship between mature stock biomass (> 14cm) take of spring fishery (biomass at 1 Oct. Y, total landings from 1 Jan to 1 Apr.Y+1 are subtracted) and 0-group index (Y+1), covering the cohorts 1980—2015. The size of bubbles indicates the number of herring at age 1 and 2 (WGWIDE 2015, ICES CM 2015/ACOM:15). Minimum diameter of bubble corresponds to 0.7 billion individuals of herring (1982), the maximum - 200.8 billion ind. (1993). The red point is the 1989 cohort which is the basis for the current reference point (Blim).

#### **Feeding conditions**

The stomach fullness expressed as Total Fullness Index (TFI) declined from around 2010 to relatively low values in 2012 and 2013, with a slight increase again in 2014 (Figure 4.1.5). In the Barents Sea, a pronounced shift in the diet from copepods to krill, mostly *Thysanoessa inermis*, has been observed (especially for larger capelin > 14 cm), with krill being the largest contributor to the diet weight in most years (Figure 4.1.5). Amphipods contributed a small amount to the diet of capelin. Migration of capelin into northerly areas (> 80°N) was observed in the recent years due to more ice-free area, which may have made arctic zooplankton more accessible to capelin.



Figure 4.1.5. Stomach fullness of capelin during survey in August-September. Number of fish sampled each year in brackets.

Capelin growth depends on the state of the plankton community (Skjoldal *et al.*, 1992; Dalpadado *et al.*, 2002; Orlova *et al.*, 2010). Capelin is able to produce a strong feedback on zooplankton stock levels through predation (Figure 4.1.6, Dalpadado *et al.*, 2003; Stige *et al.*, 2014), which has been found previously to be particularly pronounced for krill in the central Barents Sea (Dalpadado and Skjoldal, 1996).



Figure 4.1.6. Fluctuation of capelin stock and zooplankton biomass in the Barents Sea in 1984–2015.

The decrease in individual growth rate and condition of capelin observed over the last seven years for the large capelin stock may have been caused by reduced food availability due to strong grazing on the largest plankton organisms. This is suggested by reduction of the largest size fraction (> 2 mm) in the Norwegian part of the autumn survey (see 3.2.1 in the zooplankton chapter). The plankton species composition in the northeastern area has changed; abundance and biomass of large copepod species (*Calanus finmarchicus, C. glacialis*), which are important prey items for capelin, decreased in the last years with increasing abundance of small copepods (*Pseudocalanus minutus*), which are practically not eaten by capelin. The change in the composition of the plankton community is most likely caused by warming in the Barents Sea and high grazing pressure from capelin and other species.

## Growth

The growth of capelin was reduced between 2009–2014, corresponding to the reduction in the stomach fullness (Figure 4.1.7). Slow growth is generally associated with slow maturation (since capelin matures according to size rather than age), which is indicated by relatively large proportion of the 3-year-old age group and also some 4 years old (Figire 4.1.2). The slow growth may have been associated also with some individuals maturing at smaller size. During the Norwegian capelin fishery during winter-early spring the proportion of capelin of body length below 14 cm increased from < 5% in 2011–2014 to 15% in 2015.


Figure 4.1.7 Capelin growth (grammes) from age 1 to age 2.

There is some evidence of a density-dependent effect on capelin growth. This is reflected in decreasing individual fish length of 2- and 3-year-old capelin with increasing capelin numbers (Figure 4.1.8).



Figure 4.1.8. Density-dependent capelin growth at age 2 and 3.

#### Natural mortality

The estimated capelin mortality based on the survey results has shown a marked increase in the last years to annual mortality coefficients of around 1.0 for 1- and 2-year-old capelin in 2014 (Figure 4.1.9). This corresponds in time to the strong decline of the capelin stock.



Figure 4.1.9. Natural mortality of age 1-2 and 2-3 capelin. Note that the high 2003–2005 values were obtained during a capelin collapse.

Cod is the main predator on capelin, although other fish species as well as seabirds and marine mammals are also important predators. In the last 5-6 years it has been an extremely high cod stock level in the Barents Sea. Estimated biomass of preyed capelin by cod in recent years has been equivalent to the biomass of the entire capelin stock (Figure 4.1.10). Under good conditions, the capelin stock tolerated a high grazing pressure; the biomass produced during the year was equivalent to the standing stock biomass measured in autumn. The number of predators other than cod is also at high and, to our knowledge, stable levels.



Figure 4.1.10. Size of the capelin stock and estimated consumption of capelin by cod.

The estimated consumption of capelin by cod for the first and second parts of the year has shown different temporal patterns. The consumption during the 1<sup>st</sup> and 2<sup>nd</sup> quarters has been high also in previous capelin periods and includes consumption during the spawning period and the spring and early summer situation before the seasonal feeding migration of capelin. A major difference, however, is the pronounced increase to a much higher level of consumption in the 3<sup>rd</sup> and 4<sup>th</sup> quarters during the last capelin period (Figure 4.1.10). This reflects the northward movement

of cod and a larger spatial overlap between cod and capelin under the recent warm conditions compared to the situation earlier, e.g. during the capelin period in the 1990s.

The stock of polar cod in the Barents Sea has also declined as described in the next section. The decrease in polar cod abundance may have contributed to increased predation pressure on capelin since polar cod serve as additional prey for cod. The predation pressure from seals and whales may also have changed, but there is little information available regarding this. Assuming that predators such as harp seal and minke whale have a more stable occurrence in the Barents Sea, their food demand by feeding on capelin would come in addition to the heavy predation by cod.

#### 4.2 Causes of polar cod decline

The population in the northern Barents Sea is now in sharp decline and reached a low level in 2015. In 2015, the measured biomass of polar cod was only 148 000 tonnes, the lowest level in the past 25 years. No strong year classes have occurred since 2012. It appears that mortality has increased in recent years. During the recent period with polar cod, when the Barents Sea has been warm, the distribution of sea ice has decreased, and several boreal species have moved northward while the distribution area of Arctic species like polar cod has decreased.

Since the mid-1990s there has been a general rise in both air and water temperature in the Barents Sea (See chapter 3.1). The 2000s have been record warm. The area covered by sea ice has never been so low in the Arctic and the Barents Sea as 2012. In the Barents Sea the area of Arctic water decreased while a larger part of the sea has been dominated by warmer Atlantic water. These climatic changes may have 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 degrees 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, euphausiids, eggs, and molluscs larvae, while adults feeds mainly on large Arctic plankton organisms such as Calanus hyperboreus, 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 Gadidae to changes in the environment and enough available food resources. It is also observed that the area of distribution of polar cod has declined slightly despite the water warming, but the density of polar cod concentrations decreased significantly in the Barents Sea in recent years.

The diet data from 2005 to 2014 indicate that polar cod mainly feed on amphipods (mainly hyperiids, occasionally gammarids), copepods, and euphausiids, and to a lesser degree on other invertebrates. Large polar cod may also prey on fish. Similar to capelin, the total stomach fullness index was the lowest in 2012 (Figure 4.2.1), with a marked increase in 2014.



Figure 4.2.1. Stomach fullness of polar cod during survey in August-September. Number of fish sampled each year in brackets.

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 (Figure 4.2.2), and thus predation pressure on polar cod has increased, contributing to the stock decline. In the overlapping area cod feeds efficiently on polar cod (see chapter 4.3).



Figure 4.2.2. Observation of cod (left) and polar cod (middle) during the joint Barents Sea Ecosystem survey in 2004–2013. A decrease in number of fish in an area from 2004 to 2013 is shown with blue circles, while an increase is shown with red circles. The size of the circles is proportional to the change. To the right is an index of spatial overlap between the two species (2004-2013)

#### 4.3 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. 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) (Figure 4.1.10).

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, especially in mixed (polar cod and capelin) concentration (Figure 4.3.1). The polar cod are most likely more available for cod than the capelin, because they have a lower swimming speed and are distributed close to the bottom. It should be noted, however, 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.



Figure 4.3.1. Cod consumption during the ecosystem survey in August-September 2010–2015. Red dots indicate capelin, and blue dots polar cod.

Overlap with high concentration of cod and increased predation pressure most likely influenced the polar cod stock decline. The reduction of polar cod stock led probably to some increase in the consumption on capelin from cod.

## 4.4 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 (Figure 4.4.1). Using trait table analysis, 23 "high-risk" benthic species were identified, which include "large weight and upraised" taxa as "easily caught" by a bottom trawl. Further was a "low-risk" category identified containing 245 taxa/species and a "medium-risk" category with 80 species. 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 (Figure 4.4.2). This is due to the dominance of the "high-risk" species, including *Geodia* sponges in the southwestern Barents Sea, basket stars (*Gor*-

*gonocephalus*) in the northern Barents Sea, sea pen (*Umbellula encrinus*) on the shelf facing the Arctic Ocean, and sea cucumber (*Cucumaria frondosa*) in shallow southern areas.



Figure 4.4.1 Stations in the Barents Sea sampled during August–September 2011, each showing the biomass distribution of "high-risk" (red), "medium-risk" (orange), and "low-risk" (green) species being taken by a bottom fish trawl. Area: Southwest (1), Svalbard Bank (2), Southeast banks (3), Pechora Sea (4), Northern Shelf (5), Northwest (6), Central–Grand banks (7), and Arctic Northeast (8) (Figure 3 in Jørgensen *et al.*, 2015b).



Figure 4.4.2. Distribution (wet weight biomass 15 min. trawling) of identified high-risk species being caught by trawl: (a) *Gorgonocephalus* spp. (Gorg) and *Geodia* spp. (Geod); (b) *U. encrinus* (Umbe), *C. opilio* (Chio), and *Parasticopus* spp. (Stic); (c) *H. glacialis* (Heli) and *C. frondosa* (Cucu); (d) *Nephtheidae* (Neph) and *P. camtschaticus* (Para). Species mapping data are from Norwe-gian-Russian Ecosystem Surveys during August-September 2007-2013. (Figure 4. in Jørgensen *et al.*, 2015b)

## 5 Expected changes in the coming years

#### 5.1 Sea temperature

Oceanic systems have a "longer memory" than atmospheric systems. Thus, a priori, it seems feasible to realistically predict oceanic temperatures much further ahead than atmospheric weather predictions. However, the prediction 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 temperature prediction in the Kola Section (0–200 m), made using a prediction model based on harmonic analysis of data time-series (Boitsov and Karsa-kov, 2005) with use of background predictions of air temperature and ice extent, the Atlantic Water temperature in the Murman Current is expected to remain over the next two years typical of warm years in 2016 ( $4.7 \pm 0.5^{\circ}$ C) and 2017 ( $4.6 \pm 0.5^{\circ}$ C). The long-term mean for the period 1951–2010 is  $4.05^{\circ}$ C and the temperature in 2015 was  $4.98^{\circ}$ C.

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

### 5.2 Possible development of the stocks

Natural mortality of capelin is currently very high. The main predator for capelin is cod. The size of the cod stock is probably a main factor that restricts the increase of capelin stock size. However, the relationship between changes in stock size of cod and capelin is not very strong. Historical data show that the probability of increase of capelin stock to a high level is low when the cod stock is large (Figure 5.2.1).

From this view, and taking into account the high cod stock, we can expect that in the next 2-3 years, the capelin stock in the Barents Sea will not be above average, despite possible good recruitment. The 2015 year class was strong at the 0-group stage and in the 2016 winter survey 1-group capelin was abundant and widely distributed. However, the low abundance of immature capelin in 2015 indicates that the abundance of mature capelin in 2016 will also be low.



Cod spawning stock biomass in previous year, 1000 tonnes

# Figure 5.2.1. Capelin total-stock biomass vs. cod spawning-stock biomass in previous year. Circle size is proportional to capelin stock biomass the previous year. Capelin data are from the acoustic survey 1973–2015, cod data are from the report of the AFWG 2015 (ICES 2015c).

With the expected warm conditions in the coming years, cod will still have a large area available for feeding. However, the two important prey species, polar cod and capelin are now at low levels and not likely to recover to a high level in 2016 or 2017. Cod must therefore compensate by feeding more on alternative prey. Figure 5.2.2 shows the diet compositon of cod from 1984 to 2014.

During the first collapse (1985–1989) capelin importance in cod diet decreased from 53% in 1985 and then didn't exceed 20–22%. At the same time increase of other prey was observed - hyperiids (7–23%) and redfish (3–18%).

During the second collapse (1993–1997) weight percent of capelin was high in the first 2 years (47% and 30%) and then decreased to 6–16 %. In this period cannibalism level sharply increased from 4–11% to 18–26%. In addition, more intensive consumption of hyperiids was observed (1–12%), but much lower compared to the first collapse.

During the third collapse (2003–2006) consumption of capelin by cod was rather intensive (10–26%). In this collapse many prey were alternative food for cod in similar quantitative – juvenile haddock (6–11%) and cod (5–10%) herring (3–11%), blue whiting (1–5%) as well as hyperiids (1–12%). Consumption of capelin by cod during the most recent years remained more or less stable (17–31%), but was much lower compared to previous periods of high abundance of capelin (average 36–51%). It was associated with a relatively diverse diet with stable high consumption of juvenile cod and haddock (6–11 and 5–11% respectively) as well as other fish (11–15%) and other food (21–33%) (mainly ctenophores and crabs). It should be noted that there has been an increasing role of snow crab in cod diet – from 0.1–0.3% in 2009–2010 to 1.2–1.5% in 2011–2012 to 6.1% in 2014.



Figure 5.2.2. Cod diet in the Barents Sea in 1984–2014, by weight

During the first collapse, cod were not fully able to compensate on alternative prey and suffered severe growth decline. During the second collapse, cannibalism was high. During the third collapse, no negative impact of cod was detected. However, during the third collapse the ratio of pelagic to demersal fish (Figure 5.2.3) was higher than it is now, due to more herring and polar cod (see Chapter 3.5) and less cod and haddock.



Figure 5.2.23. Pelagic (juv. Herring, capelin and polar cod) to demersal (haddock, cod) biomass ratio. Capelin collapse (Total stock < 1 million tonnes) years are shown in red.

Compared to the last capelin collapse, the availability of alternative prey appears more limited although accurate quantitative estimates are not available. Hyperiids and juvenile cod and haddock have been important alternative prey for cod in previous collapses (Figure 5.2.1). Currently there is very little hyperiids in the Barents Sea. If cod switch to larger proportion of juvenile cod and haddock in the diet now when levels of hyperiids, herring, polar cod and capelin are low, recruitment to the stocks of cod and haddock will suffer. In addition, the cod stock is larger than during the last collapse. The likely implication is a moderate decrease in individual cod growth eventually affecting the stock biomass.

Although not evident from the above figure, krill is also an alternative prey for cod, and krill biomass appears to stay high. Snow crab and cod overlap on the banks, and cod have increased its consumption of snow crab as this species have become more abundant. The large cod could have a top down effect and regulate the snow crab expansion. There are now more large cod in the stock. Large cod could feed on a larger range of prey and swim faster so they can use a larger area. This might partly counteract some of the negative impact of the capelin decline on cod feeding and growth.

Other fish and other food including benthos have made up about 40% of the recent diet of the cod stock. The abundance of these food sources is not known and the predation impact by cod is therefore difficult to quantify. Small demersal Arctic fish such as eelpouts, blennies, and sculpins are potential prey as are various crabs, shrimps and other benthos. The large cod stock, which is likely continued to feed in the northern Barents Sea, may have a large impact on other parts of the ecosystem. It is desirable to document the feeding and predatory impact of cod in order to distinguished effects related to climate change. This is important also for understanding the impacts back on the cod stock itself. The fate of the cod stock is uncertain and it may decline over the next years due to food limitation and lower carrying capacity of the ecosystem to support production of cod.

Polar cod is a key species in the food chain in the Barents Sea and important prey for cod, Greenland halibut, seals, whales and seabirds. Estimation of harp seals diet show that harp seals alone can consume up to 100–400 thousand tonnes of polar cod during migration to the whelping area in the White Sea during November -December and up to 350 thousand tonnes during northwards migration in July. The significance of polar cod prey increases in summer when parts of the northern and eastern Barents Sea are free of ice and polar cod becomes available for migratory species. Due to predation pressure from a large cod stock that are distributed to the north in the Barents Sea, and the expected continued warm conditions in the Barents Sea in the coming years, a further reduction in the polar cod population is expected. This may have major consequences for the ecosystem. A decline in the condition of harp seals has been observed (Bogstad *et al.*, 2015), and harp seals are likely to suffer from the extended period of low polar cod abundance.

#### 6 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.
- 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 Cooperation. Pp 121-159. Ed by T. Jakobsen, V. Ozhigin. Tapir Academic Press, Trondheim Norway.
- Anisimova, L., and Jørgensen, L.L. 2015. Monitoring of snow crab In Survey report from the joint Norwegian/Russian ecosystem survey in the Barents Sea and adjacent waters, August-October 2015. Prozorkevich D (Ed.) IMR/PINRO Joint Report Series xx.
- Antipova, T.V. 1975. Distribution of the Barents Sea benthos biomass Trudy PINRO, 35: 121-124 (In Russian)
- Berenboim et al., editors. The red king crab in the Barents Sea, 2nd revised and enlarged edition, Murmansk: PINRO Press, p. 189-203 (in Russian).
- Berenboim B.I. 1992. Northern shrimp Pandalus borealis Kroyer in the Barents Sea (biology and fishery). Murmansk: PINRO Press, 1992. 136 pp. (In Russian)
- Bochkov, Yu.A., and Kudlo, B.P. 1973. Long-term fluctuation of the water temperature in the Barents Sea and its influence to the total biomass of the benthos. Pp. 3-7 in: Composition, distribution and ecology of the bottom fauna in the Barents Sea. PINRO Press. Murmansk (In Russian).
- Boitsov, V.D., and Karsakov, A.L. 2005. Long-term projection of water temperature to be used in the advance assessment of the Barents Sea productivity. In Ecosystem dynamics and optimal long-term harvest in the Barents Sea fisheries. pp. 324-330 Proceeding of the 11th Russian-Norwegian Symposium, 15-17 August 2005. IMR/PINRO Joint Report Series, 2005.
- Bogstad, B., Dingsør, G.E., Ingvaldsen, R.B., and Gjøsæter H. 2013. Changes in the relationship between sea temperature and recruitment of cod, haddock and herring in the Barents Sea Marine Biology Research, 9: 895-907
- Bogstad, B., Gjøsæter, H., Haug, T., and Lindstrøm, U. 2015. A review of the battle for food in the Barents Sea: cod vs. marine mammals. Front. Ecol. Evol. 3:29. doi: 10.3389/fevo.2015.00029
- Bryazgin V.F. 1973. Ecological and geographical analysis of the sublittoral amphipod fauna of the Barents Sea / Distribution, composition and ecology of benthic fauna of the Barents Sea. Abstracts of the Murmansk regional scientific conference. Murmansk: PINRO Press. Pp. 11-12 (In Russian).
- Dalpadado, P., and Skjoldal, H.R., 1996. Abundance, maturity and growth of the krill species, Thysanoessa inermis and T. longicaudata in the Barents Sea. Marine Ecology Progress Series 144, 175–183.
- Dalpadado, P., Bogstad, B., Gjøsæter, H., Mehl, S., and Skjoldal, H. R. 2002. Zooplankton–fish interactions in the Barents Sea. In Large Marine Ecosystems of the North Atlantic, pp. 269– 291. Ed. by K. Sherman, and H. R. Skjoldal. Elsevier Science, Amsterdam.
- Dalpadado, P., R. Ingvaldsen and A. Hassel. 2003. Zooplankton biomass variation in relation to climatic conditions in the Barents Sea. Polar Biol. 26: 233–241.
- Dalpadado, P. 2016. Dyreplankton i Barentshavet. In Havforskningsrapporten 2016, ed by Bakketeig et al., Fisken og havet, in press. (in Norwegian).
- Dalpadado, P., Arrigo, K.R., Hjøllo, S.S., Rey, F., Ingvaldsen, R.B., Sperfeld, E., et al. 2014. Productivity in the Barents Sea - Response to Recent Climate Variability. PLoS ONE 9(5): e95273. doi:10.1371/journal.pone.0095273

- Dolgov, A.V., Johannesen, E., and Høines, Å. 2011. Main species and ecological importance. In The Barents Sea Ecosystem Resources and Management. Half a century of Russian-Norwegian Cooperation. Pp 193-200. Ed by T. Jakobsen, V. Ozhigin. Tapir Academic Press, Trondheim Norway.
- Eriksen, E. 2015. Do scyphozoan jellyfish limit the habitat of pelagic species in the Barents Sea during the late feeding period? ICES J Mar Sci ICES, doi: 10.1093/icesjms/fsv183
- Eriksen, E., Dalpadado, P. and Dolgov, A. 2015a. Biomass indices and distribution of krill and amphipods. In Survey report from the joint Norwegian/Russian ecosystem survey in the Barents Sea and adjacent waters Ed by Prozorkevich, D., August-October 2015. IMR/PINRO Joint Report Series x.
- Eriksen E, Prokhorova T, Falkenhaug T and Dolgov A 2015b. Biomass indices and distribution of jellyfish. In Survey report from the joint Norwegian/Russian ecosystem survey in the Barents Sea and adjacent waters Ed by Prozorkevich, D., August-October 2015. IMR/PINRO Joint Report Series x.
- Eriksen, E., Ingvaldsen, R. B., Nedreaas, K. and Prozorkevich, D. 2015c. The effect of recent warming on polar cod and beaked redfish juveniles in the Barents Sea. Regional Studies in Marine Science 2: 105–112.
- Fossheim, M., Primicerio, R., Johannesen, E., Ingvaldsen, R.B., Aschan, M., and Dolgov, A.V.. 2015. Recent warming leads to a rapid borealization of fish communities in the Arctic. Nature Climate Change, 5: 673–677
- Galkin YI (1987) Climatic fluctuations and long-term changes in benthic biomass in the Barents Sea (by the example of the mollusc Lepeta coeca – Gastropoda: Lepetidae). In: O.A. Skarlato, A.P. Alekseev and T.G. Lyubimov (ed) Biological Resources of the Arctic and Antarctic, Nauka Press, Moscow, p 90-122 (In Russian)
- Gjøsæter, H., Bogstad, B., and Tjelmeland, S. 2009. Ecosystem effects of the three capelin stock collapses in the Barents Sea. Mar. Biol. Res., : 40-53.
- Gjøsæter, H., Hallfredsson, E. H., Mikkelsen, N., Bogstad, B., and Pedersen, T. Predation on early life stages is decisive for year-class strength in the Barents Sea capelin (Mallotus villosus) stock. – ICES J. Mar. Sci., 73: 182–195.
- ICES. 2013. Report of the Working Group on Harp and Hooded Seals (WGHARP), 26-30 August 2013, PINRO, Murmansk, Russia. ICES CM 2013/ACOM:20. 65 pp.
- ICES 2015a. Report of the NAFO/ICES Pandalus Assessment Group (NIPAG), 9–16 September 2015, St. John's, Newfoundland, Canada. ICES CM 2015/ACOM: 14. 85 pp.
- ICES. 2015b. Report of the Working Group on Widely Distributed Stocks (WGWIDE), 25 August 31 August 2015, Pasaia, Spain. ICES CM 2015/ACOM:15. 588 pp.
- ICES 2015c. Report of the Arctic Fisheries Working Group, Hamburg, 23-29 April 2015. ICES C.M. 2015/ACOM:05, 590 pp.
- Ingvaldsen, R.B., Bogstad, B., Dolgov, A.V., Ellingsen, K.E., Gjøsæter, H., Gradinger, R., Johannesen, E., Tveraa, T., and Yoccoz. N.G. 2015. Modelled and observed cod distributions. Nature Climate Change, 5: 788-789.
- Johannesen, E., Johansen. G.O., and Korsbrekke, K. 2016. Seasonal variation in cod consumption and growth in a changing sea. Can. J. Fish. Aquat. Sci., 73: 235-245
- Jørgensen, L.L., Ljubin, P., Skjoldal, H.R., Ingvaldsen, R.B., Anisimova, N., Manushin, I. 2015a. Distribution of benthic megafauna in the Barents Sea: baseline for an ecosystem approach to management. ICES J Mar Sci, 72: 595-613
- Jørgensen, L.L., Planque, B., Thangstad, T.H., Certain, G. 2015b. Vulnerability of megabenthic species to trawling in the Barents Sea. ICES J Mar Sci. doi: 10.1093/icesjms/fsv107. 14 pp.

- Kiyko, O.A., Pogrebov, V.B., 1998. Statistical analysis of spatio-temporal structure of the bottom population of the Barents Sea and adjacent waters. Biologiya Morya, 24: 3-9. (In Russian).
- Kiyko, O.A., Pogrebov, V.B. 1997. Long-term benthic population changes (1920-1930s-present) in the Barents and Kara Sea. Marine Pollution Bulletin, 35: 7-12:322-332.
- Kjesbu, O.S., Bogstad, B., Devine, J.A., Gjøsæter, H., Howell, D., Ingvaldsen, R.B., Nash, R.D.M., and Skjæraasen, J.E. 2014. Synergies between climate and management for Atlantic cod fisheries at high latitudes. Proc. Natl. Acad. Sci. U. S. A., 111: 3478-3483.
- Klepikovskiy, R., and Øien, N. 2015. Marine mammals. In Survey report from the joint Norwegian/Russian ecosystem survey in the Barents Sea and adjacent waters Ed by Prozorkevich, D., August-October 2015. IMR/PINRO Joint Report Series x: xxx-xxx.
- Kortsch, S., Primicerio, R., Fossheim, M., Dolgov, A.V., Aschan, M. 2015. Climate change alters the structure of arctic marine food webs due to poleward shifts of boreal generalists. Proc R Soc B 282: 20151546. doi: 10.1098/rspb.2015.1546
- Lien, V.S., Y. Gusdal, J. Albretsen, A. Melsom, and F.B. Vikebø, 2013: Evaluation of a Nordic Seas 4 km numerical ocean model archive. Fisken og Havet, 7, 79pp
- Ljubin, Lindal Jørgensen, L., Zakharov, D., Tankovskaya, T., Zakharov, D. and Krivosheya, P. 2015a. Distribution of the Red King Crab (Paralithodes camtschaticus), Ch. 6.2.2. In: Eriksen, E. (Ed.) Survey report from the joint Norwegian/Russian ecosystem survey in the Barents Sea and adjacent waters, August-October 2014. IMR/PINRO Joint Report Series, No. 1/2015. ISSN 1502-8828, 153 pp.
- Mecklenburg, C.W., I. Byrkjedal, J.S. Christiansen, O.V. Karamushko, A. Lynghammar and P. R. Møller. 2013. List of marine fishes of the arctic region annotated with common names and zoogeographic characterizations. Conservation of Arctic Flora and Fauna, Akureyri, Iceland
- Orlova, E. L., Rudneva, G. B., Renaud, P. E., Eiane, K., Vladimir, S., and Alexander, S. Y. 2010. Climate impacts on feeding and condition of capelin, Mallotus villosus in the Barents Sea. Evidence and mechanisms from a 30 year data set. Aquatic Biology, 10: 105–118.
- Prozorkevich, D (Ed). 2015. Survey report from the joint Norwegian/Russian ecosystem survey in the Barents Sea and adjacent waters. August-October 2015. IMR/PINRO Joint Report Series x: xxx-xxx.
- 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.
- Skjoldal, H.R., Gjøsæter, H., Loeng, H., 1992. The Barents Sea ecosystem in the 1980s: ocean climate, plankton and capelin growth. ICES Marine Science Symposium 195, 278–290.
- Stige, L.C., Dalpadado, P., Orlova, E., Boulay, A.C., Durant, J.M., et al. 2014. Spatiotemporal statistical analyses reveal predator-driven zooplankton fluctuations in the Barents Sea. Progr Oceanogr, 120: 243–253.
- Wiedmann, M.A., Aschan, M., Certain, G., Dolgov, A.V., Greenacre, M., Johannesen, E., Planque. B., and Primicerio, R. 2014. Functional diversity of the Barents Sea fish community. Marine Ecology progress series, 495: 205–218.

# 7 Appendix. Time-series used in Integrated Trend Analysis

Description of the 54 time-series used in the Integrated Trend Analysis, grouped into abiotic (17 time-series), biotic (33 series) and pressures (4 series).

# 7.1 Abiotic

## Atmosphere and Air

Winter North Atlantic Oscillation (NAO) index (PC-based) from December, January, February, and March. 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).

## lce

IceareamaxApril and IceareaminSept - Ice area in the Barents Sea (10–60°E, 72–82°N) 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 Norwegian 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 resolution 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 Zemlya (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 Zemlya (positive out of the Barents Sea).

#### Water masses

Areas of Arctic Water (Area\_ArW, T < 0°C), Atlantic Water (Area\_AW, T > °C) and Mixed water (Area\_MW 0°C < T < 3°C) were calculated based on the mean 50–200 temperature fields from temperature measurements taken during the annual scientific surveys in the third quarter. 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 north-eastern Barents Sea based on data from the annual scientific surveys in the third quarter. 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 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 salinity averaged over the 0–200 meter depth range between 73°N and 74°N in the Kola Section

## 7.2 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, Zoopl180, Zoopl1000, Zoopl2000). 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 We include two krill biomass index series Krill\_S is from the Russian winter survey (October-December), sampled with a plankton net attached to the demersal trawl, this survey covers mostly the ice free BS. The dataseries is the longest time-series of zooplankton in the Barents Sea, going back to the 1950s. The series was discontinued in 2016. The second series is from 0-group survey (now the ecosystem survey) covering most of the BS shelf in August-September (Krill). A pelagic trawl is used, and only larger (>15 mm) specimens are retained in the trawls.

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

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 Capelin\_cond, (weighed average across age groups, % mature age 2 (Capelin\_Mat2). 0-group abundance is from the ecosystem survey/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 northeast outside the survey area, so the estimate of the polar cod is uncertain, especially before 2004. 0-group abundance is from the ecosystem survey/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 ecosystem survey/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), weight-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 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 (Haddock\_R3), and predation mortality age 3 from cod (Haddock\_M\_age3). Data from assessments (ICES

2015c) 0-group abundance is from the ecosystem 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 ecosystem survey/0-group survey, pelagic trawl (LRD\_0).

# 7.3 Pressures

Fishing mortality of shrimp (Relative\_F\_Shrimp) is from the last shrimp assessment (ICES 2015a).

Fishing mortality and haddock (Cod\_F510 and Haddock\_F47) are from the last stock assessments (ICES 2015c).

Fishing Mortality of Capelin (Relative\_F\_Capelin) was calculated as the sum of catches in autumn and the next spring divided by biomass in autumn.