

# ICES WGINOR REPORT 2018

INTEGRATED ECOSYSTEM ASSESSMENTS STEERING GROUP

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REF SCICOM

## Report of the Working Group on Integrated Ecosystem Assessments for the Norwegian Sea (WGINOR)

26-30 November 2018

Reykjavik, Iceland



**ICES**  
**CIEM**

International Council for  
the Exploration of the Sea

Conseil International pour  
l'Exploration de la Mer

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

H. C. Andersens Boulevard 44–46  
DK-1553 Copenhagen V  
Denmark  
Telephone (+45) 33 38 67 00  
Telefax (+45) 33 93 42 15  
[www.ices.dk](http://www.ices.dk)  
[info@ices.dk](mailto:info@ices.dk)

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## Executive summary

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The final meeting of a 3-year term for Working Group on Integrated Ecosystem Assessments for the Norwegian Sea (WGINOR) was held in Reykjavik, Iceland, on 26–30 November 2018 and was chaired by Per Arneberg (Norway) and Guðmundur J. Óskarsson (Iceland). The number of participants were 20, representing Norway (5+6 on correspondence), Iceland (6), the Faroes (2) and Canada (1).

Progress on ToR A included updated assessment of the main components of the ecosystem, a scoping process among stakeholders in Norway, development of methodology for integrated trend analyses and further development of the overall approach for IEA. New elements added for the latter are a system for ocean climate forecast, a food-web assessment, a framework for assessing warning signals with relevance for management and repeated scoping among stakeholders. The state and development of the main components are as follows:

- The Atlantic water mass in the Norwegian Sea was warmer and saltier over the period 2000–2016 than the long-term mean. However, during the last two years, 2017 and 2018, the temperature remained relatively warm while the salinity had a marked decrease. Two different mechanisms can explain this, increased fraction of subpolar water (fresh and cold) and low heat loss to the atmosphere in the Norwegian Atlantic flow. Under the assumption that circulation patterns do not change, this situation with anomalously fresh Atlantic water in the Norwegian Sea can be expected to continue and even increase in the coming years.
- From high levels during the early 2000s, the zooplankton biomass index declined until 2010. Since then the index has increased and is currently around the long-term mean.
- Norwegian spring-spawning herring *Clupea harengus* has not produced a strong year class after the productive period of 1998–2004, causing declining stock size since 2010. Individual growth rate has been relatively high in later years.
- Stock size and summer feeding area of mackerel *Scomber scombrus* has increased the last decade, but estimated stock size declined from 2017 to 2018. There are indications of shifts in both spawning and nursery grounds. Individual growth varies and is related to mackerel density for all age groups.
- Blue whiting *Micromesistius poutassou* biomass increased for several years after 2011 but declined during the last year. Several strong year classes have been produced during the last years, but the 2016 and 2017 year classes are expected to be poor.
- Since approximately 2013, Atlantic bluefin tuna *Thunnus thynnus* have returned to Norwegian waters and may have increased predation of pelagic fish.
- The most strongly ice-associated seal species like harp, ringed and bearded seals are only found along the fringes of the Norwegian Sea, but they may nevertheless be affected by changes occurring in stocks like mackerel (*Scomber scombrus*), herring and blue whiting, which over the past decade have entered habitats that were previously Arctic.
- Based on the most recent estimates, fin whales have the largest biomass of any marine mammals in the Norwegian Sea, followed by the much more abundant but smaller minke whales, and the few but large sperm and hump-back whales.

- Ongoing analyses suggest that marine mammals in the Norwegian Sea have a more fish dominated diet than in adjacent areas and that there is a potential for resource competition between fisheries and the marine mammal community.
- The breeding populations of kittiwake, Atlantic puffin, and guillemot in seabird colonies along the Norwegian coast has declined since monitoring started in 1980. The causes of the declines are not completely known. The situation for seabirds in the Faroes is similar to that in Norway, but the declines have been less drastic.
- Supporting the work under ToR A, a workshop on the overall dynamics of the pelagic ecosystem in the Norwegian Sea was held in Bergen in October 2018. A report from the workshop can be found in Annex 6.
- Progress on ToR B includes further model work with ENAC and Atlantis. Multispecies management strategy evaluation of pelagic fish in the Northeast Atlantic using the ENAC model indicated that interspecific interactions mediated through individual growth rate has insignificant impact on harvest control rules for these stocks. However, interactions affecting other processes (e.g. mortality and/or recruitment, neither tested here) may be important. Exploration of six different HCRs for NEA mackerel in Atlantis indicated that the main difference in biomass is driven by stock numbers and not weight. Also, the HCRs accounting for ecosystem variability resulted in more variation in the stock biomass.
- For ToR C, an update to the ecosystem overview has been drafted and is included in Annex 7.

## 1 Administrative details

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**Working Group name**

Working Group of Integrated Assessment of the Norwegian Group (WGINOR)

**Year of Appointment within the current three-year cycle**

3

**Reporting year concluding the current three-year cycle**

2018

**Chair(s)**

Guðmundur J. Óskarsson, Iceland

Per Arneberg, Norway

**Meeting venue(s) and dates**

28 November –2 December 2016, Bergen, Norway, 28 participants

27 November –1 December 2017, Tórshavn, Faroe Island, 22 participants

26–30 November 2018, Reykjavík, Iceland, 20 participants

## 2 Terms of Reference a) – c)

ToR	Description	Science Plan topics addressed	Duration	Expected Deliverables
a	Perform up to date integrated assessment for the Norwegian Sea ecosystem focusing on fisheries, but also considering other human pressures.	1, 6, 7, 9, 19, 20, 27, 30	Years 1-3	Report to IEASG in 2019 and research papers
b	Utilize multi-species and ecosystem models to investigate effects of single and multi-species harvest control rules on fishing yield and ecosystem state for the purpose of developing ecosystem based advice.	5, 19	Years 1-3	Report to IEASG in 2019 and a research paper
c	Update the Ecosystem Overview for the Norwegian Sea.	1	Year 3	Ecosystem Overview to IEASG in 2019

**3      Summary of Work plan**

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<b>Year 1</b>	Focus on understanding expectations of IEA end-users, continue the compilation of relevant time-series, and continue the work on integrated assessment for the Norwegian Sea
<b>Year 2</b>	Focus on, through modelling, single vs. multispecies harvest control rules for development on ecosystem-based advice, and outstanding issues for integrated assessment
<b>Year 3</b>	Focus on advancing IEA in management advice, revise the time-series, perform integrated assessment, and update the Ecosystem Overview.

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

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- The dataserieS collected by the group on ocean climate, zooplankton, pelagic fish, other fish and seabirds have been updated.
- Qualitative assessments of the state and development of key elements of the ecosystem have been performed, based on the collected dataserieS and literature.
- The framework for integrated ecosystem assessment (IEA) has been developed.
  - First, a simulation study showed that results from Principal Component Analyses (PCA) on multiple time-series of the type collected by WGINOR primarily may reflect methodological artefacts and should not be used by the group. Other potential statistical tools have been identified (Dynamic Factor Analysis, DFA, and Structural Equation Modelling, SEM). Recruitment variation of NSS-herring will be used as a case study to validate the application of these methods for this purpose.
  - Second, an approach for the further development of IEA has been outlined. This includes developing a system for ocean climate forecast, methodology for a foodweb assessment, a framework for assessing warning signals with relevance for management and repeated scoping among stakeholders.
- On the Norwegian side, a scoping process has been run among stakeholders, identifying a number of questions and problems with relevance to management that can be addressed by WGINOR.
- A discussion on the expectations of end-users has been initiated. End-users were defined within ecosystem-based fisheries management and holistic ecosystem-based management. It was also discussed what the needs of end-users may be now and in future. Possible types of questions end-users may have for WGINOR has also been discussed.
- A workshop on the overall dynamics of the pelagic ecosystem in the Norwegian Sea was organized jointly by WGINOR and the EcoNorSe project in Bergen in October 2018.
- Revision of the section “Ecosystem considerations” within the 2018 Working Group on Widely Distributed Stocks (WGWIDE) report was initiated. This was done to make use of the experts in the different fields within WGINOR, which are not attending WGWIDE.
- Presentation and discussions on the various research survey results (e.g. IESNS and IESSNS1), recent research papers, research projects have been made. They are fundamental for advancing the future work of WGINOR as represented by its ToRs.
- Development of modelling work in Atlantis and ENAC to evaluate efficacy of multispecies harvest control rules for the Norwegian Sea has been continued
- A protocol describing krill trawl sampling and analyses of the samples in IESNS (the May survey in the Norwegian Sea) has been prepared in order to standardize the methodology among the participants so the results can be used in a quantitative manner in future.
- The first steps in development of a protocol for sampling and analyses of stomach content of pelagic fish have been taken during the meeting (Annex

5), which will hopefully result in more standardization and facilitate comparison between countries.

- Work has started on a protocol for opportunistic sightings of marine mammals to be used by the participants of the international ecosystem summer survey in Nordic waters.
- Data on zooplankton dry weight from IESNS have been missing in the NAPES database for the years 1995–2007. The estimates in the WGINOR reports for that period have been based on data of low quality and insufficient information about the samples. Consequently, uploading of quality checked data with all relevant information attached was initiated during the 2017 WGINOR meeting and will hopefully be completed in 2019.
- The ecosystem overview has been developed and updated.

## 5 Final report on ToRs, work plan and Science Implementation Plan

### 5.1 Progress on ToR A

ToR A is on performing up to date integrated assessment for the Norwegian Sea ecosystem focusing on fisheries, but also considering other human pressures. Detailed description is provided below while the progress for the last three years can be summarized as follows:

- The state of the main components of the ecosystem has been assessed based on the updated dataserie;
- General basis for making inference about processes have been improved through studies that have been performed during these three years;
- Methodological development of integrated trend analyses has been examined and avenues for future development identified;
- On the Norwegian side, a scoping process has been run among stakeholders, identifying a number of questions and problems with relevance for management that can be addressed by WGINOR;
- An approach for the further development of IEA has been outlined. This includes developing a system for ocean climate forecast, methodology for a foodweb assessment, a framework for assessing warning signals with relevance for management and repeated scoping among stakeholders.

#### 5.1.1 Oceanographical conditions

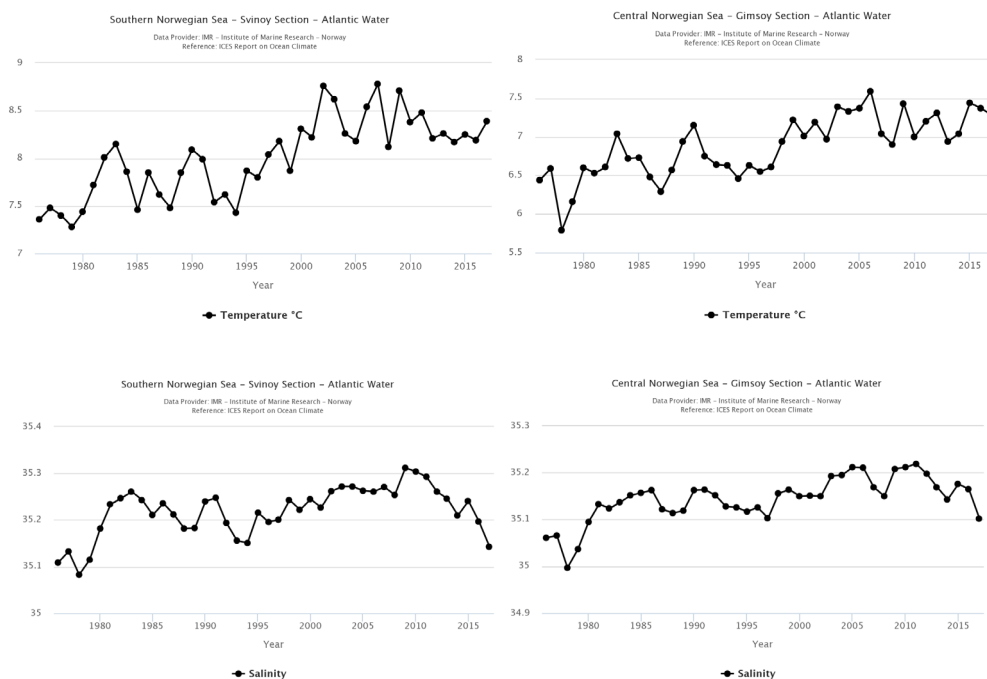
The climate of the Norwegian Sea, or water mass distribution, is mainly determined by the properties of the two main currents connecting the Atlantic and the Arctic; The Norwegian Atlantic Current that transports relatively warm and salt water northwards in the eastern part and the East Greenland Current which brings relatively cold and freshwater to the south in the western part of the Norwegian Sea. The properties (temperature, salt, nutrients, biological material) of these "source" waters and how they vary in time largely govern the climate development in the Norwegian Sea. Based on historical observations and knowledge of the ocean currents, this provides a certain basis for predictability related to propagation of variability (anomalies) with the ocean currents.

One complicating factor associated with the prediction of climate development is that the weather, or the atmospheric forcing, varies stochastically from year to year. This means that atmospherically driven processes and ocean currents in the Norwegian Sea, which control relative distribution and mixing of Atlantic and Polar water (so-called Arctic water) also can vary from year to year. In particular, the strength of the basin-scale gyre circulation in the Norwegian Sea, which in turn controls the distribution of water masses is closely linked to variability of the windfield. Further, in the southern Norwegian Sea we have varying transport of relatively cold and fresh Arctic water from the west with the East Icelandic Current entering the Atlantic domain. Along with variation in the south-westerly winds, this largely governs the western distribution of Atlantic water in the Norwegian Sea, the Subarctic front.

The description below on the oceanographic conditions and changes are derived mainly from three sources (González-Pola *et al.*, 2018; Mork *et al.*, 2014; Skagseth and Mork, 2012). The climate development in the Atlantic inflow can be described using the fixed hydrographic sections in the Norwegian Sea, the Svinøy section and the Gisøy section (Figure 5.1). Based on these sections, mean values of temperature and salt are reported for between 50 and 200 metres in the Norwegian Atlantic Current (the slope



branch). These measurements show that both in the south (Svinøy section) and in the north (Gimsøy section) the temperature has increased by about 1°C and the salinity has increased by 0.1‰ over the record starting in 1977. After 2000 and up to 2016, the Atlantic waters have generally been warmer and saltier than the long-term mean values. However, during the last two years, 2017 and 2018 the basic covariance between cold/fresh and warm/salt condition has broken down. Instead, the situation is now that the temperature is still relative warm, but that the salinity has a marked decrease. In the Svinøy section, we now have the lowest values since "The Great Salinity Anomaly" of the late 1970s. We find qualitatively the same development when we consider the entire Norwegian and Lofoten basins and calculate year-to-year changes in heat and freshwater content (Figure 5.2).



**Figure 5.1.** Temperature (upper panel) and salinity (lower panel) at the Svinøy section (to left) and the Gimsøy section (to right) over the years 1976–2017 (source: <https://ocean.ices.dk/iroc/>).

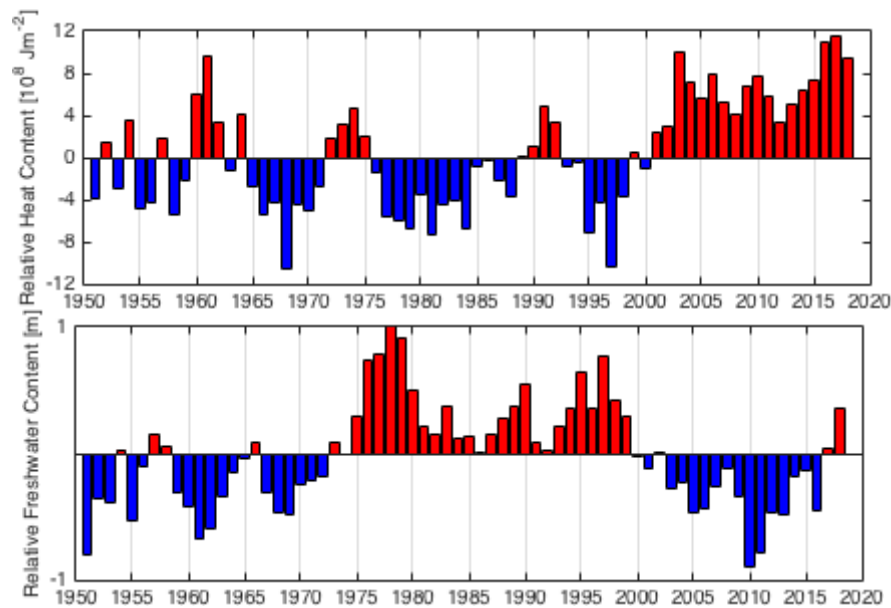


Figure 5.2. Time-series of anomalies of heat content (upper panel) and salinity (lower panel) of and the Atlantic waters in Norwegian Sea for the years 1951–2017 (source: [http://www.imr.no/temasider/klima/klimastatus/norskehavet/norskehavet\\_2/nb-no](http://www.imr.no/temasider/klima/klimastatus/norskehavet/norskehavet_2/nb-no)).

### Reasons for changes

The development in recent years toward relatively warm but fresh Atlantic water can be explained by a combination of two different mechanisms. First, there are indications of an increased fraction of subpolar (cold/fresh) water in the North Atlantic Drift that is the source of the Norwegian Atlantic Current. Data from the Faroe-Shetland channel show that the Atlantic waters at the inflow to the Norwegian Sea have become somewhat colder but most markedly fresher in recent years. It can be mentioned that the change towards warmer / saltier conditions in the middle of the 1990s oppositely was explained by a reduced fraction of relatively fresh and cold subpolar water. The second mechanism explains the cause of the continuous relative warm state of the Norwegian Sea and is linked to the fact that the heat loss to the atmosphere in the Norwegian Atlantic flow has been relatively low in recent years. The reduced heat loss to the atmosphere is due an increased tendency for southwestern relatively warm winds in the Norwegian Sea in recent years. A robust goal for this is the winter index for the North Atlantic Oscillation (NAO), which has been positive throughout the period 2014–2018. Such a consistent long period without the NAO index changing sign is very unusual. The last comparable period during which the NAO index was consistently positive was in the period 1992–1995. However, more typically after 1995 are irregular changes between positive and negative NAO index from year to year.

### What can we say about changes over the next 5 years?

The changes in the Norwegian Sea in 2017 and 2018 with relative warm water with low salinity are unusual when we consider the entire observation period with systematic measurements that started in the 1950s. This affects the vertical stability of the water column, of importance both for biological production and as well as for the conversion to denser water that contribute to the large-scale thermohaline circulation. Observations upstream in the North Atlantic Current, in the Icelandic Basin, in 2016 and 2017 show a prominent freshwater anomaly (about -0.1 in salinity). Under the assumption

that circulation patterns do not change, we expect this situation with anomalously fresh Atlantic water in the Norwegian Sea to continue and even increase in the coming years. Although the temperature upstream in the Atlantic is also relatively low in the period 2013–2017, this has been compensated by reduced heat loss inside the Norwegian Sea, linked to a coincidence with the positive NAO index. If, on the other hand, we get a winter with a negative NAO index, we can expect a decrease in the temperature in the Norwegian Sea. However, this is not very predictable because the atmosphere is largely stochastic on time-scales beyond about 5–10 days.

### 5.1.2 Zooplankton

The zooplankton plays an important role in the ecosystem by transferring energy from the phytoplankton to higher trophic levels. One of the most important zooplankton groups in the Norwegian Sea is the genus *Calanus*, both in numbers and biomass (c.f. Melle *et al.*, 2004). This genus displays strong seasonal vertical migrations as part of its life cycle. However, there are also many other important groups of zooplankton such as other copepods, krill and amphipods (Melle *et al.*, 2004; Skjoldal *et al.*, 2004).

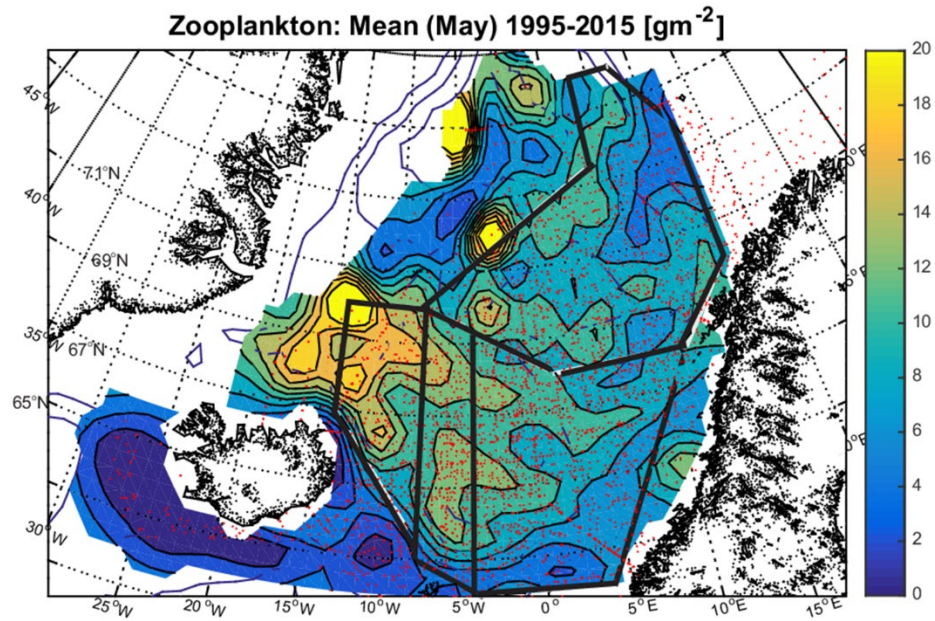
### Dataseriers

WGINOR has identified two datasets, based on the ICES-coordinated ecosystem surveys IESNS and IESSNS, that are particularly relevant to the integrated assessment. The time-series/datasets are based on regional coverage, and represent May and July/August, respectively. The sampling is made by WP2 nets with 180–200 µm mesh size from 200 m (or bottom when shallower) to the surface. Each sample is routinely split in two parts, one used for taxonomic/stage processing and the other half for size-fractionated biomass measurements. Due to the time and cost-consuming taxonomic analysis, only selected samples are processed for identification of species and stage composition. In contrast, the biomass values are readily available for all samples.

### **May time-series (IESNS). Zooplankton biomass from regional coverages from 1995 to present.**

The averaged total biomass (dry weight) of zooplankton for the uppermost 200 m across the whole coverage area is shown for the period 1995–2015 (Figure 5.3a) and for the last three years (Figure 5.3b). The mean zooplankton biomass for the last three years (2016–2018) was relatively evenly distributed in the entire examined area, except for a restricted area just outside Lofoten and two restricted areas in the northwestern part of the covered area. However, in the areas with higher biomass, only a few stations were contributing to the elevated biomass levels. This distribution was somewhat different from the mean zooplankton biomass of the whole dataset for the previous years (the years 1995–2015), where the zooplankton biomass was higher in the western part than in the eastern part of the study area.

a)



b)

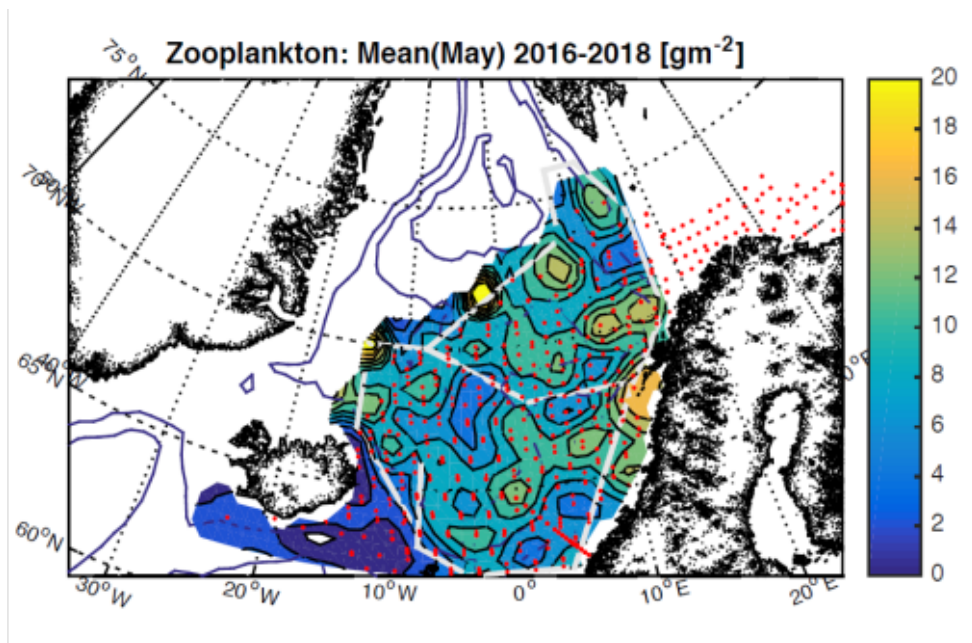


Figure 5.3. Means of zooplankton biomass ( $\text{g dw m}^{-2}$ , WP2, 200–0 m) in the Norwegian Sea and surrounding waters in May the years 1995–2015 (a) and the years 2016–2018 (b). The maps show the 4 subareas defined for further evaluations 1) Southern Norwegian Sea, 2) Lofoten Basin, 3) w2w i.e. Jan Mayen to Iceland and 4) East of Iceland.

Year to year variations in the zooplankton biomass was studied, and to examine regional difference in the biomass, the total area where divided into 4 subareas 1) Southern Norwegian Sea, 2) Lofoten Basin, 3) w2w i.e. Jan Mayen to Iceland and 4) East of Iceland. The zooplankton data were interpolated using objective analysis utilizing a Gaussian correlation function (Bretherton *et al.*, 1976; Gandin, 1963). The first step was to calculate a mean spatial climatology using all available zooplankton data for a given

period of the year. In this report two periods were investigated separately; May and July-August. The spatial influence radius for this step were set to 100 km. The next step was then to run the similar procedure for the individual years. Since there is less data for the individual years, the influence radius was increased to 150 km. Outside this radius the solution converges toward the climatology. From these annually gridded fields polygons are defined to extract area-mean time-series. In some previous reports area averaged time-series of zooplankton biomass were taken as the mean of the samples obtained within a specified area. It is expected that calculating the similar time-series based on the gridded fields would tend to give more smooth results, e.g. in the case of few data the solution would converge toward the long-term mean. Means of zooplankton biomass for each of these subareas as well as the whole area is shown in Figure 5.4. The zooplankton biomass in the Norwegian Sea and surrounding areas in May show strong long-term variability. Following a period with high biomass from mid-1990s to early 2000s, the biomass declined to minimum in 2006. From 2010, the downward trend reversed, and the biomass may have increased after that. Interestingly, all areas show the same long-term trend, however the area east of Iceland had a longer high-biomass period and the decreasing trend started a few years later than the other areas. The biomass has been at about the same level for all the subareas the last three years (between 6 and 12  $\text{gm}^{-2}$ ).

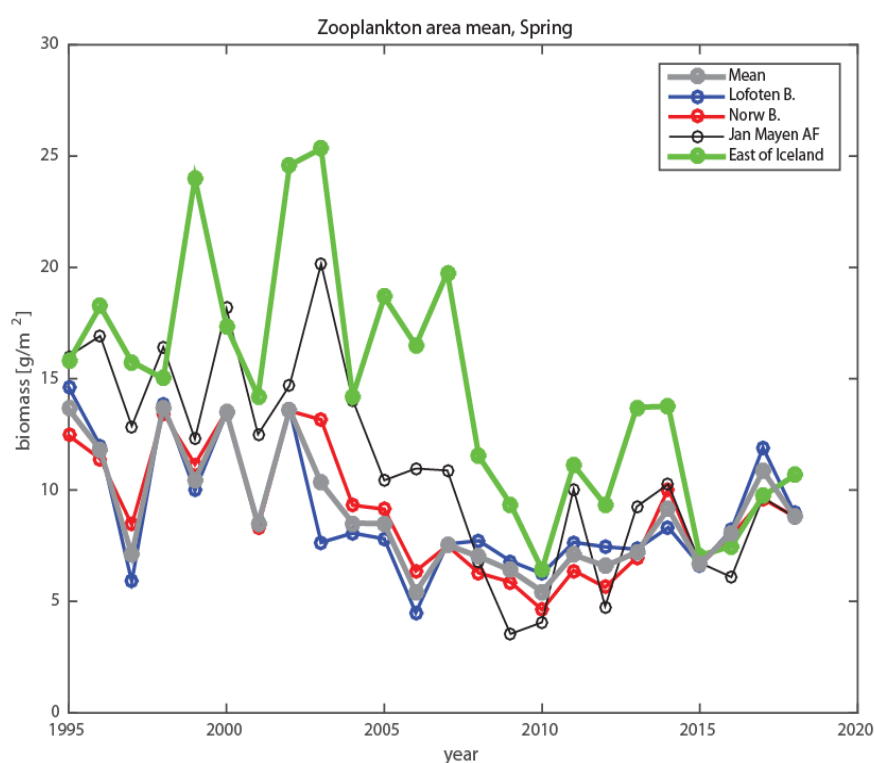


Figure 5.4. The annual mean dry weight of zooplankton biomass ( $\text{g dw m}^{-2}$ ), sampled with WP2 in the upper 200 m of the water column, in 4 subareas for the period 1995–2018.

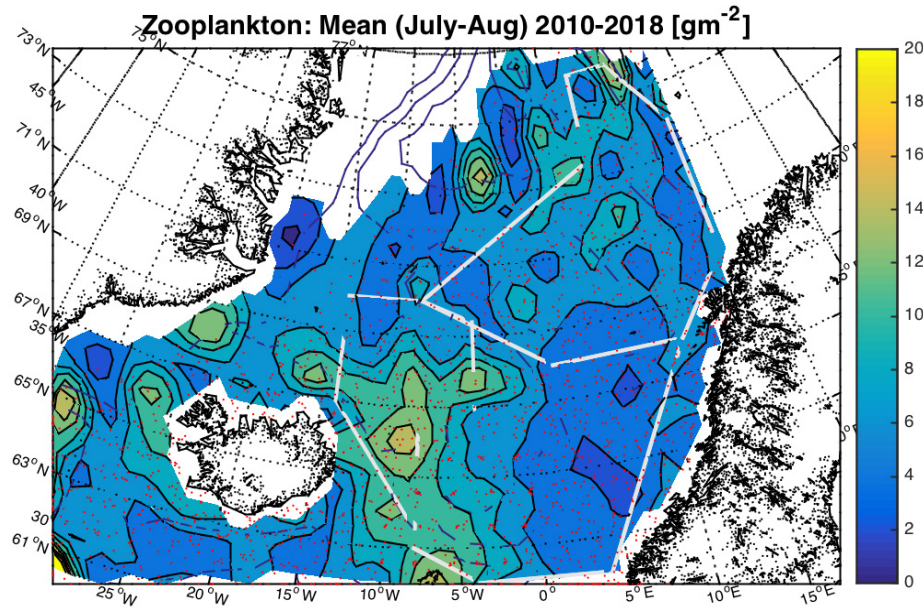
**July/August time-series (IESSNS). Zooplankton biomass from regional coverages from 2009–2010 to present.**

The averaged total biomass (dry weight) of zooplankton for the uppermost 200 m across the whole coverage area in July-August is shown for the period 2010–2018 (Figure 5.5a) and for the last three years (Figure 5.5b). The zooplankton distribution the



last three years (2016–2018) was similar to the averaged distribution for all years sampled. Highest concentrations were found in northern parts of the sampled area, in southwestern Norwegian Sea (east of Iceland and north of Faroe Islands), north of Iceland, and at the westernmost part of the sampled area.

a)



b)

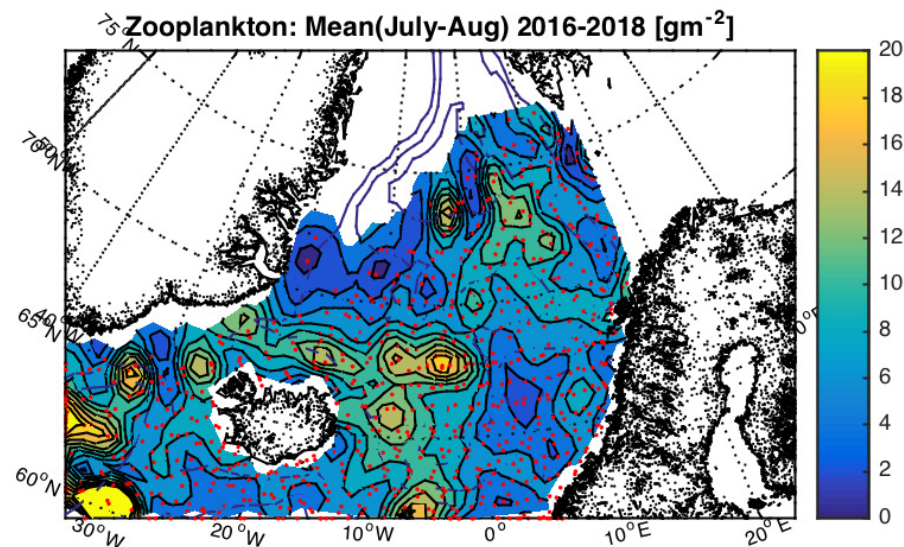


Figure 5.5. Means of zooplankton biomass ( $\text{g dw m}^{-2}$ , WP2, 200–0m) in the Norwegian Sea and surrounding waters in July-August the years 2010-2018 (a) and the years 2016-2018 (b). The maps show the 4 subareas defined for further evaluations 1) Southern Norwegian Sea, 2) Lofoten Basin, 3) w2w i.e. Jan Mayen to Iceland and 4) East of Iceland.

Year-to-year variations of zooplankton biomass in July and August are shown in Figure 5.6. After a minimum level in 2011, the biomass may have increased the following years. Highest biomass was found in the subareas Jan Mayen and east of Iceland. All

subareas seem to have a similar long-term trend. However, the dataset is too short to draw robust conclusions.

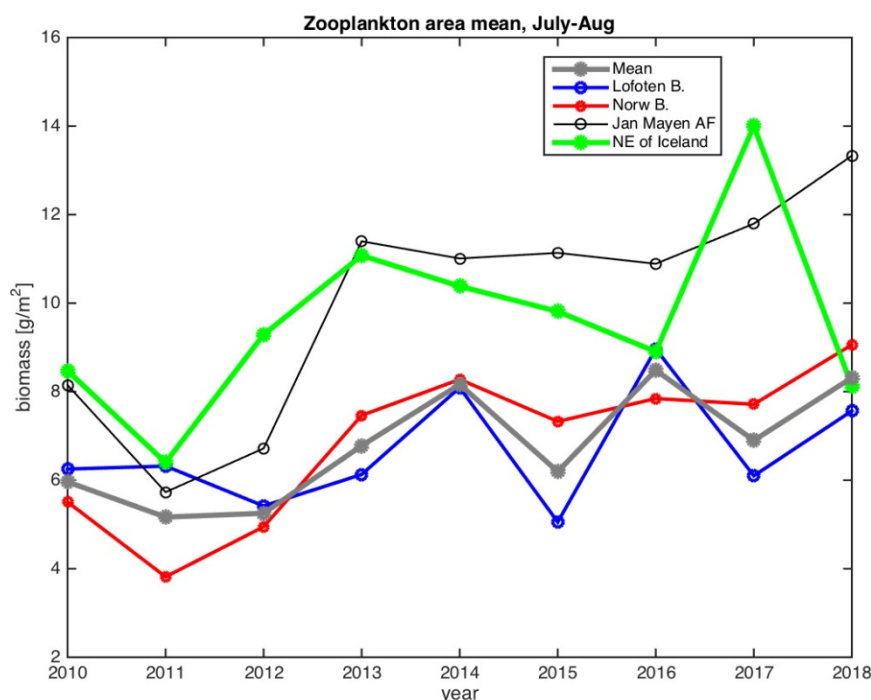


Figure 5.6. The annual mean dry weight of zooplankton biomass ( $\text{g dw m}^{-2}$ ), sampled with WP2 in the upper 200 m of the water column, in July/August in the 4 subareas (defined in Figure 5.1.2.1/5.1.2.3) in the years 2010-2018.

### Discussion

Both datasets representing May (Figure 5.4) and July/August (Figure 5.6) showed similar long-term trends with a minimum in the years 2010/2011 followed by a general increase in biomass until present. The reasons for the year-to-year fluctuations and long-term trends of zooplankton in the Norwegian Sea and surrounding areas has been studied only to a small extent. Increased temperature and changes in ocean current patterns affect the distribution and abundance of zooplankton, but the underlying mechanisms causing the changes are poorly understood. (Kristiansen *et al.*, 2016; Kristiansen *et al.*, submitted) found a sudden reduction of *C. finmarchicus*, *C. hyperboreus* in Subarctic water north of the Faroe Island and in biomass east of Iceland in 2003, which has persisted. This was explained by lower influx of Subarctic and Modified east Icelandic Water from the west. Reduction in zooplankton biomass throughout the Norwegian Sea and surrounding areas presented in the present report and reduction of *C. finmarchicus* in the southeastern Norwegian Sea (Dupont *et al.*, 2017) all during the same period, support that significant changes has taken place concerning zooplankton abundance. The parallel changes in all subareas (Figure 5.4), with a high-biomass period prior to early 2000s and a lower-biomass period until 2010 followed by an increase, indicate that impacts on a larger geographical scale is taking place. We propose that changes seen in the studied area are caused by large-scale factors, in addition to the Subarctic inflow influencing southwestern Norwegian Sea. The period with lower zooplankton biomass after early 2000s until present, is coinciding with the heat contents of Atlantic water in the Norwegian Sea being above average (see present report (Skagseth and Mork, 2012). Studies on bottom-up factors affecting the zooplankton,

and zooplankton changes related to climate change is needed. Zooplankton dynamics impact changes in planktivorous fish distribution and abundance, and at the same time the planktivorous fish may affect the zooplankton production. Recently, (Bachiller *et al.*, 2018) estimated that herring, blue whiting and mackerel consumed 135 million tonnes of zooplankton each year. This is more than previously assumed. To which extend top-down factors affect the zooplankton dynamics in the studied area needs to be examined.

### 5.1.3 Pelagic fish stocks

The three dominating pelagic fish species in the Norwegian Sea are Norwegian Spring-spawning-herring (NSS-herring), mackerel, and blue whiting. In addition, we describe here Atlantic salmon, which also reside in the central Norwegian Sea.

#### Summary of state and development

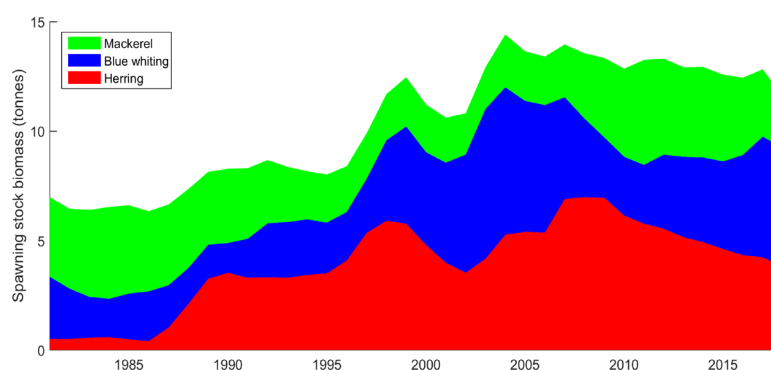
##### Norwegian spring-spawning herring (NSS herring)

The spawning-stock biomass (SSB) of NSS herring is estimated at 3.9 million tonnes in 2019 ((ICES 2018f); Figure 5.7). The stock has declined since 2010, mainly due to poor recruitment since 2004 (Figure 5.8). In this period of poor recruitment, the 2006, 2009 and 2013-year classes were the strongest at around the level corresponding to average recruitment since 1988. The newest information from the surveys in the Barents Sea (ICES 2018c) indicate that the 2016-year class might be above average size. A consequence of the poor recruitment is that the stock is composed of relatively large number of old fish (age 12+).

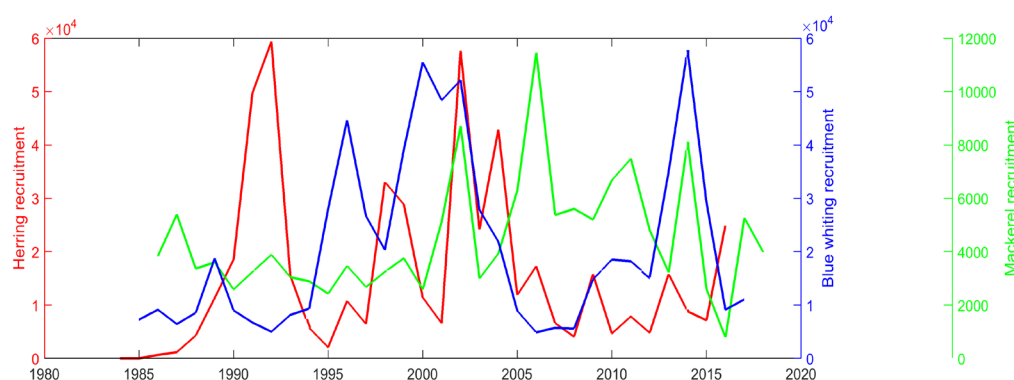
The annual migration pattern in the latest years has generally followed the usual pattern with spawning along the Norwegian coast in February and March. Subsequently there was a feeding migration into the Norwegian Sea, where the main concentrations have been observed farther west in July (ICES 2018a) than in May (ICES 2018c). A change in the later years is that part of the herring stays in the south western part of the Norwegian Sea longer into the autumn months. In 2017/2018, there was also a shift in the northern wintering areas; the 2013-year class overwintered in fjords farther north than usual and the older herring seemed to occupy oceanic wintering areas. It is unclear what has induced this change in the migration pattern. Feeding opportunities, competition and oceanographic conditions are likely factors, but beside environmental factors, age composition of the stock may also influence the observed migration pattern. This is illustrated by the mean length of herring increasing towards west (ICES 2018c).

Herring growth (size-at-age) has varied over time but has been relatively good in the later years. Length-at-age appears to be negatively related to stock size (Homrum *et al.*, 2016). This indicates density-dependent effects on growth.





**Figure 5.7.** The cumulative spawning-stock biomass of Norwegian spring-spawning herring, blue whiting and mackerel from 1981 to 2018 according to the most recent assessments (ICES 2018f).



**Figure 5.8.** Year-class strength (i.e. recruitment) of Norwegian spring-spawning herring, blue whiting and mackerel over 1986-2018 based on the most recent assessments (ICES 2018f). The herring and blue whiting recruitment is of 2 and 1 years old, and these have therefore been moved 2 and 1 years back in time, respectively.

### Mackerel

The spawning-stock biomass of mackerel has declined and is estimated to be 2.4 million tonnes at spawning time 2018 (ICES 2018c; Figure 5.7). There have been several strong year classes of mackerel in recent years ((ICES 2018f; Jansen, 2016); Figure 5.8).

The distribution of mackerel in the Nordic Seas in the feeding season has showed an increased northerly and westerly distribution since around 2005, but in 2018 abundance of mackerel in the Nordic Seas was lower and the distribution not as westerly and northerly as it has been in the later years (ICES 2018a). The spawning distribution of mackerel in 2016 was more northerly and occurred later in the year than what has been observed in earlier years (ICES 2017a). This observation was supported by the fact that 0-group mackerel occurred along the Norwegian coast in 2016. In the following years this year class has continued to reside in the eastern part of the Norwegian Sea. Preliminary small-scale studies on northerly spawning in 2017 and 2018 have indicated that spawning these years has been more southerly than in 2016. There are also indications of a shift in nursery grounds, because also year class 2017 was observed in relatively large numbers in the Norwegian Sea as one year olds in summer 2018 (ICES 2018c).

Growth varies and is related to mackerel density for all age groups (Jansen and Burns, 2015; Olafsdottir *et al.*, 2015). For the juveniles, growth was related to density of juveniles in the nursery area, whereas for adults the growth was related to the combined biomasses of mackerel and NSS herring. Generally, recruitment has been weaker after 2014, and mean weights have stopped declining and even increased for some age groups.

#### **Blue whiting**

The spawning-stock biomass of blue whiting increased over the period 2011 to 2017, but has since then decreased and is estimated to be 4.3 million tonnes in 2019 (ICES 2018f); Figure 5.7). Blue whiting has produced several strong year classes in recent years (Figure 5.8), but the 2016 and 2017 year classes are expected to be poor (ICES 2018b). The blue whiting stock is currently dominated by 3-5-year-old individuals.

The migration dynamics of blue whiting have followed the usual pattern in the latest years. Main spawning has occurred in March-April on the continental slope of the British Isles. Post-spawning migration has been into the southern Norwegian Sea and continental slope off the Norwegian coast. Less juvenile blue whiting was observed in the Norwegian Sea in 2018 (ICES 2018c), which is probably related to the poorer recruitment the last two years.

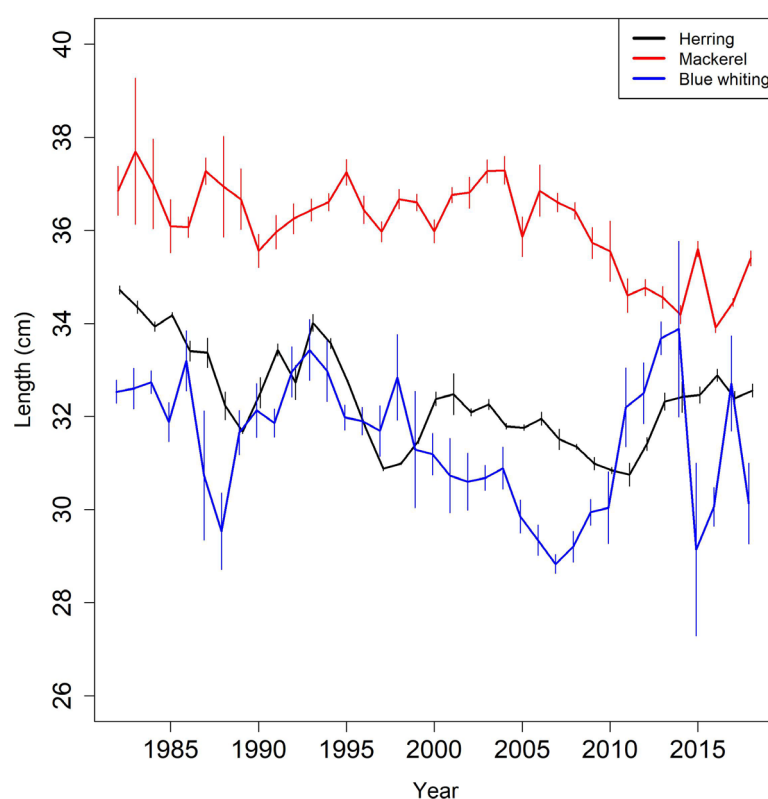
#### **Atlantic Salmon**

The available time-series is the pre-fishery abundance of salmon in the northern part of Europe (Norway, Finland, northern Iceland, Sweden, Russia). The number of salmon returning from the feeding grounds have decreased since the available time-series started in 1983 (ICES 2018e). Most of the decrease happened before year 2000, and the number of returning salmon have been stable at around 750 000 fish the last decade. Salmon are affected by a wide range of factors in the rivers, coastal regions and open oceans. Parts of the decrease for salmon can be explained by issues such as acid rain, salmon lice and parasites. Further, the different populations probably use different feeding areas including the Barents Sea. Nevertheless, part of the decline can be explained by lower survival in the sea. The Norwegian Sea is an important feeding area, especially for the postsmolt during summer. Poorer feeding conditions for postsmolt has been forwarded as a hypothesis for the lower survival in the sea.

#### **Trophic interactions**

There are strong indications for interspecific interaction regarding food among NSS-herring, blue whiting and mackerel (Huse *et al.*, 2012). Mackerel may have an advantage in the interaction with NSS herring, because mackerel stomach fullness index was higher (Bachiller *et al.*, 2016; Bachiller *et al.*, 2018; Debes *et al.*, 2012; Langøy *et al.*, 2012; Óskarsson *et al.*, 2015). Additionally, the diet composition of herring was different from previous periods when the mackerel stock size was smaller. Langøy *et al.* (2012) and (Debes *et al.*, 2012) also found that mackerel consumed a wider range of prey species than herring. In the later years, the geographical distribution overlap has been most pronounced in the south-western part of the Norwegian Sea. In 2018, there was very little overlap between mackerel and NSS herring in the central Norwegian Sea.

Length-at-age give an indication of the last years' feeding conditions, and a reduction can partly be explained by intraspecific competition (see paper for blue whiting by (Trenkel *et al.*, 2015) and for mackerel by (Olafsdottir *et al.*, 2015)). Updated length-at-age information show variable length-at-age for blue whiting, an increase for mackerel and stable length-at-age for NSS herring in the latest years (Figure 5.9).



**Figure 5.9. Mean total length for six year old NSS-herring, blue whiting and mackerel in the Norwegian Sea. Data are from the winter period (varying between species).**

Regarding predation on larvae, there is some evidence of opportunistic predation of NSS-herring larvae by mackerel (Skaret *et al.*, 2015) and predation of Atlantic bluefin tuna on mackerel larvae in Norwegian waters (observed in a Norwegian survey).

#### **Summary of stock trends of the three main pelagic species**

In conclusion, the three main pelagic species are all estimated to be decreasing in size in the latest stock assessment. The NSS herring has been declining for nearly a decade due to poor recruitment since 2004, but there are indications from surveys in the Barents Sea that the 2016 year class is above average size (ICES, 2018a). The mackerel stock was estimated to be below the trigger biomass reference point and the summer distribution appeared to have changed significantly from the last years. The blue whiting stock has been increasing in the last five years mainly due to a series of years with good recruitment, but this year the biomass was estimated to decrease probably mainly due to poor recruitment the last two years. All species are currently harvested with a realized  $F$  above  $F_{MSY}$ , mainly due to disagreement between the coastal states on quota allocations.

#### **Short discussion on causes of what we see**

##### **NSS herring**

The declining stock trend since 2010 is mainly due to poor recruitment since 2004. However, what has caused the poor recruitment is not clear; potential factors affecting recruitment include spawning success of spawning stock, survival of larvae, which may be influenced by coastal currents along the Norwegian coast, and finally dynamics in the main nursery area, the Barents Sea.

In the later years, the summer distribution of NSS herring has been mainly in the western Norwegian Sea. This may be related to environmental causes (good feeding conditions; Figure 5.5) and to interactions with other species (mainly mackerel). In addition, the distribution of the NSS herring stock is also affected by the size-composition of the stock, since larger individuals migrate farther west, and currently the stock is comprised of relatively old and large herring, due to the poor recruitment.

Over the last decade the migration to wintering areas off northern Norway, has been delayed farther into the autumn months. It is currently unclear what has caused this change. It is also unclear why there was a shift in wintering area in 2017–2018. As with some of the changes in migration patterns, also changing wintering areas have previously been associated with large year classes entering the stock, but this does not appear to be the case at present.

Size-at-age of NSS herring has varied over time and appears to be related to abundance of herring, mainly in adjacent year classes. This indicates that density-dependent mechanisms in the juvenile stages contribute to the variation in size-at-age.

#### **Mackerel**

The north-westerly expansion of mackerel into the Norwegian Sea and Icelandic and Greenlandic waters since 2005 has been linked to increased stock size and environmental factors (*Astthorsson et al., 2012; Nikolioudakis et al., 2018; Olafsdottir et al., 2018; Pacariz et al., 2016*). However, it is not clear what has caused the lesser abundance observed and more central distribution of mackerel in the Nordic Seas in summer 2018.

The spawning of mackerel in 2016 appeared to be peak later than usual and there was more spawning in the northern areas than in the earlier years. The reasons for this delay and northward shift are not fully understood, but based on small-scale investigations in 2017 and 2018 this shift did not appear to continue.

The shift in spawning in 2016 appears to have affected the pelagic community in the Norwegian Sea and Norwegian coastal waters such that these in 2016, 2017, and 2018 have comprised part of the nursery grounds for mackerel.

Size-at-age of mackerel has varied over time. For juveniles growth is related to abundance of juveniles. For adults growth is related to the combined biomass of NSS herring and mackerel – indicating density-dependent effects.

#### **Blue whiting**

The decrease in biomass of blue whiting is related to poor recruitment, which in turn is possibly linked to the recent freshening of Atlantic water. Freshening of Atlantic water has been hypothesized to affect the size of the potential spawning area of blue whiting (*Miesner and Payne, 2018*).

The distribution of blue whiting in the Nordic Seas in summer 2018 was not as extensive as it has been for some years (*ICES 2018a; ICES 2018b*), and this is likely linked to the poorer recruitment from the 2016 and 2017 year classes.

#### **Atlantic salmon**

The abundance of Atlantic salmon returning from feeding grounds has decreased for several decades, but the decrease has stopped the last years. Various antropogenic activities (fish farming, power development, acidic rain) have negative effects on salmon abundance, but it has been speculated poorer feeding conditions for postsmolt

also has contributed to the decrease. A slower growth rate will make the fish vulnerable for predation for a longer period and thereby increase the total mortality.

#### **5.1.4 Redfish**

Adult beaked redfish (*Sebastes mentella*) migrates into the Norwegian Sea and forms a sizeable component of its pelagic fish community. Spawning-stock biomass (SSB) has peaked at 933 kt in 2007 and has since stabilized at around 800 kt (ICES 2018d). Recruitment has likewise peaked towards the end of the 2000s and has then come down to <200 Mio. per year. SSB is dominated by fish between 20 and 30 years of age, whereas the stock biomass is dominated by age groups around age-10. Juvenile fish are found in the Barents Sea until at least age-6 (Drevetnyak and Nedreaas, 2009). Since 2015 the TAC advice was around 30 000 tonnes, but was raised to 53 757 tonnes for 2019. This corresponds to  $F = 0.06$ , evaluated as precautionary during a workshop on harvest control rules (ICES 2018g)

#### **5.1.5 Tuna**

##### **Comeback kid – Atlantic bluefin tuna feeding in the Norwegian Sea and along the Norwegian coast**

Bluefin tuna have probably been present in Norway for thousands of years (Tangen, 1999). Norway was one of the largest and dominating fishing nations targeting Atlantic bluefin tuna in the Northeast Atlantic Ocean during the 1950s and 1960s, with purse-seine catches reaching 15 000 metric tonnes inside the Norwegian Exclusive Economic Zone (EEZ) (Hamre and Tiews, 1964; ICCAT 2016; Nøttestad and Graham, 2004; Nøttestad and Graham, 2005; Tangen, 1999). The bluefin tuna arrived historically along the Norwegian coast, at the northern borders within their natural distribution area and migration routes, in several runs with the timing and migration pattern depending on the size and age composition of the schools (Hamre and Tiews, 1964; Tangen, 1999). The first fish appeared in early July, starting with the arrival of the largest fish, and extended through to October (Nøttestad and Graham, 2004). There were two important periods with respect to migrations affecting the Norwegian fishery, from 1950 to 1962 and from 1963 to 1985 (Hamre and Tiews 1964; Nøttestad and Graham, 2004; Nøttestad and Graham, 2005).

The first recorded catch of bluefin tuna taken by purse-seine in Norway was done in 1926 (Tangen, 1999). The first major period started in the 1940s, which was categorized by a range of age groups being present in Norwegian waters. In the early period, several year classes, probably from the early 1940s, provided high catches along the whole coast of Norway up to at least 71°N. The older fish, up to 200 kg, arrived in early July and migrated to the northerly part of the Norwegian coast. After feeding there for 3-4 weeks the fish migrated quickly southwards into the bank area of the North Sea (Hamre and Tiews, 1964). The youngest individuals, up to 70 kg, migrated to the south-eastern part of Norway, while most medium sized tuna remained in south-western Norway from July to October (Hamre and Tiews, 1964; Tangen, 1999). During this period, the fishery gradually decreased in range, and by the early 1960s very few fish were caught north of 62°N, presumably due to the demise of the year classes from the early 1940s. From about 1956 onwards, the fishery relied mostly on the strong year classes from 1950 and 1952 (Cort and Nøttestad, 2007).

From 1963 onwards, the fishery in Norway consisted mainly of the 1950 and 1952-year classes, while the largest tuna from the 1940s was not present in sufficient numbers for a viable fishery of the northern areas off the Norwegian coast, and the majorities of catches were taken south of 62°N (Cort and Nøttestad, 2007).

Norway sustained the largest fishery for bluefin tuna in the Atlantic Ocean between 1950 and 1964 with catches reaching 15 000 metric tonnes. The vessels engaged in the fishery in Norway, counted 450 fishing vessels during the most active years in the 1950s. These fishing vessels were normally engaged in the herring and mackerel fisheries outside the bluefin tuna season stretching from July to October. They were typically 15–22 m in length, using purse-seine nets ranging from 400 to 1000 m in length and between 60 to 100 m in depth. Individual and groups of vessels searched for tuna along the coast up to fifty nautical miles offshore, using seabird activity and surface behaviour of individual tuna as indicators of bluefin tuna shoals. The Norwegian fishery ceased in the early 1980s as the abundance of bluefin tuna was severely reduced. Bluefin tuna was occasionally observed in Norwegian waters during the 1980s and 1990s, but not in quantities that could sustain a commercial fishery.

Atlantic bluefin tuna (*Thunnus thunnus*) has now returned to Norwegian waters and is re-establishing its traditional annual feeding migration pattern. Schools of bluefin tuna are distributed into the Norwegian Sea and along the Norwegian coast as documented in previous decades. The recent observations of bluefin tuna in Norwegian waters started to appear around 2013. In 2014, more observations were made, including a by-catch of bluefin tuna taken by a purse-seiner fishing on western horse mackerel in the southern part of the Norwegian Sea in August 2014.

There have been numerous observations concerning bluefin tuna in 2016 (Figure 5.10) and 2017 (Figure 5.11), from Lindesnes in the south to Tromsø in the north and from June to November. Bluefin tuna have been observed feeding as far north as 68°30'N in late February 2017. This is the first time bluefin tuna have ever been observed and reported in Norwegian waters during winter, probably due to highly favorable feeding conditions. Totally 191 individuals and around 44 000 kg were caught from targeted bluefin tuna fishing in 2016. Totally 235 individuals and around 53 000 kg were caught from targeted bluefin tuna fishing in 2017. A positive sign of the stock rebuilding is now visible in northern waters due to numerous sightings where sightings of small to large aggregations/schools have been recorded in Norwegian waters during the last few years.

The major driving force for the reappearance of bluefin tuna in Norwegian waters is probably increased need for prey, due to increased stock size over the last decade. Bluefin tuna are thus migrating further and further northeast into the very productive Norwegian Sea ecosystems, probably representing some of the most important feeding grounds for decades concerning Atlantic bluefin tuna due to the high biomasses in the range of 10-15 million tonnes of preferred prey species for bluefin tuna, including Norwegian spring-spawning herring (*Clupea harengus*), mackerel (*Scomber scombrus*) and blue whiting (*Micromesistius poutassou*) (ICES 2018f; Nøttestad *et al.*, 2016)). Based on stomach samples from bluefin tuna caught in Norwegian waters in 2016 and 2017 they had predominantly preyed on 0-group mackerel. Individuals had also to a lesser extent eaten larger mackerel, herring, blue whiting, and gadoid species.

A 300 kg bluefin tuna coming from the Mediterranean Sea in spring, could eat so much that the same individual could weigh up to 350 kg when the feeding period ended in October. Due to the high metabolism of bluefin tuna a large individual may possibly consume in the range of 1500 kg prey during one feeding season. Furthermore, large amount of bluefin tuna that may potentially feed in increasing numbers within Norwegian waters in the years to come, may account for in the range of 100 000 tons of valuable pelagic prey species taken out by bluefin tuna each year in Norwegian waters (Trenkel *et al.*, 2014). Since the Norwegian Sea and surrounding waters are among the most productive marine ecosystems sustaining some of the most abundant pelagic fish

species in the Atlantic Ocean (Huse *et al.*, 2012; ICES 2018a; ICES 2018c; Nøttestad *et al.*, 2016), it should not be surprising that Norway used to be one of the largest fishing nations on bluefin tuna within the Atlantic Ocean. An increasing bluefin tuna stock will exploit feeding opportunities further and further to the north due to increased in-  
traspecific and interspecific competition for available prey.

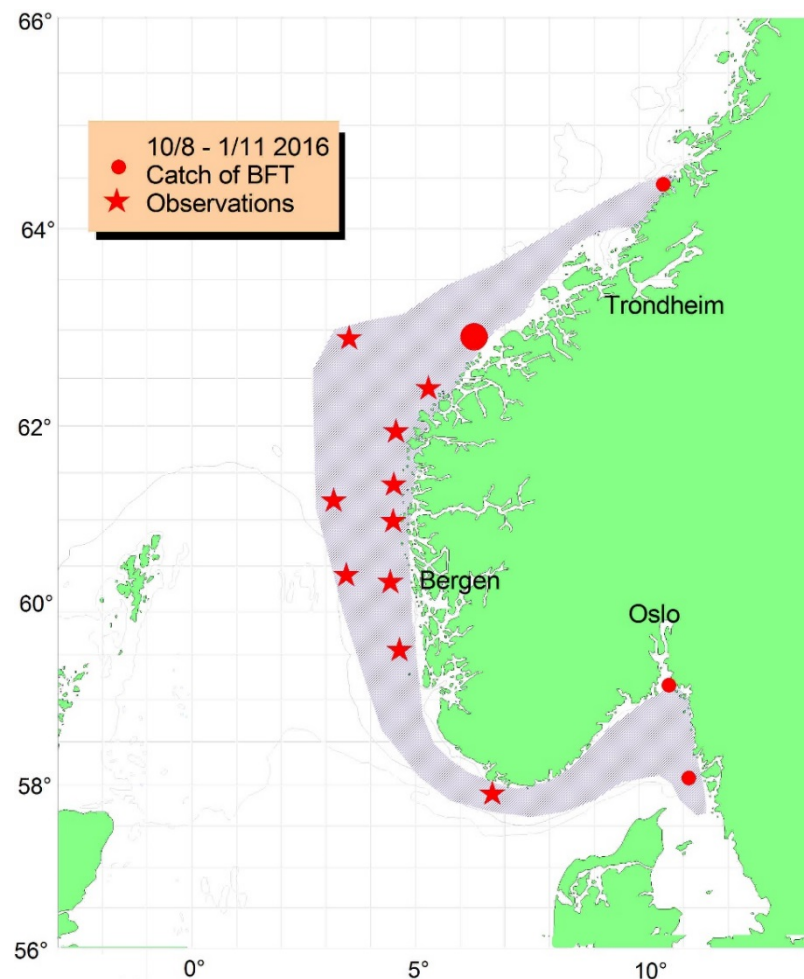


Figure 5.10. Geographical positions on catches and observations of bluefin tuna from August to November 2016.



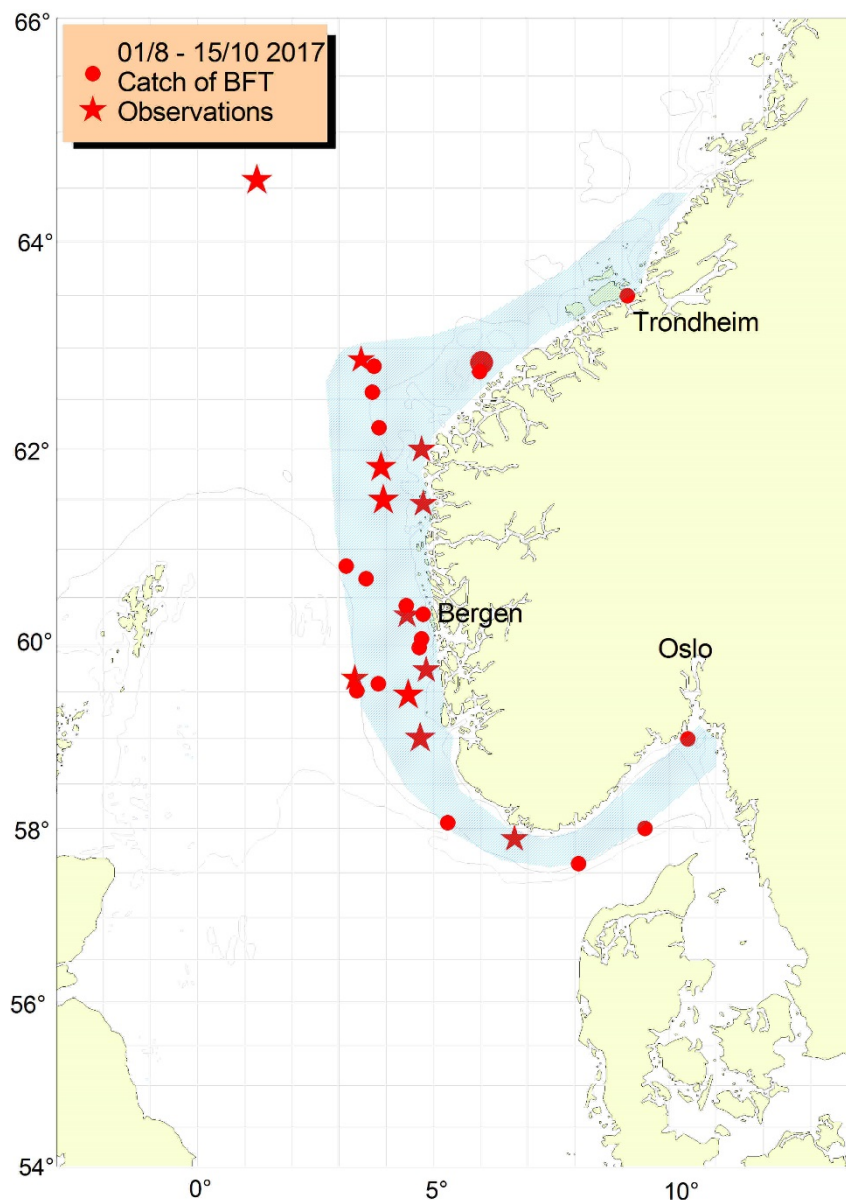


Figure 5.11. Geographical positions on catches and observations of bluefin tuna from August to October 2017.

#### 5.1.6 Marine mammals

About 23 species of marine mammals (7 pinnipeds, polar bears, 6 baleen whales and 9 toothed whales) occur regularly within the Norwegian Sea area. In the following we have divided the most common species into three groups and describe their biological characteristics, population status and interactions with the environment and anthropogenic pressures.

##### Pinnipeds and polar bears

With an estimated total population of ~650 000 individuals for the Greenland Sea breeding population, harp seals (*Pagophilus groenlandicus*) may be considered the most abundant marine mammal in the Norwegian Sea area, although they spend large parts of their time outside the area (Folkow *et al.*, 2004). Breeding and moulting occurs in the pack ice off Northeast Greenland and is generally followed by a north- and eastward



feeding migration along the ice edge to the Fram Strait, along the west coast of Spitsbergen and into the Barents Sea. The most important summer prey items appear to be amphipods, krill and polar cod (Enoksen *et al.*, 2017; Haug *et al.*, 2007; Lindstrøm *et al.*, 2013). In winter, most Greenland Sea harp seals return to East Greenland. Many of them feed in the Denmark Strait, mainly on crustaceans and capelin (Haug *et al.*, 2007). Some harp seals from the Barents Sea population also feed off West Spitsbergen in summer but remain in the Barents Sea-White Sea area for the rest of the year (Folkow *et al.*, 2004). Historically, both populations were strongly reduced by commercial hunting (ICES 2016a), but started to recover in the early 1970s after a reduction in hunting pressure. The Greenland Sea population is currently at its highest level since the starting point of abundance modelling in 1945 (Øigård *et al.*, 2014).

Hooded seals (*Cystophora cristata*) also breed and moult in the Greenland Sea pack ice but spend ~60% of their time feeding in rather deep waters along the continental slopes of the Norwegian Sea area (Folkow and Blix, 1999; Folkow *et al.*, 1996; Vacquie-Garcia *et al.*, 2017). The modelled trajectory of this population shows a dramatic decline from 1.3 million in 1945 to ~200 000 in 1980 and a continued slow decline to ~84 000 (95% 68 060–99 980) by the last pup count in 2012 (Øigård *et al.*, 2013). The decline is mainly thought to be driven by hunting, but relatively low reproductive rates and somatic growth rates suggest that other factors may have increased this populations sensitivity to hunting mortality (Frie and Haug, 2018). Diets are mainly known from digestive tracts collected in pack ice areas during breeding and moulting. These samples are dominated by the squid *Gonatus fabricii* and polar cod (*Boreogadus saida*) (Haug *et al.*, 2007; Potelov *et al.*, 2000). Out of the breeding and moulting seasons, also redfish (*Sebastes sp.*), Greenland halibut (*Rheinhardtius hippoglossoides*), Atlantic cod (*Gadus morhua*) capelin (*Mallotus villosus*) and sandeel (*Ammodytes sp.*) have been found in diet samples from East Greenland and Northeast Iceland (Enoksen *et al.*, 2017; Haug *et al.*, 2007; Hauksson and Bogason, 1997) This is more similar to diets reported from the Northwest Atlantic, which are dominated by various benthic-pelagic and demersal fish species (Hammill and Stenson, 2000; Tucker *et al.*, 2009). Diving and distribution patterns through the year also suggest that species like herring (*Clupea harengus*) and blue whiting (*Micromesistius poutassou*) may be important prey in some parts of the Norwegian Sea (Folkow and Blix, 1999).

In areas where the continental slope comes close to shore, feeding areas of grey seals (*Halichoerus grypus*) and to a lesser extent harbour seals (*Phoca vitulina*), may partly overlap with those of hooded seals. Grey and harbour seals, are mainly piscivorous, but are restricted to the upper pelagic layers. Total population sizes of grey seals in Norway and Iceland are estimated at ~3850 (95% CI: 3504-4196) and ~4200 (95% CI: 3400-5000), respectively (NAMMCO 2016). Both harbour and grey seals are hunted in Iceland and Norway and population sizes are thought to be affected by past and present hunting and bycatches.

Although the most strongly ice associated seal species like harp, ringed and bearded seals are only found along the fringes of the Norwegian Sea, they may nevertheless be affected by changes occurring in stocks like mackerel (*Scomber scombrus*), herring and blue whiting, which over the past decade have entered previously Arctic habitats. This is presumably affecting the traditional prey base for Arctic seal species as well as whale species like bowheads, belugas and narwhals. Ringed seals (*Pusa hispida*) all over Svalbard have responded negatively to the reduction in sea ice and retreat of glacier fronts (Hamilton *et al.*, 2015; Hamilton *et al.*, 2016). In contrast, bearded seals (*Erignatus barbatus*) around Svalbard generally appear to be benefitting from reduced ice occurrence in the fjords and the presence of Atlantic fish species (Hamilton *et al.*, 2018). This is

even more true for harbour seals in Svalbard (Blanchet *et al.*, 2015). Ringed and bearded seals are subject to some subsistence and leisure hunting in Svalbard and Greenland, but this is not likely to have a significant effect on overall population sizes in the Norwegian Sea area.

Small numbers of walruses (*Odobenus rosmarus*) and polar bears (*Ursus maritimus*) are found in East Greenland and Svalbard. These species may be expected to react negatively to climate driven changes in the prey base and availability of ice/snow as a habitat for resting, hunting and breeding. So far, however, the walrus population in Svalbard appears to be recovering from overexploitation prior to protection in 1952 (Kovacs *et al.*, 2014). Walruses in East Greenland are thought to have recovered almost completely from previous overexploitation although some subsistence hunting still occurs (Born and Witting, 2005). Polar bears in Svalbard are also thought to have responded positively to protection in 1972 but have probably not yet reached the environmental carrying capacity. Surveys in 2004 and 2015 estimated total abundance in Svalbard at 700 and 1000 animals, respectively (Aars *et al.*, 2017). This increase is not significant, but even a status quo is notable considering significant declines in sea ice, which have reduced the availability of breeding habitat and sea ice suitable for hunting (Hamilton *et al.*, 2017). Little is known about polar bear abundance in East Greenland, but declining ice extent off East Greenland has been followed by increased polar bear predation in the pupping areas of harp and hooded seals (Laidre *et al.*, 2015a; McKinney *et al.*, 2013).

#### **Baleen whales and sperm whales**

These large and medium-sized whales were the main targets of whaling in the Norwegian Sea area. They are also generally well surveyed from the Norwegian and Icelandic minke whale (*Balaenoptera acutorostrata*) surveys in the Norwegian Sea area ((Øien, 2009); Table 5.1). With the exception of Bowhead whales (*Balaena mysticetus*), baleen whales, are generally thought to breed in subtropical and tropical areas, but a firm understanding of links to breeding grounds is lacking for the Northeast Atlantic (e.g. Kavanagh *et al.*, 2018; Smith and Pike, 2009). In the case of humpback whales (*Megaptera novaeanglia*), there are indications of breeding taking place close to Iceland (Magnúsdóttir *et al.*, 2014). Bowhead whales stay in Arctic waters all year and breeding activity appears to occur in the Western Fram Strait during the winter (Stafford *et al.*, 2012). In sperm whales (*Physeter macrocephalus*) only the males undertake poleward feeding migrations beyond subtropical waters.

In terms of biomass, large and medium sized whales are the most dominant marine mammals in the Norwegian Sea area. Based on the most recent Norwegian abundance estimates, the largest biomass of any marine mammal in the Norwegian Sea is estimated for fin whales (Table 5.1), followed by the much more abundant but smaller minke whales, and the few but large sperm and humpback whales.

**Table 5.1. Most recently published abundance estimates for focal marine mammal species and total estimated biomass. Sources: <sup>1</sup>Øien, 2009., <sup>2</sup>Solvang *et al.*, 2015., <sup>3</sup>Øigård *et al.*, 2014b., <sup>4</sup>Dommasnes *et al.*, 2000.**

Species	period	Est. Abundance	Mean Weight (Kg)	Est. Total Biomass (tonnes)
Fin whales	1996-2001	10 369 <sup>1</sup>	42 279 <sup>4</sup>	438 391.0
Humpback whales	1996-2001	4695 <sup>1</sup>	31 782 <sup>4</sup>	149 216.5
Minke Whales	2008-2013	53 936 <sup>2</sup>	5251 <sup>4</sup>	283 217.9
Sperm Whales	1996-2001	6375 <sup>1</sup>	34 322 <sup>4</sup>	218 802.8
Hooded seals	2012	84 020 <sup>3</sup>	262 <sup>4</sup>	21 222.0

Numbers in the present table differ somewhat from previous WGINOR reports because they now include all survey blocks outside the North Sea, Barents Sea and Northern Svalbard. A detailed analysis of marine mammal consumption in the Norwegian Sea and adjacent areas is under preparation (Lindstrøm, In press). A preliminary report from this work estimates the total consumption by marine mammals in the Norwegian Sea/Greenland Sea area at 4.5 million tonnes. For most of the large whale species in Table 5.1, newer abundance estimates are underway based on data collected by the IMR. Several preliminary accounts, however, suggest that the overall abundance of baleen whales in the Norwegian Sea area has decreased at least over the last decade. This seems due to a shift in distribution to more Northern and Eastern areas (Nøttestad *et al.*, 2015; Øien, 2016) following changes in prey distribution. The observed increase in minke whales in the Barents Sea is, however, unlikely to also explain a decline in minke whales on the north Icelandic shelf between 2001 and 2007 and 2009 (Vikingsson *et al.*, 2015). The latter change coincides with a change in summer distribution of capelin from the Icelandic Sea to the East Greenland continental shelf, but no survey data are available to verify whether the minke whales have indeed followed the capelin.

Blue whales (*Balaenoptera musculus*), fin whales (*Balaenoptera physalus*), sei whales (*Balaenoptera borealis*) and humpback whales as well as sperm whales and bottlenose whales (*Hyperoodon ampullatus*) were subject to intensive hunting in Norwegian and Icelandic waters from the 1880s to about 1915 (Christensen *et al.*, 1992; Vikingsson *et al.*, 2015), which is thought to have reduced abundance levels dramatically. Periods of protection of large whales in Icelandic waters since 1915 likely allowed a significant recovery of fin whales around Iceland, while effects for other species and areas are uncertain. Humpbacks and blue whales were completely protected in the North Atlantic in 1955 and 1959, respectively, while fin, sei and sperm whales were hunted in Norway up to 1973. An Icelandic hunt for fin and sei whales continued up to the late 1980s. Minke whales were mainly hunted from the 1930s and were the most commonly caught species by Norwegian small-boat whalers, although also bottlenose, killer whales and pilot whales were taken (Brunvoll, 2002). Available hunting statistics from 1945 and onwards show a declining trend from maximum levels of >4000 whales per year in the 1950s to <1000 in the mid-1980s and onwards. During a 5-year moratorium on commercial whaling 1988-1992, massive whale abundance surveys were conducted in the North Atlantic to estimate population status for as many species as possible, but with special focus on the previously hunted species (Pike *et al.*, 2009a; Øien, 2009). This effort has continued from 1993, when Norway resumed a small-scale commercial hunt for minke whales. Iceland resumed commercial whaling for minke whales in 2003 and for fin whales in 2009. Both countries conduct rather intensive abundance monitoring

and research into the ecology of several different species of whales. Annual catches are below 1% of the abundance estimates of the targeted populations. So far Norwegian monitoring of the Northeast Atlantic minke whale stock has not shown any significant overall changes in abundance over three available counting periods from 1987-1995, 1995-2001, 2002-2007 and 2008-2013 (Solvang *et al.*, 2015).

The abundance of humpback whales in Icelandic waters appears to have increased from 1800 to 11 600 individuals over the period 1987 to 2007 (Vikingsson *et al.*, 2015). Over the same period, fin whale abundance increased from 15 200 to 20 600 individuals. Most of these whales are, however, observed to the west and south of Iceland and are not included in the estimates of Table 5.1.

Blue whales appear to have recovered to a much less extent than other baleen whales in the Northeast Atlantic and were only estimated to number about ~1000 animals in the period 1987-2001 (Pike *et al.*, 2009b). There are, however, signs of an increasing trend in observations from 1969-2001. During this period, blue whales were very rarely seen in previous hot spot areas around Svalbard and in the Barents Sea. Blue whales were the main initial target in the large whale hunt of the late 19<sup>th</sup> century with ~3500 caught off north Norway from the 1860s to 1904. Over the period 1904-1913 at least 973 blue whales were caught around Svalbard and a further ~1500 blue whales were caught in other parts of the Northeast Atlantic over the period 1894-1955. During the period 1987-2001, the distribution of blue whales appeared to shift somewhat to the Northeastern part of Iceland and more recently observations have also increased significantly around Svalbard (Storrie *et al.*, 2018)). Here blue whales appear to follow concentrations of krill as these have entered the fjords in Western Svalbard. One of the reasons for the slow recovery of blue whales could be that they have a narrower foraging niche than most of the other baleen whales. High abundance of pelagic fish could therefore reduce prey availability for this species.

Several studies have shown that fin, humpback and minke whales may feed on both macrozooplankton and several species of fish. According to (Nøttestad *et al.*, 2015), fin and humpback whales in the northern Norwegian Sea showed preference for macrozooplankton during 2006-2007 but not during 2009-2012. Minke whales appear to feed mainly on herring in the Norwegian Sea, but on macrozooplankton and capelin in the Barents Sea (Windsland *et al.*, 2007). Studies of minke whales over the period 1993-2013 showed a decline in body condition over time mainly in the Lofoten basin of the Norwegian Sea (Solvang *et al.*, 2017).

Reported abundance estimates for sperm whales in Table 5.1 are not corrected for long dive times, which could imply an underestimation by about 50% (Gunnlaugsson *et al.*, 2009). Little is known about the diet of sperm whales in the Norwegian Sea but stomach data from the Northeast Atlantic generally suggest a diet comprised by squid (mainly *Gonatus fabricii* and mesopelagic fish, most notably lump sucker (*Cycloptera lumpus*) (Christensen *et al.*, 1992; Martin and Clarke, 1986).

Bowhead whales occur on the northern fringes of the Norwegian Sea off East Greenland and western Svalbard. These animals are considered to belong to a population also including whales in the northern Barents Sea and Atlantic part of the Arctic Ocean. This stock is thought to have been almost exterminated by whaling over the period 1611-1911 (Woodby and Botkin, 1993). Over the past decades, however, an increasing number of observations have been made around Svalbard and the Atlantic gateway to the central Arctic Ocean. Based on recent surveys in Northeast Greenland and north of Svalbard, this population is thought to number a few hundred individuals (Vacqu  -Garcia *et al.*, 2017). It has been speculated that an apparent increase in Bowhead whales

around Svalbard might partly be due to increased productivity of phytoplankton and copepods along the continental shelf north of Svalbard caused partly by reduced ice cover (Falk-Petersen *et al.*, 2015).

### **Gregarious toothed whales**

Most of the toothed whales in the Norwegian Sea are medium sized to small species which are often observed in groups. The most common species in the Norwegian Sea are longfinned pilot whales (*Globicephala melas*), killer whales (*Orcinus orca*), bottlenose whales, dolphins (typically white beaked and white sided dolphins (*Lagenorhynchus albirostris* and *Lagenorhynchus acutus*)), and harbour porpoises (*Phocoena phocoena*). These species are thought to both feed and reproduce in the Norwegian Sea area. They are generally not covered well by minke whale surveys, because of little time to estimate group size. Based on data from ecosystem surveys in the Norwegian Sea, Nøttestad (2015) reported an increase in relative occurrence of killer whales over the period 2006-2012 and longfinned pilot whales over the period 2009-2012. In the absence of absolute abundance estimates, it is not known if this was due to changes in distribution, abundance or both. Spatio-temporal overlap with potential prey species showed that pilot whales and white beaked dolphins were mainly associated with herring, while killer whales were mainly associated with mackerel (Nøttestad *et al.*, 2015). Some killer whales in the Norwegian Sea area also prey on seals (Foote Andrew *et al.*, 2013; Jourdain *et al.*, 2017).

Northern bottlenose whales belong to the family of beaked whales (*Ziphiidae*). The species is endemic to the North Atlantic and occur mainly in the Norwegian, Irminger and Labrador Seas and the Scotian shelf (Whitehead and Hooker, 2012). Over the period 1880-1920, they are thought to have been dramatically reduced by hunting (Whitehead and Hooker, 2012) perhaps from ~900 000 to 30 000 animals (Christensen and Ugland, 1983; Whitehead and Hooker, 2012). From the 1930s to 1972, they were also occasionally taken during the minke whale hunt, but the population effect of this is highly uncertain. Stomach samples from the Norwegian Sea have shown a diet dominated by the squid *Gonatus fabricii* (Benjaminsen and Christensen, 1979). In the Labrador Sea, also fish species such as Greenland halibut, redfish and herring were found (Benjaminsen and Christensen, 1979). Unlike minke whales, bottlenose whales were completely protected from hunting in 1973. This may have allowed numbers to increase, but no comprehensive abundance estimates are available to verify this (Øien and Hartvedt, 2011). In the Northeast Atlantic whale surveys conducted since 1987, the largest summer concentrations of bottlenose whales have been observed around Iceland and the Faroe Islands (Whitehead and Hooke, 2012). Abundance in this area has been estimated at ~28 000 individuals in both 1995 and 2001 (Pike *et al.*, 2003). These estimates are likely subject to negative biased due to long dive times and positive bias due to attraction to slow-moving ships. No abundance estimates have so far been calculated for other parts of the Norwegian sea area due to small numbers of primary sightings (Øien, 2009).

The abundance of longfinned pilot whales in the central and Northeast Atlantic has been estimated at >750 000 in the late 1980s (Buckland *et al.*, 1993). Later monitoring of a reference area does not suggest significant changes in overall population size (Pike *et al.*, In press). Little is, however, known about the relationship between the main concentrations of longfinned pilot whales and the animals occurring in the Norwegian Sea.

About 6500 narwhals (*Monodon monoceros*) inhabit waters off East Greenland, mainly in the North (Heide-Jørgensen *et al.*, 2010). They are also deep-diving foragers and appear to feed on Greenland halibut, which may make them vulnerable to competition

from commercial fisheries (Heide-Jørgensen *et al.*, 2015). No abundance trends are known for this population. Beluga whales (*Delphinapterus leucas*) are mainly found in coastal areas of Svalbard feeding particularly on polar cod at tidal glacier fronts (Lydersen *et al.*, 2014). No abundance estimates are available (Laidre *et al.*, 2015b).

So far very few data has been available on the abundance of harbour porpoises in the Norwegian Sea area. In 2015, however, surveys in the North Sea were extended along the Norwegian coast up to the Lofoten Islands (Hammond *et al.*, 2017) and estimated an abundance of ~25 000 harbour porpoises (*Phocoena phocoena*) for the areas bordering the Norwegian Sea. The abundance of harbour porpoises in Icelandic waters were estimated at 5156 (95% CI 3,027–8,739) in 1995 (Pike *et al.*, 2009a).

### Interactions with fisheries

Data from the Norwegian reference fleet since 2006 have provided useful insights into bycatches of harbour porpoises, grey and harbour seals in gillnet fisheries for cod and monkfish in Norwegian waters. An annual bycatch of ~3000 individuals has been estimated for Norwegian harbour porpoises, most of which are taken in coastal areas bordering the Norwegian Sea. Population effects of this bycatch depends on assumptions regarding population structure and site fidelity but is likely to be locally significant for the ~25 000 harbour porpoises in the eastern Norwegian Sea. Annual bycatches of 555 and 466 grey and harbour seals in the same fisheries are also thought to have a significant impact on these populations in the Norwegian Sea area (NAMMCO, 2016). (Pike *et al.*, 2009a) also expressed concern over bycatches levels for Icelandic harbour porpoises. More information on population effects of bycatches around the Norwegian Sea and adjacent areas will be available in the report from a workshop on harbour porpoises held in 2018 (NAMMCO 2018).

Lindstrøm *et al.* (2018) have found a rather high general potential for indirect resource competition between commercial fisheries and marine mammals in the Norwegian Sea compared to the Barents Sea and the waters around Iceland (Lindstrøm *et al.*, 2018). This is mainly due to the greater occurrence of toothed whales, which generally feed on a higher trophic level than baleen whales. Also, hooded seals are more piscivorous than harp and ringed seals, which are the dominant seal species in the Barents Sea area.

### Sensitivity to underwater noise

Research on marine mammal reactions to noise in the Norwegian Sea area has mainly focused on effects of mid-range military sonars (6-7 kHz) based on field experiments with humpback whales, minke whales, pilot whales, killer whales, sperm whales and Northern bottlenose whales (Sivle *et al.*, 2015; Sivle *et al.*, 2012)). All species showed some kind of behavioral response to the sound for shorter or longer periods. Most of the species reacted by staying close to the surface while moving away from the sound source. Seals behave roughly in the same way (Kvadsheim *et al.*, 2010). Experiments with captive seals have furthermore shown rather fast habituation leading to reduced physiological stress but increased duration of evasive behavior. In pilot whales evasive behavior lasted only for as long as the exposure itself (Antunes *et al.*, 2014), while other species avoided the exposure habitat for several hours after the end of exposure – up to more than 24 hours in bottlenose whales, during which time the animals did not appear to feed (Miller *et al.*, 2015). The reaction in bottlenose whales also occurred at lower exposure levels and differed from the other species by involving abrupt and very deep escape dives. This may increase the risk of symptoms similar to “the bends” (Kvadsheim *et al.*, 2012). Gas bubbles have been seen in a number of stranded beaked whales and there appears to be significant associations between naval exercises and

unusual mortality events in beaked whales around the world (Fernandez *et al.*, 2005; Filadelfo *et al.*, 2009). Military sonar activity is also considered a possible cause of a mass mortality event in late summer 2018 when ~80 beaked whale carcasses stranded along the shores of western Scotland and Ireland (Kvadsheim, pers. comm., Norwegian Defence Research Establishment). Higher than usual numbers of stranded beaked whale carcasses were also reported in Iceland and Norway at the same time (Bjørge, 2018). Although less sensitive than bottlenose whales, killer whales and minke whales react to military sonars at lower exposure levels than several other investigated species (Miller *et al.*, 2012; Sivle *et al.*, 2015). Humpback whales have been observed to increase the length of songs in response to sonar exposure (Miller *et al.*, 2000).

Responses to more low frequency noise such as seismic air guns and vessel noise are poorly studied in the Norwegian Sea area, although passive acoustic monitors in the Fram strait have shown considerable levels of this type of noise (Ahonen *et al.*, 2017). In other areas many marine mammals react to this type of noise in much the same way as to sonars, although vertical evasive dives have so far not been reported. There are indications that narwhals are particularly vulnerable to underwater noise including seismic airguns (Heide-Jørgensen *et al.*, 2013). Baleen whales using low frequency calls for communicative purposes often respond to low frequency noise by increasing their vocalization efforts (Di Iorio and Clark Christopher, 2010). In some cases, behavioral responses such as reduced foraging activity have been reported to last for considerably longer than the evasive response (Pirotta *et al.*, 2014). Reduced foraging rates may be particularly worrying in species such as the harbour porpoise, which has a high metabolic rate and must eat almost continuously to be able to grow and reproduce. Sometimes animals appear to endure higher noise levels in high quality feeding habitats or if they are in bad nutritional state (Tougaard *et al.*, 2015). This may, however, have costs in the form of high levels of stress hormones and possible long-term physiological effects. To understand the effects of noise exposure, it is therefore important to have species and area specific baseline information on habitat use. In this context it should be noted that a large-scale joint analysis of all available data from whale surveys in the North Atlantic has been initiated by the North Atlantic Marine Mammal Commission (NAMMCO) to understand patterns of habitat use of as many whale species as possible for this area (NAMMCO 2018).

## **Pollution**

Toothed whales in general are particularly prone to accumulation of high levels of chemical pollutants, due to their generally high trophic level and low capacity for metabolism of pollutants. In several toothed whale species around the British Isles, levels of persistent organic pollutants (POPs) like PCB have recently been found to exceed thresholds for reduced health status and reproductive rates (Jepson *et al.*, 2016). Furthermore, modelled population responses to different PCB loads have suggested that about half of the world's killer whale populations will likely disappear within 100 years due to PCB related health problems (Desforges *et al.*, 2018). This study has been criticized for assuming too low background growth rates of most killer whale populations (Witting, 2018), but may serve as a worst-case scenario and illustration of the range of PCB levels in killer whales and some potential effects and mechanisms. Most of the highly polluted populations inhabit industrialized areas. However, also mammal-eating killer whales from polar areas are predicted to decline. Fish-eating killer whales from the Norway and Iceland area are among the least polluted populations and may thus constitute a stronghold of the species. Still, POP levels in Norwegian killer whales are higher than in other marine mammals in the area (Wolkers *et al.*, 2007). Belugas and narwhals around Svalbard also have higher values than pinnipeds from

the same area (Wolkers *et al.*, 2006). Levels of PCB and several other persistent organic pollutants in hooded seals have been shown to be below known threshold levels for effects on reproductive capacity and the immune system but did show effects on thyroid hormone levels, which may affect growth (Villanger *et al.*, 2013). High levels of other POPs than PCB have been found in pilot whales and white sided dolphins around the Faroe Islands (Rotander *et al.*, 2012a; Rotander *et al.*, 2012b). These species also showed increasing levels of “new” pollutants such as perfluorated carboxylic acids (Rotander *et al.*, 2012a). In addition, levels of mercury in pilot whales around the Faroe Islands exceeded threshold levels for liver damage (Dietz *et al.*, 2013). Critically high levels of mercury are also found in East Greenland polar bears, but not in polar bears from Svalbard (Dietz *et al.*, 2013).

In 2017, post-mortem investigations of a Cuviers beaked whale (*Ziphius cavirostris*) in Western Norway, showed large numbers of plastic bags in the digestive tract, which were thought to have prevented prey digestion (Christoph Noever, University of Bergen, Norway, pers.com.). A stranded carcass of a bottlenose whale later that year in the same region had large amounts of plastic in the intestines, which is also thought to have potentially affected digestive capability. Plastic debris in the stomachs of some bottlenose whales was also reported by Benjaminsen and Christensen (1979). Beaked whales appear to be particularly prone to ingestion of macroplastic (ICES 2017c).

### Summary

The Norwegian Sea area is inhabited by a diverse marine mammal community exploiting a variety of ecological niches. Ongoing analyses, however, suggest that marine mammals in the Norwegian Sea have a more fish dominated diet than in adjacent areas and that there is a potential for resource competition between fisheries and the marine mammal community. Bycatches are observed in some coastal fisheries and may have significant effects on the abundance of harbour porpoises, grey and harbour seals in the Norwegian Sea area.

Other potentially significant anthropogenic effects include underwater noise and pollutants. The potential importance of these two factors are underlined by a recent mass mortality event for beaked whales and predicted PCB related population declines in killer whales eating mammals or inhabiting industrialized areas.

Reliable series of abundance estimates are fundamental for understanding the ecological role of marine mammals in the Norwegian Sea and the relative importance of environmental and anthropogenic effects on marine mammal abundance. These data are mainly available for the commercially exploited species and a few other species surveyed along with them. Unfortunately, some of the species that are not regularly surveyed are likely among the most vulnerable such as beaked whales and harbour porpoises. Few absolute abundance estimates are also available for killer whales and pilot whales, which could be of significant ecological importance in the Norwegian Sea. Data are lacking because whale counting is a resource demanding and highly specialized activity. Even estimation of relative abundance, as has been done on some integrated ecosystem surveys (Nøttestad *et al.*, 2015), requires a rather dedicated effort with possibilities for stopping or going off transect.

WGINOR has discussed the possible gains from a common protocol for opportunistic marine mammal observations. It is clear that this type of data has many limitations. In light of the marine mammal distribution study by Storrie *et al.* (2018), it should, however, be considered if a similar opportunistic data collection approach can be applied by WGINOR member institutions.



### 5.1.7 Seabirds

#### 5.1.7.1 From the Faroe Islands

In the Faroes, the main food of seabirds is sandeel and Norway pout. The situation of the stocks has been almost the same as in Norway, with a general decline since the 1960s, although the decline has not been as drastic as in Norway. The gannet *Sula bas-sana*, which takes larger food, has, however, been increasing, especially in the last decade.

#### 5.1.7.2 From Norway

Three species of seabirds feeding in the pelagic part of the ecosystem have been selected to be included in the analyses. These are black-legged kittiwake (*Rissa tridactyla*), Atlantic puffin (*Fratercula arctica*) and common guillemot/common murre (*Uria aalge*). The reason for selecting these species is that they feed in different parts of the pelagic ecosystem. In the Norwegian Sea, the black-legged kittiwake obtains its food within the upper half meter of the sea surface layer in the form of first-year herring, sandeels, gadids, lanternfish, crustaceans, and pteropods. The common guillemot is a pelagic fish specialist, which typically feeds at depths down to 80 metres. Although the breeding adult may feed heavily on very small fish such as 0-group cod (Erikstad *et al.*, 2013), it feeds its chick in the Norwegian Sea mainly young saithe and haddock, and to a lesser extent sandeel and herring, of which all are brought back to the colony one by one (Barrett *et al.*, In manuscript). The Atlantic puffin typically feeds at depths down to 30 metres and brings loads of smaller fish to the chick, in the Norwegian Sea in particular first-year herring along with sandeel and gadids, but outside the breeding season, they also feed on crustaceans. Average total lifespan for birds that reach maturity is around 10–12 years for black-legged kittiwake, 25–30 years for common guillemot and 15–20 years for Atlantic puffin. Kittiwakes typically lay two (1–3) eggs, whereas the common guillemot and Atlantic puffin lay a single egg. Except for the breeding season, all three species spend their entire life at sea.

#### Population sizes

The total population size of seabirds breeding on the coasts of the Norwegian parts of the Norwegian Sea in 2013 was estimated based on the latest counts in all areas (Table 5.2, (Anker-Nilssen *et al.*, 2015)), which for the mainland were also adjusted for trends in numbers at the monitored colonies (Fauchald *et al.*, 2015). Insufficient data did not allow such calculations for northern fulmar and black guillemot, but we have subjectively adjusted the estimate for the former to account for some very apparent recent declines. The SEAPOP programme aims to publish annual updates of national and regional population estimates on [www.seapop.no](http://www.seapop.no) in 1-2 years.

**Table 5.2. Estimated population sizes (numbers of breeding pairs) of seabirds in the Norwegian parts of the Norwegian Sea in 2013, compared to the Norwegian and European totals (after (Anker-Nilssen *et al.*, 2015; Fauchald *et al.*, 2015), adjusted for fulmar numbers (see text), European numbers are from (Mitchell *et al.*, 2004)).**

Species	Mainland coast	Jan Mayen	Sum	Norway total (incl. Svalbard and Jan Mayen)	Europe total
Northern fulmar	<1000	>170 000	<b>177 500</b>	±1 000 000	3 000 000
European storm-petrel	>1000	0	<b>&gt;1000</b>	<10 000	690 000
Leach's storm-petrel	>100	0	<b>&gt;100</b>	<1000	150 000
Northern gannet	3600	0	<b>3600</b>	5700	300 000
Great cormorant	13 500	0	<b>13 500</b>	21 000	45 000
European shag	9000	0	<b>9000</b>	28 000	81 000
Common eider	41 000	<100	<b>41 000</b>	104 000	2 000 000
King eider	0	0	<b>0</b>	500	500
Great skua	90	<10	<b>100</b>	1100	16 000
Arctic skua	<1000	<10	<b>&lt;1000</b>	3000	17 500
Common tern	<3000	0	<b>&lt;3000</b>	<11 000	300 000
Arctic tern	20 000	<1000	<b>21 000</b>	<40 000	750 000
Common gull	75 000	0	<b>75 000</b>	90 000	500 000
Lesser black-backed gull	6500	<10	<b>6500</b>	28 000	180 000
Herring gull	42 000	<10	<b>42 000</b>	72 000	850 000
Glaucous gull	0	>200	<b>&gt;200</b>	4000	21 500
Great black-backed gull	30 000	<10	<b>30 000</b>	43 000	120 000
Black-legged kittiwake	44 000	<10 000	<b>&gt;50 000</b>	340 000	2 500 000
Ivory gull	0	0	<b>0</b>	2000	2000
Common guillemot	2600	<1000	<b>&gt;3000</b>	150 000	2 900 000
Brünnich's guillemot	0	>110 000	<b>&gt;110 000</b>	725 000	1 000 000
Razorbill	<10 000	<100	<b>&lt;10 000</b>	55 000	500 000
Little auk	0	<100 000	<b>&lt;100 000</b>	±1 000 000	>1 000 000
Black guillemot	15 000	<1000	<b>&gt;15 000</b>	55 000	200 000
Atlantic puffin	553 000	<5000	<b>&lt;558 000</b>	1 500 000	5 500 000
Total	870 000	400 000	<b>1 270 000</b>	5 500 000	23 000 000

Only for three species that are relatively sparse in numbers (northern gannet, lesser black-backed gull and great skua), the estimates are higher than the previous ones published by (Anker-Nilssen and Lorentsen, 2004; Barrett *et al.*, 2006). For many of the more abundant species, such as the Atlantic puffin, several gulls (including the black-legged kittiwake), common eider and the two cormorants, numbers have dropped substantially and mainly reflect substantial population declines in the preceding decade (see below).

### **Dataseries**

For the three selected species, time-series of abundance of populations breeding along the Norwegian coast (Figure 5.12) were assessed from their estimated total size in 2013 (Fauchald *et al.*, 2015) and relative changes in populations size in selected breeding colonies documented by the SEAPOPOP programme and the National seabird monitoring programme. The main colonies (key-sites) where these species are monitored along the Norwegian part of the Norwegian Sea coastline are Runde (62.4°N), Sklinna (65.2°N), Røst (67.5°N), Anda (69.1°N, only black-legged kittiwake and Atlantic puffin), and the remote island of Jan Mayen (71.1°N, only common guillemot), but the latter time-series is not included here. As there was no monitoring of common guillemots in 1984–1987 at Runde and Røst, we assumed a constant rate of change over those years.

### **State and recent trends**

Data for seabird population trends for this report were only available from the Norwegian areas, where most of the annual monitoring of the three focal species was initiated in 1979–1980.

### **Black-legged kittiwake**

The breeding population of black-legged kittiwake in the Norwegian part of the Norwegian Sea has declined by 86% since monitoring started in 1980. Its outlook is grim, with many colonies risking to go extinct within this century (Sandvik *et al.*, 2014).

### **Atlantic Puffin**

The breeding population of Atlantic puffin in the Norwegian part of the Norwegian Sea has declined by 71% since monitoring started in 1980.

### **Common guillemot**

The breeding population of common guillemot Norwegian part of the Norwegian Sea has declined by as much as 99% since monitoring started in 1980 and the species is at risk of extinction as a breeding species along the Norwegian mainland coast of the Norwegian Sea.

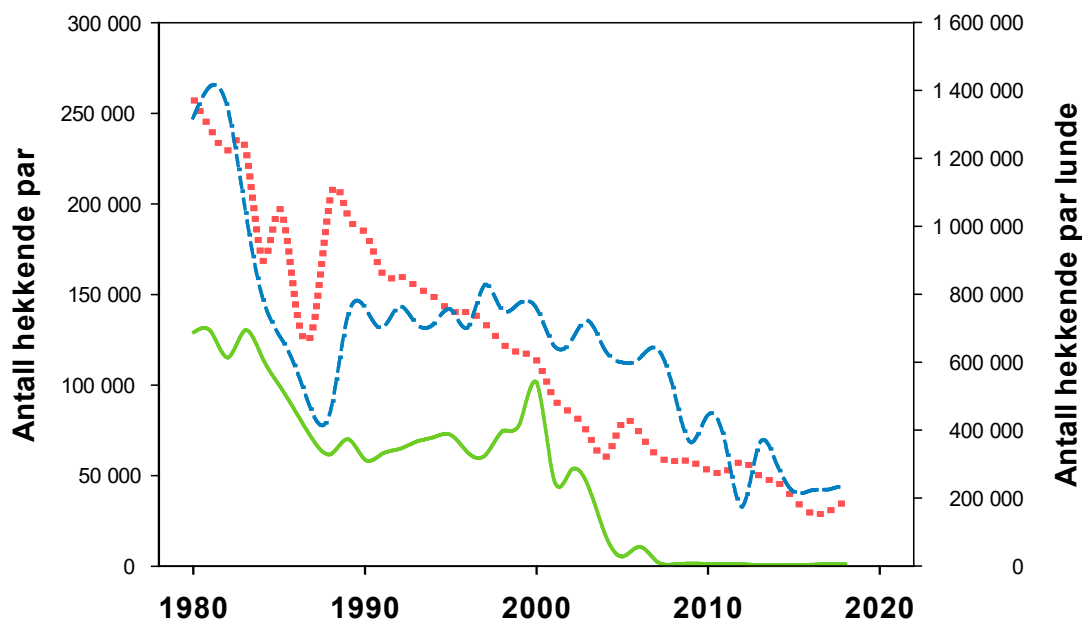


Figure 5.12. Development in the breeding populations of black-legged kittiwake (red dashed line) and common guillemot (green line) (both left axis) and Atlantic puffin (dashed blue line, right axis) in the Norwegian part of the Norwegian Sea in the period 1980–2018.

The causes for the negative trends registered for breeding seabirds in the Norwegian Sea are not fully understood, but changes in food availability and climate play a major role. This has recently been clearly demonstrated by a study of the common guillemot in the Barents Sea (Mesquita *et al.*, 2015), which is also an important post-breeding area for many seabirds from the Norwegian Sea, including common guillemots (Lorentsen and May, 2012)(Erikstad *et al.*, unpublished data), black-legged kittiwakes (Moe *et al.*, unpublished data) and Atlantic puffins (Anker-Nilssen and Aarvak, 2009b; Fayet *et al.*, 2017), see also species- and site-specific maps at [www.seapop.no/en/seatrack.en](http://www.seapop.no/en/seatrack.en) (SE-ATRACK, unpublished data). At the SEAPOP key-sites on the Norwegian coast (i.e. Runde, Sklinna, Helgeland, Røst, and Anda), numbers of most species have dropped drastically over the last decade, although common guillemots and razorbills have been doing reasonably well where they breed in shelter (Anker-Nilssen *et al.*, 2018). Access to shallow coastal waters and fjord systems in close vicinity of the colonies seems however to be of extra value when the supply of pelagic prey fails, as illustrated by an overall poorer success in such years for the pelagic species at Røst than at the other key-sites (SEAPOP data portal, [www.seapop.no](http://www.seapop.no)). A key factor in this context is the long-term lack of 0-group herring, perhaps the most important food source for pelagic seabirds along the mainland coast of the Norwegian Sea. Breeding failure has been observed as the typical result for both Atlantic puffins and black-legged kittiwakes when herring year-class strength drops below one third of its historical maximum (Cury *et al.*, 2011). The Norwegian spring-spawning herring has not produced a strong year class since 2004, and none of the breeding seasons after 2006 can be termed as successful for pelagic seabirds in this part of the Norwegian Sea. This is surprising as the general environmental conditions for the production of *Calanus finmarchicus* were seemingly reasonably adequate over the same period (Frederiksen *et al.*, 2013). It is therefore of extra interest to know to what extent the failing recruitment of herring can

be attributed to the extreme expansion and stock increase of mackerel in the Norwegian Sea since 2007 (Nøttestad *et al.*, 2016). Recent research does however indicate that boosts of cold, nutrient-rich water from winter convections in the Labrador Sea (Yashayaev and Loder, 2017) that are transported eastwards with the Subpolar Gyre (SPG), is an important driver of *Calanus* productivity on the Icelandic and Faroese shelves (Hatun *et al.*, 2016) by triggering growth of important prey for breeding seabirds, such as sandeels (Hatun *et al.*, 2017). It may well be that similar positive effects of these pulses can be traced further into the NE Atlantic. In addition, the dynamics of the SPG has proven important for the survival of pelagic seabirds that spend winter in the Central or NW Atlantic (Fluhr *et al.*, 2017), which also include many Atlantic puffins and black-legged kittiwakes that breed in the Norwegian Sea.

The extensive tracking of seabird movements with geolocator loggers now undertaken by the SEATRACK module of SEAPOP, vastly increases our knowledge of where seabirds spend the non-breeding season and allow us to study effects on their population dynamics from conditions encountered far away from their breeding grounds. An interesting example is the impact of Thecosomata snail abundance off Newfoundland in winter on the adult survival of black-legged kittiwakes from Hornøya (Reiertsen *et al.*, 2014).

In contrast to Atlantic puffins and black-legged kittiwakes, breeding common guillemots and razorbills are able to forage efficiently in shallow waters where they can access and utilize other prey such as sandeels and 0-group saithe. As these large auks are doing better where they breed in shelter, the decrease of their populations on exposed ledges is probably also an effect of increased disturbance and predation pressure from non-breeding white-tailed eagles that boosted in numbers on the Norwegian coast in the late 1990s (Hipfner *et al.*, 2012). This effect is also documented as a very significant factor limiting chick production of black-legged kittiwakes (Anker-Nilssen and Aarvak, 2009a). The rich kelp forest along this coast-line is also the nursery ground for young saithe, which has proved to be an important food source for European shag (Lorentsen *et al.*, 2018; Lorentsen *et al.*, 2015), probably also for common guillemots, black guillemots, and Arctic terns (SEAPOP data portal [www.seapop.no](http://www.seapop.no) and unpublished data).

### **Ecosystem interactions**

The numbers of breeding pairs of three species of seabirds (kittiwake (*Rissa tridactyla*), Atlantic puffin (*Fratercula arctica*) and common guillemot/common murre (*Uria aalge*)) have been declining more or less the whole time-series period from the early 1980s to date. The main diet of these species varies from zooplankton, fish larvae and juveniles, to adult pelagic fish. All three spp. also feed on adult sandeels and capelin. The reasons for the declining seabird populations are not obvious and possibly not the same for the three species focused in this report, but research affiliated to the SEAPOP programme is constantly exploring this in further detail (see [www.seapop.no](http://www.seapop.no)).

#### **5.1.8 Future development of framework for integrated assessment**

Last year the group discussed the use of PCA in integrated trend analyses and concluded, based on the work by (Planque *et al.*, 2018), that PCA is not informative for the type of time-series data collected by WGINOR (see science highlights). Another experience from 2018 is the scoping exercises that have been performed in Norway and that has identified several issues that can be addressed by WGINOR as a way to develop an ecosystem approach to fisheries management or ecosystem-based fisheries management (see Annex 5 for a full description of the scoping process and the results). With

this as a background, and with the aim of developing integrated ecosystem assessments (IEA) with stronger relevance for advisory processes, the group decided to develop the work with stronger emphasis on operational products. More specifically, the aim is to build IEA through the following:

- Initiate development of a forecast system for the physical environment with a forecast horizon of e.g. 1-2 years;
- Initiate development of a model-based foodweb assessment with both hindcast and projection properties. The projection horizon may for example be in the range 2-5 years. Details about how this can be done using Chance and Necessity modelling and other modelling approaches is described in Annex 5;
- Initiate development of a framework for assessing whether there are warning signals in the ecosystem that are of relevance for management. This is anticipated to draw on the two operational products described above;
- Perform repeated scoping with managers and relevant stakeholders. This can be approached by inviting to the yearly WGINOR meeting representatives for relevant management institutions and other stakeholders from the country hosting the meeting. Through a limited session of the meeting, a scoping exercise can then be done (see Annex 5 for details).

This planned development of IEA in WGINOR in the years to come is reflected in the new Terms of Reference (Annex 3).

## 5.2 Tor B – Multispecies Modelling

Tor B is on utilizing multispecies and ecosystem models to investigate effects of single and multispecies harvest control rules (HCRs) on fishing yield and ecosystem state for the purpose of developing ecosystem-based advice. The main findings can be summarized as follows:

- Several possible research questions to be dealt with in three different models, ENAC, NORWEGOM and Atlantis, were identified and reported in the 2016 report (ICES 2017b).
- Multispecies management strategy evaluation of pelagic fish in the Northeast Atlantic using the ENAC model indicated that interspecific interactions mediated through individual growth rate has insignificant impact on harvest control rules for these stocks. However, interactions affecting other processes (e.g. mortality and/or recruitment, neither tested here) may be important.

The Atlantis framework was used to explore six different HCRs for NEA mackerel. The main findings show that there was <5% change in body condition in mackerel (all cohorts) for the six HCRs, hence the differences in biomass between the HCRs was driven by changes in numbers. The HCRs accounting for ecosystem variability resulted in more variation in the stock biomass, as expected. The largest difference in mean biomass was between a HCR with constant flat  $F_{MSY}$  and a HCR with a broken stick  $F_{MSY}$ , accounted for ecosystem variability and where  $F$  was decreased when the zooplankton level dropped below 50%.

### 5.2.1 Multispecies management strategy evaluation of pelagic fish in the Northeast Atlantic using the ENAC model

#### Introduction

Pelagic fish stocks can have interactions with negative impact on the stocks. The most obvious is intraguild predation (predation on egg or larvae of potential competitors,

e.g. Skaret *et al.*, 2015), but competition for common prey can also have a negative effect on fish stocks (Huse *et al.*, 2012; Bachiller *et al.*, 2018). There are three large pelagic fish stocks in the Northeast Atlantic (NEA); Norwegian spring-spawning herring (NSS-herring), NEA mackerel and blue whiting. These species have interannual variation in individual growth, which is hypothesized to be correlated to total biomass of pelagic fish in the Northeast Atlantic. This has raised the question whether management of these pelagic species can be improved by accounting for these interactions and perform management strategy evaluation where individual growth is a function of biomass of other species.

This question is here addressed with a multispecies model. The model itself and all underlying analyses have not been published peer-reviewed and have not been through a proper scientific quality control. The results can therefore not be used directly into management decisions per se. The objective of this study was to evaluate different HCRs in terms of acceptable fishing mortality (F) and annual landings given that interspecific interactions are accounted for.

### Analysing growth of the pelagic fish

A key issue for this study is whether variability of individual growth is due to inter-specific interactions. A model where the intrinsic growth rate is varying with covariates where applied for the three species. A range of different covariates was initially tested, but all are not mentioned here.

Data of length-at-age for the three species was retrieved from the IMR database for the period 1980-2016. This includes both data from scientific surveys and commercial catches, and  $N > 10\,000$  for all species. A discrete time-series model based on von Bertalanffy model was applied to model incremental growth, including time invariant parameters modelled as functions of covariates. Assuming  $L_{t_0} = L_0 = 0$  yields the standard form of the von Bertalanffy growth model

$$L_t = L_\infty [1 - e^{-k(t-t_0)}] \quad (1)$$

This model is usually fitted to data applying additive or multiplicative error structure obtained by normal or lognormal distribution. However, the model does not predict the incremental growth which is a conditional process where the current size depends on earlier sizes. The discrete approximation of the derivatives of equation (1) yields  $\Delta L = (L_\infty - L)k\Delta t$  for small  $\Delta t$  such that

$$L_{t+\Delta t}|L_t \approx L_t + (L_\infty - L_t)k\Delta t \quad (2)$$

The analyses are based on the approximation of the growth represented by equation 2 with stochastic variability added to the  $k$  parameter by the following equation:

$$K_t = k_t \exp(\varepsilon_t) \quad (3)$$

where  $\varepsilon_t \sim N(0, \sigma_\varepsilon^2)$  positive growth increments are ensured. This model can be fitted by maximizing the likelihood function. The general model for the growth parameter depend on an age specific annual varying covariate  $y$  through

$$k_{ai} = k_a^* e^{\beta_a y_{ai}} \quad (4)$$

at age  $a$  at time  $i$  with parameters  $k_a^*$  and  $\beta_a$ . A working paper describing the modelling approach and underlying statistics in detail is available upon request.

Individual growth for NSS-herring has previously been modelled and is not repeated here due to low temporal variability of size-at-age (Homrum *et al.*, 2016)). The main variability of growth is seen for juvenile herring and this variability is correlated to

year-class strength. Variation in juvenile growth is not related to interspecific competition as herring has the main nursery area in the Barents Sea where mackerel and blue whiting are rare.

Updated growth analyses were done for blue whiting and mackerel. The best model fit for blue whiting was achieved with a growth model where the intrinsic growth rate is a function of TSB of blue whiting (Table 5.3, and Trenkel *et al.*, 2014). This model gave a better fit to observed growth than if total biomass of pelagic fish (sum of TSB mackerel, TSB blue whiting and SSB NSS-herring) were used as covariate. Since this is single-species interactions, blue whiting will not be addressed here.

For mackerel the best model fit was achieved when the intrinsic growth rate is a function of mackerel TSB and herring SSB. This finding is also in agreement with previous published results (Olafsdottir *et al.*, 2015). Example of individual growth for mackerel is shown in Figure 5.13. The following study will therefore evaluate HCRs where individual growth is a function of mackerel TSB and herring SSB.

### 5.2.1.1 Simulations

The first set of simulations estimate  $F_{MSY}$  for mackerel when fixed and variable individual growth is applied in the model. In simulations with variable growth this is a function of mackerel TSB and herring SSB. Secondly, simulations with variable individual growth are tested further to estimate if different HCRs for NSS-herring affect mackerel  $F_{MSY}$ . The relative importance of the two stocks biomass is not differentiated on mackerel growth, giving equal contribution in the simulations.

**Table 5.3. Model fits for blue whiting and mackerel; the predictor, estimated parameters and AIC values are shown. TSB-total-stock biomass, TBF – Total biomass pelagic fish (the sum of TSB mackerel, TSB blue whiting and SSB NSS-herring).**

Species	Model	log(Linf)	log(k)	$\beta$	log( $\sigma^2$ )	AIC
BW	k - TSB BW	3.58037	-1.02523303	-0.06097217	-6.50108423	177794.9
BW	k – TBF	3.58749	-0.77723754	-0.04532306	-6.52610992	178500.3
BW	k - constant	3.61199	-1.510580	-	-6.545213	182351.1
Mackerel	k -TSB mac + SSB her	3.701141	-0.71512709	-0.06568387	-6.82303419	135463.8
Mackerel	k- TSB mackerel	3.695824	-0.90483374	-0.09149225	-6.71818598	136864
Mackerel	k - TBF	3.696673	-0.90486792	-0.02631778	-6.73742884	136980.7
Mackerel	k - constant	3.690944	-1.251721	-	-6.639318	138016.6



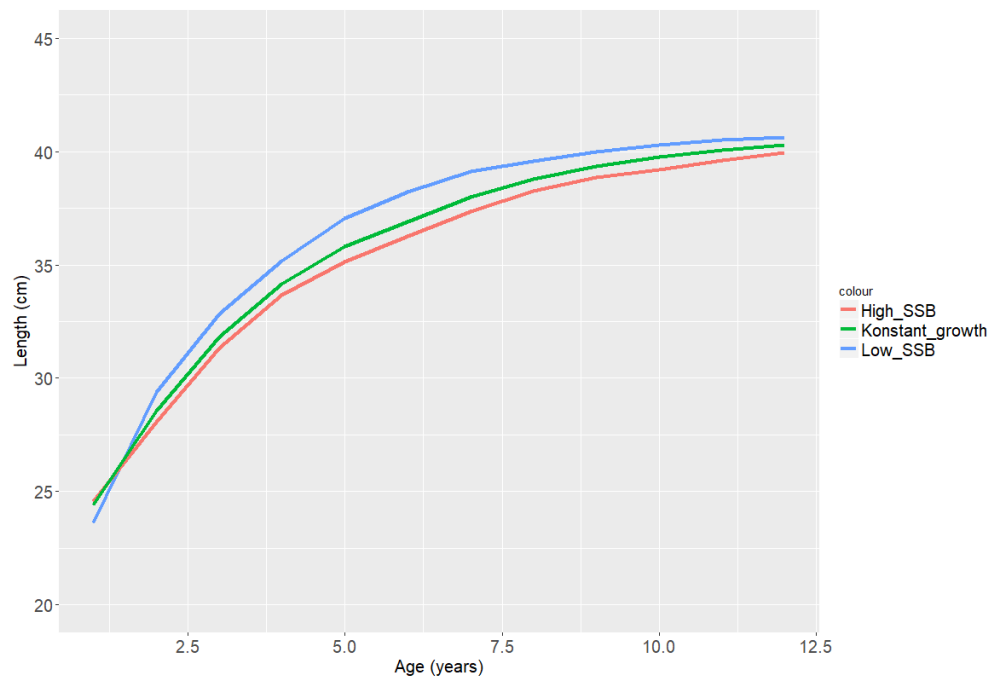


Figure 5.13. Example of length-at-age for mackerel in the model with parameter  $k$  in equation (1) constant (green line) or varying with stock sizes of mackerel and herring (low – blue line, high – red line). The length-at-age is randomly picked model super individuals for illustrative purpose, and there is randomly generated variation between individuals in the model.

### The model

The model, using a MSE approach, follows the standard template (Basson, 1999; Butterworth and Punt, 1999; Sainsbury *et al.*, 2000) and consists of four different sub-models; an operational model (OM), a management model (MM), a harvest model (HM) and a resource operating model (ROM). The OM represents the perceived “real world”, where the dynamics of the stocks are described by recruitment, growth, maturation and mortality. The MM adds random noise to the output from the OP to mimic that managers never have perfect knowledge of the stocks, but base their knowledge of stock indices from commercial catches, research surveys etc. The HM projects the development of the stocks forward in time and estimate a fishing mortality ( $F$ ) based on a HCR. Here different HCRs can be tested to explore how this will affect fish abundance, Total Allowable Catch (TAC) and stock dynamics. In the ROM the actual number of fish that should be removed in the OM is calculated from the TAC, and time for removal is split into seasons, as the fisheries vary throughout the year. The model setup is presented in Figure 5.14.

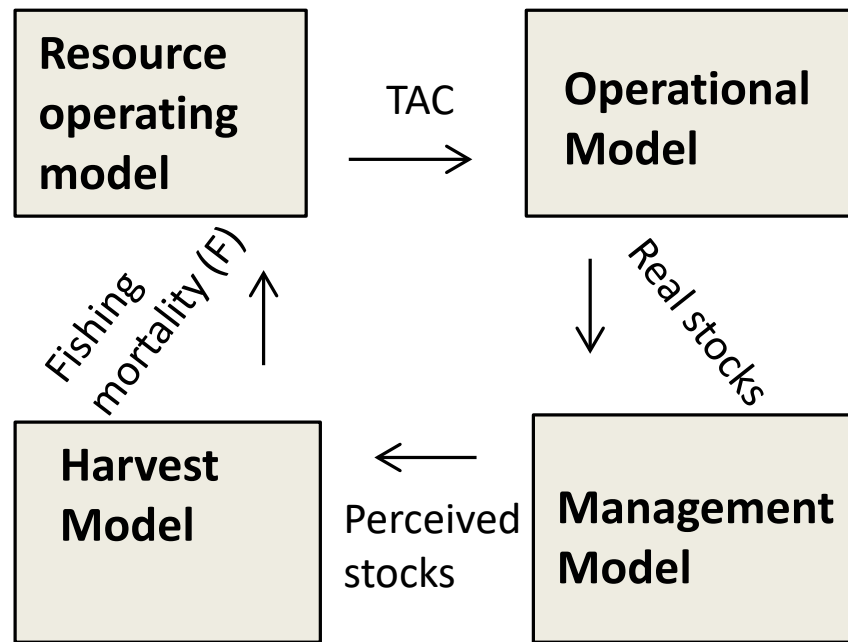


Figure 5.14. Overview and flow structure of the models included in the MSE.

The model includes the three species NSS-herring, blue whiting and NEA mackerel. The stocks are modelled by using Super Individuals (SI) (Scheffer *et al.*, 1995) with Attribute Vectors (AV) (Chambers, 1993). Each SI represents several identical individuals. The reason for using SI is to get a detailed representation of the stocks while maintaining some variation. The AV is a system for internal bookkeeping to keep track of the states used to specify the SI and includes the internal number, age, length, weight and a logical value for whether the fish is mature or not.

A full description of the model and species-specific parameters will not be given here. Species-specific parameters are used for recruitment, maturation and selectivity in the fishery. The parameters were either found by fitting models to assessment data or taken from previous evaluation of reference points for these species (Miller *et al.*, 2013). Hence, most of the parameters are not updated according to the latest stock assessments. Further, some of the settings in the model may be suboptimal for representing the actual forecasts as the management and harvest model are different from, for instance, the SAM model. Hence, the results presented here cannot be applied directly to management as is, and the objective of this study is to present a possible outcome of multispecies management where interactions affecting growth is included.

## Results

The first step was to find  $F_{MSY}$  for mackerel where individual growth is constant and independent of interaction. Simulation results gave  $F_{MSY}$  constrained by  $P(SSB < B_{lim}) < 0.05$  and  $F_{MSY}$  was therefore set equal to  $F_{05}$ . This is in agreement with the present applied  $F_{MSY}$  for mackerel. However,  $F_{MSY}$  from the model simulations ( $F=0.23$ ) deviated slightly from the present applied  $F_{MSY}=0.21$ . This is not surprising given the sensitivity of  $F_{MSY}$  to model settings and the parameters applied. The results are given in Table 5.4.

The second step is to find  $F_{MSY}$  for mackerel with simulations where individual growth is varying with the biomass of NSS-herring and mackerel. Simulations results gave

$F_{MSY} = 0.23$ , which is identical as the simulations with constant individual growth (Table 5.4.a). However, estimated  $P(SSB < B_{lim})$  and mean total allowable catch (TAC) for  $F = 0.23$  vary with whether fixed or variable individual growth is used in the simulations. This  $F_{MSY}$  for mackerel is from simulations where the present management plan is applied for NSS-herring.

The third step is to change the HCR for NSS-herring and evaluate the potential effect on  $F_{MSY}$  for mackerel. Simulations with  $B_{trigger}$  at 5 million tonnes (currently applied  $B_{trigger}$ ) gives a  $F_{MSY} = 0.16$ . This  $B_{trigger}$  is identical with the previous  $B_{pa}$ , but with the recent revision of reference points  $B_{pa}$  is now reduced to 3.184 millions tonnes. Simulations with a lower  $B_{trigger}$  (3 millions) for herring and the same target  $F$  (0.16), gives an increase in  $F_{MSY}$  for mackerel from 0.23 to 0.24. However, this HCR is not precautionary for herring as  $P(SSB < B_{lim}) > 0.05$ . If  $F$ -target is reduced to 0.09, which is the maximum precautionary value with a  $B_{trigger} = 3$  millions tonnes, then  $F_{MSY}$  for mackerel is 0.23 (Table 5.4.c-d). Hence, the model simulation indicates that changing HCR for NSS-herring to a lower  $B_{trigger}$  with the aim of optimizing yield for mackerel is not beneficial.

**Table 5.4. Overview of HCRs and the respective target  $F$ ,  $B_{trigger}$  and  $B_{lim}$ , and the respective descriptive measurements resulting from the HCRs.**

Species	F	$B_{lim}$	$B_{trigger}$	mean SSB	mean TAC	$P(SSB < B_{lim})$	IAV
Constant growth							
Blue whiting	0.39	1 500 000	2 250 000	2 557 653	923 981	0.0356	0.53
Mackerel	0.23	1 940 000	2 570 000	2 518 367	473 148	0.0467	0.60
NSS-herring	0.16	2 500 000	5 000 000	3 736 687	358 149	0.0476	0.37
Variable growth							
a)							
Mackerel	0.23	1 940 000	2 570 000	2 528 322	489 105	0.0410	0.58
NSS-herring	0.16	2 500 000	5 000 000	3 745 955	359 726	0.0418	0.38
b)							
Mackerel	0.24	1 940 000	2 570 000	2 502 940	496 681	0.0491	0.61
NSS-herring	0.16	2 500 000	3 000 000	3 345 048	401 343	0.1151	0.42
c)							
Mackerel	0.24	1 940 000	2 570 000	2 488 679	488 280	0.0505	0.62
NSS-herring	0.09	2 500 000	3 000 000	4 035 613	322 983	0.0483	0.22
d)							
Mackerel	0.23	1 940 000	2 570 000	2 519 938	484 606	0.0418	0.58
NSS-herring	0.09	2 500 000	3 000 000	4 042 165	323 431	0.0425	0.22

## Discussion

Interspecific interaction mediated through individual growth have been tested and discussed in MSE for mackerel and blue whiting (ICES 2016b; ICES 2017d). However, the causal mechanisms for reduced individual growth are still debated in the scientific community, despite several peer-reviewed manuscripts addressing the issue (Jansen and Burns, 2015; Olafsdottir *et al.*, 2015; Trenkel *et al.*, 2015). Intraspecific interactions have not yet been considered in the evaluations. Here,  $F_{MSY}$  for mackerel was evaluated with individual growth varying with spawning biomass of NSS-herring, and with two different HCRs for NSS-herring. HCRs with varying  $B_{trigger}$  for NSS-herring did not change  $F_{MSY}$  for mackerel in these simulations. However,  $P(SSB < B_{lim})$  for mackerel  $F_{MSY}$  was slightly reduced when the HCR for NSS-herring had a low  $B_{trigger}$ , although not

enough to increase  $F_{MSY}$  for mackerel. Results from model simulations are sensitive to how the biological processes are parameterized as well as to model structure and applied software. Other model settings or applied parameters may give a minor change in  $F_{MSY}$  for mackerel, but probably not more than a deviation of 0.01.

So why isn't there a larger effect of NSS-herring HCRs on the result? There are a several reasons for the rather limited effect on mackerel  $F_{MSY}$ .

- Although mackerel has large variation in individual growth, not all this variation can be explained by biomass of mackerel or NSS-herring. Hence size-at-age in the model have less variation than observed historically.
- The range of HCRs that are practically acceptable for NSS-herring is limited, as this is a stock of high commercial value with a rather high  $B_{lim}$  (2.5 millions tonnes). A HCR must minimize the  $P(SSB < B_{lim})$  while ensuring a high long-term yield and reducing interannual variability of TAC. Hence, the possible range of target  $F$ 's and  $B_{trigger}$ 's that ensure an acceptable management of herring is fairly limited.
- Different HCRs will affect the median, mean, minimum and maximum of the population biomass. However, HCRs that ensure long-term yield and low interannual variability also give rather large fluctuations in stock biomass. Hence, these HCRs do not keep the biomass at a constant low level. Due to natural fluctuations in stock biomass, there will be periods of high abundance of mackerel and herring, and low individual growth of mackerel irrespective of the applied HCRs. A reasonable HCR can therefore not ensure good individual growth of mackerel at all times.

A challenge with multispecies management is that the interactions between the species are poorly understood and quantified. Although mackerel growth is best explained by a model that includes mackerel and NSS-biomass, the relative importance of each variable is not quantified. Most likely are the intraspecific interactions more important for individual growth than the interspecific interactions. In this study the importance of both biomasses where of equal importance, which may overestimate the effect of herring biomass.

Although the simulations do not indicate that interspecific interactions mediated through individual growth is an important issue when evaluating HCRs for the species considered here, interactions affecting other processes (e.g. mortality and/or recruitment) may be important.

### 5.2.2 Atlantis modelling

Atlantis (Fulton *et al.*, 2011) is a modular modelling framework capable of producing realistic simulations of ecosystem dynamics. Atlantis serves as a strategic management tool capable of exploring ecological hypotheses, simulating climate scenarios, and testing human impacts on the environment including fisheries and the effect of wind farms. Atlantis integrates physical, chemical, ecological, and fisheries dynamics in a spatially-explicit, three-dimensional domain.

The Atlantis framework has been developed for the Nordic- and Barents Seas, including the Norwegian Sea (NoBa). A preliminary work on evaluation on multispecies harvest control rules for mackerel in Norwegian Sea was introduced to the group (Annex 8). This work was done by Kaplan and Hansen and a manuscript addressing this is planned to be submitted. Their main findings when running the model for the period 2004–2068 were as follows: Generally, there was <5% change in condition (weight) in mackerel (all cohorts) for the six different scenarios, hence the differences in biomass

between the scenarios was driven by changes in numbers. The HCRs accounting for ecosystem variability resulted in more variation in the stock biomass, as expected. The largest difference in mean biomass was between a HCR with constant flat  $F_{MSY}$  (biomass of ~2.4 million tons) and a HCR with a broken stick  $F_{MSY}$ , accounted for ecosystem variability and where  $F$  was decreased when the zooplankton level dropped below 50% (biomass of ~6 million tonnes).

### 5.3 ToR C Update on Ecosystem overview for Norwegian Sea

The ecosystem overview has been updated (see Annex 7). The content of the OV is otherwise similar to previous version.

### 5.4 Science highlights

#### Oceanographic indices

(Hatun *et al.*, 2017) has demonstrated how SPG variability can affect bloom dynamics in the Norwegian Sea. Silicate observations from the Norwegian Sea show a pre-bloom silicate decline of 1.5–2  $\mu\text{m}$  throughout the winter mixed layer in the period 1990–2015. The decline is attributed to natural multidecadal variability through decreased winter convection depths since the mid-1990s, a weakening and retraction of the SPG and an associated increased influence of nutrient-poor water of subtropical origin. These marked fluctuations in pre-bloom silicate inventories will likely have important consequences for the spatial and temporal extent of diatom blooms, thus affecting ecosystem productivity and ocean-atmosphere climate dynamics in the region.

#### Zooplankton

Northeastward expansion of the Subpolar Gyre results in biologically productive periods in the waters southwest of Iceland (Hatun *et al.*, 2016).

A persistent shift in *Calanus* spp. and zooplankton biomass in the southwestern Norwegian Sea since 2003, related to reduced influx of Subarctic water from the west (Kristiansen *et al.*, 2016, Kristiansen *et al.*, submitted).

A decreasing long-term trend of *C. finmarchicus* in southeastern Norwegian Sea since 2000, with up to 80% reduction. Changes in phenology was observed, with an earlier and shorter peak abundance of *C. finmarchicus*.

(Dupont *et al.*, 2017) presented the spring abundance of adult *Calanus finmarchicus* in the oceanic end of the Svinøy section along the Norwegian coast (bottom depths greater than 1300 m) for 1996–2012. The results indicate at least 50% decrease in abundances over two decades, with maximum abundances in 2000 and minimum abundances in 2011. The statistical analyses suggest that the decline levelled off in 2011–2012, but whether this is the start of a recovery is uncertain as only data up to 2012 are part of the paper.

#### Mackerel

(Pacariz *et al.*, 2016) linked mackerel migration into the Icelandic shelf with silicate and suggest that it is driven by bottom-up processes. During summer, the oligotrophic waters – and thus low prey availability, in the central Iceland Basin, force the mackerel to migrate through a narrow ‘corridor’ along the south Iceland shelf, where nutrients are replenished and both primary and secondary production are higher.

The geographic expansion of mackerel during the summer in the Nordic Seas 2007–2014 has been documented by Nøttestad *et al.* (2016). The publication presents the results from annual swept-area surveys and thereby demonstrates the geographic changes observed this period, with mackerel migrating into Icelandic waters, and later into Greenlandic waters.

Two publications have used the survey data presented in Nøttestad *et al.* (2016) and addressed the mechanisms for the observed expansion of mackerel. Olafsdottir *et al.* (2018) apply simple statistical methods to address specific hypothesis, while Nikolioudakis *et al.* (2018) applied a Bayesian hierarchical spatio-temporal model to identify the factors influencing the geographic distribution of mackerel. Olafsdottir *et al.* (2018) showed that the geographic expansion was strongly correlated to stock biomass, and that the observed changes could not be directly explained by increased water temperatures. Although there is no clear correlation between mackerel expansion and prey abundance, the spatial differences in condition factor for mackerel, indicate that the expansion is driven by prey availability. Nikolioudakis *et al.* (2018) showed that the spatial distribution of mackerel was correlated to temperature, prey availability, longitude and herring abundance.

Two publications have investigated the spawning distribution and how this is related to environmental conditions. (Brunel *et al.*, 2018) showed that bottom depth and spatial location is more important than water temperature and salinity to determine where mackerel spawning is taking place. (Brøge *et al.*, 2016) used a thermal spawning niche model to describe the observed geographic spawning distribution, and to predict the future spawning distribution based on different climate scenarios. The model assumption is that the spawning distribution is a function of temperature and bathymetry, and not geographic position. The predictions for the next decades are a north- and eastwards shift in spawning distribution.

### **Blue whiting**

A study by (Miesner and Payne, 2018) demonstrated that changes in spawning distribution of blue whiting are associated with variations in marine environment, particularly salinity. Blue whiting larvae findings from CPR observations are generally limited to a window of salinities between 35.3–35.5. The high predictability of salinity in the Northeast Atlantic can potentially form the basis for forecasting the spawning distribution of blue whiting.

### **NSS-Herring**

(dos Santos Schmidt *et al.*, 2017) addressed the link between herring condition factor and reproductive capacity. The spawning success in one year is affected by environmental influences, such as food availability, during a period up to four years prior to the spawning. This is due to the fact that the oogenesis occurs several years before the eggs are being spawned.

### **Trophic interactions**

Two studies have focused on the feeding conditions and the interactions between pelagic fish and their prey. The first publication (Bachiller *et al.*, 2016) presented the diet for herring, mackerel and NSS-herring for the years 2005–2010. Although there are interannual variations in the diet, it clearly shows the difference between the species and the seasonal development. The diet overlap is highest between herring and mackerel, with a diet consisting mainly of calanoid copepods. Blue whiting is feeding more on

euphausiids and amphipods. Herring reduce the proportion of copepods in the diet during summer, and thereby also reduce the diet overlap with mackerel.

The results from the study by Bachiller *et al.* (2016) was used to parameterize bioenergetics modelling, where the objective was to estimate the total consumption of the different prey groups by the pelagic fish (Bachiller *et al.*, 2018). The average annual total consumption by the pelagic fish was estimated to 135 million tonnes, with the consumption of copepods accounting for 53–85 million tonnes. It must be emphasized that prey consumed outside the Norwegian Sea is also included in this estimate. However, the results indicate that pelagic fish consume more prey than previously assumed.

### **Integrated trend analyses**

Principal Component Analysis (PCA) is one of the most common multivariate techniques within marine integrated ecosystem assessments. The applications are potentially problematic because basic assumptions of the method are violated when used on time-series that are autocorrelated and/or non-stationary. A study has examined this by comparing results from PCA analyses on datasets used for IEA groups from the Barents Sea, the Norwegian Sea, the North Sea and the Baltic Sea (Planque *et al.*, 2018). The study shows that most of the patterns revealed by the PCA can emerge from random time-series and that the fraction of the variance that cannot be accounted for by random processes is minimal. The Norwegian Sea dataset is a pathological case in which the variance explained by the first two components only exceeds what would be expected from randomly simulated time-series by 2%. It is concluded that outputs from explorative multivariate analyses provide very little insight into ecosystem status, trajectories and functioning and that IEA groups need to be equipped with methods that can provide better insight into how marine ecosystems function, the drivers of their changes and their possible future trajectories.

## **6 Cooperation**

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### **Cooperation with other WG**

The text in section “ecosystem considerations” in the introduction chapter of the WGWIDE report, is largely derived from the WGINOR report on the integrated assessment. In addition to this, the two international ecosystem surveys (IESNS and IESSNS) that are most important source of data for integrated assessment of the Norwegian Sea, provide abundance indices for analytical assessment of the large stocks of NSS-herring and NEA-mackerel. A close cooperation and discussion between WGINOR and WGWIDE in terms of data need and quality is therefore important.

### **Cooperation with Advisory structures**

The work around the ecosystem-based holistic management plan for Norwegian Sea established by Norway and the work within WGINOR benefits and feeds each other. The WGINOR reports and Norwegian members of the group contribute to assessments of the status of the epipelagic ecosystem for the management plan work. Information and assessments made for the management plan contributes particularly to the ecosystem overviews made by WGINOR.

### **Cooperation with other IGOs**

No contributions currently exist.



## **7 Summary of Working Group self-evaluation and conclusions**

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- Despite limitation of resources between meetings that limits the achievements of the group, WGINOR has managed to cover the workplan adequately for the last three years as planned.
- The new ToRs for the WG for the period 2019–2021 are consistent with the ICES Science Plan, signifying the need for the WG continuation.
- Modelling people have been involved in the group but more involvement and stronger connection is required (e.g. exploration within Atlantis and updating Ecopath with Ecosim model for Norwegian Sea and Barents Sea).
- The WG can only do its work if the key expertise exists in the group, in particular expertise on pelagic fish, oceanography, zooplankton and integrating ecosystem analyses and modelling.
- A copy of the full Working Group self-evaluation can be found in Annex 3 to this report.

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## Annex 1: List of participants

Name	Country	Institution	Email
Eydna í Homrum	Faroe Islands	Faroe Marine Research Institute	eydnap@hav.fo
Sólvá Káradóttir Eliassen	Faroe Islands	Faroe Marine Research Institute	solvae@hav.fo
Gudmundur J. Oskarsson	Iceland	Marine and Freshwater Research Inst.	gjos@hafro.is
Hildur Petursdóttir	Iceland	Marine and Freshwater Research Inst.	hildur@hafro.is
Anna H. Ólafsdóttir	Iceland	Marine and Freshwater Research Inst.	anna.olafsdottir@hafogvatn.is
Lísa Libungan	Iceland	Marine and Freshwater Research Inst.	lisa.libungan@hafogvatn.is
Tomas Didrikas	Iceland	Marine and Freshwater Research Inst.	Tomas.didrikas@hafogvatn.is
Héðinn Valdimarsson	Iceland	Marine and Freshwater Research Inst.	hv@hafro.is
Per Arneberg	Norway	Institute of Marine Research	per.arneberg@imr.no
Kjell Utne	Norway	Institute of Marine Research	kjell.utne@imr.no
Cecilie Broms	Norway	Institute of Marine Research	cecilie.thor-sen.broms@imr.no
Benjamin Planque	Norway	Institute of Marine Research	benjamin.planque@imr.no
Mimi Lam	Norway	University of Bergen	Mimi.Lam@uib.no
Tony Pitcher	Canada	University of British Columbia	pitcher.t@gmail.com
<b>By correspondence:</b>			
Elvar H. Hallfredsson	Norway	Institute of Marine Research	elvar.hallfredsson@imr.no
Øystein Skagseth	Norway	Institute of Marine Research	oistein.skagseth@imr.no
Cecilie Hansen	Norway	Institute of Marine Research	cecilie.hansen@imr.no
Anne Kirstine Frie	Norway	Institute of Marine Research	anne.kristine@imr.no
Svein-Håkon Lorentzen	Norway	Norwegian Institute for Nature Research - NINA	svein.lorentsen@nina.no
Tycho Anker Nilsen	Norway	Norwegian Institute for Nature Research - NINA	tycho@nina.no

## Annex 2: Recommendations

Recommendation	Addressed to
1. To provide an updated survey index for the mesopelagic fauna in the Norwegian Sea (Siegelman-Charbit, L., and Planque, B. 2016. Abundant mesopelagic fauna at oceanic high latitudes. Marine Ecology Progress Series, 546: 277-282.)	WGDEEP

### **Annex 3: Copy of Working Group self-evaluation**

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**1) Working Group name.**

Working Group of Integrated Assessment of the Norwegian Sea (WGINOR).

**2) Year of appointment.**

2015

**3) Current Chairs.**

Guðmundur J. Óskarsson, Iceland, and Per Arneberg, Norway

**4) Venues, dates and number of participants per meeting.**

Marine and Freshwater Research Institute, Reykjavik, Iceland, 26-30 November 2018, with 14 participants and 6 by correspondence.

#### **WG Evaluation**

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

The essence of the Science Plan is an integrated assessment of marine ecosystems, which is the focus of WGINOR. Hence, we believe that the products of WGINOR provide a significant contribution to the research prioritize of the Science Plan.

**6) In bullet form, highlight the main outcomes and achievements of the WG since their last evaluation. Outcomes including publications, advisory products, modelling outputs, methodological developments, etc.**

- The dataseries collected by the group on ocean climate, zooplankton, pelagic fish, other fish and seabirds have been updated.
- Qualitative assessments of the state and development of key elements of the ecosystem have been performed, based on the collected dataseries and literature.
- The framework for integrated ecosystem assessment (IEA) has been developed.
  - First, a simulation study showed that results from Principal Component Analyses (PCA) on multiple time-series of the type collected by WGINOR primarily may reflect methodological artefacts and should not be used by the group. Other potential statistical tools have been identified (Dynamic Factor Analysis, DFA, and Structural Equation Modelling, SEM). Recruitment variation of NSS-herring will be used as a case study to validate the application of these methods for this purpose.
  - Second, an approach for the further development of IEA has been outlined. This includes developing a system for ocean climate forecast, methodology for a foodweb assessment, a framework for assessing

warning signals with relevance for management and repeated scoping among stakeholders.

- On the Norwegian side, a scoping process has been run among stakeholders, identifying a number of questions and problems with relevance for management that can be addressed by WGINOR.
- A discussion on the expectations of end-users has been initiated. End-users were defined within ecosystem-based fisheries management and holistic ecosystem-based management. It was also discussed what the needs of end-users may be now and in future. Possible types of questions end-users may have for WGINOR has also been discussed.
- A workshop on the overall dynamics of the pelagic ecosystem in the Norwegian Sea was organized jointly by WGINOR and the EcoNorSe project in Bergen in October 2018.
- Revision of the section “Ecosystem considerations” within the 2018 Working Group on Widely Distributed Stocks (WGWIDE) report was initiated. This was done to make use of the experts in the different fields within WGINOR, which are not attending WGWIDE.
- Presentation and discussions on the various research survey results (e.g. IESNS and IESSNS), recent research papers, research projects have been done made. They are fundamental for advancing the future work of WGINOR as represented by its ToRs.
- Development of modelling work in Atlantis and ENAC to evaluate efficacy of multispecies harvest control rules for the Norwegian Sea has been continued
- A protocol describing krill trawl sampling and analyses of the samples in IESNS (the May survey in the Norwegian Sea) has been prepared in order to standardize the methodology among the participants so the results can be used in a quantitative manner in future.
- The first steps in development of a protocol for sampling and analyses of stomach content of pelagic fish have been taken during the meeting (Annex 4), which will hopefully result in a more standardization and be of advance for comparison between countries.
- A work has started for making a protocol on opportunistic sightings of marine mammals to be used by the participants of the International ecosystem summer survey in Nordic waters.
- Data on zooplankton dry weight from IESNS have been missing in the NAPES database for the years 1995–2007. The estimates in the WGINOR reports for that period have been based on data of low quality and insufficient information about the samples. Consequently, uploading of quality checked data with all relevant information attached was initiated during the 2017 WGINOR meeting and will hopefully be completed in 2019.
- The ecosystem overview has been developed and updated.

**7) Has the WG contributed to Advisory needs? If so, please list when, to whom, and what was the essence of the advice.**

A description from the WGINOR reports on status of key ecosystem- and environmental components in the Norwegian Sea has been used in the WGWIDE reports (2017 and 2018) under the section on “Ecosystem considerations”.



The same parts of the WGINOR report for 2018 will be used when preparing a status report for the Norwegian Sea for the Norwegian ecosystem-based holistic management plan for the Norwegian Sea.

- 8 ) Please list any specific outreach activities of the WG outside the ICES network (unless listed in question 6). For example, EC projects directly emanating from the WG discussions, representation of the WG in meetings of outside organizations, contributions to other agencies' activities.**

WGINOR, in cooperation with a Norwegian research project (EcoNorSe), held a workshop in Bergen, Norway in October 2018 (Dynamics of the Norwegian Sea Pelagic Ecosystem; see Annex 6 in the WGINOR 2018 report).

Two scoping meetings have been held in Norway with participation from fisheries organizations, management bodies, industries and NGOs. The organizations identified several questions and problems that are relevant to them and that may be addressed by WGINOR.

- 9 ) Please indicate what difficulties, if any, have been encountered in achieving the workplan.**

Limitation of resources between meetings (a combination of persons, time and funding) is the main factor limiting the achievements of the group. However, we believe that WGINOR has managed to cover the workplan adequately for the last three years as planned.

## **Future plans**

- 10 ) Does the group think that a continuation of the WG beyond its current term is required? (If yes, please list the reasons)**

The answer is yes because:

The ToRs for the WG are consistent with the ICES Science Plan, signifying the need for the WG continuation.

The WG forms an important research body of international and interdisciplinary scientist focusing on the environment and ecosystem of Norwegian Sea; and as such creates a platform for bringing together knowledge, experience, ideas, data and workload for contributing to and encouraging further development in marine ecology and assessing the human impacts thereon.

- 11 ) 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.**

*(If you answered YES to question 10 or 11, it is expected that a new Category 2 draft resolution will be submitted through the relevant SSG Chair or Secretariat.)*

- 12 ) What additional expertise would improve the ability of the new (or in case of renewal, existing) WG to fulfil its ToR?**

The suggested ToRs for 2019-2021 call for climate scientists for climate projections (e.g. in relation to Ecosystem Overview). An effort will be made to reach that point.

Modelling people have been involved in the group, but more involvement and stronger connection is required (e.g. exploration within Atlantis and updating Ecopath with Ecosim model for Norwegian Sea and Barents Sea).

Possible future inclusion of other parts of the ecosystems in the Norwegian Sea than the epipelagic layer to the ToRs will require additional expertise (mesopelagic, hydro-thermal vent ecosystem).

The WG can only do its work if the key expertise exists in the group, in particular expertise on pelagic fish, oceanography, zooplankton and integrating ecosystem analyses and modelling.

**13 ) 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)**

The work done by the group on collecting information on multiple aspects of the pelagic ecosystem in the Norwegian Sea and develop our understanding of the overall dynamic of the system, is relevant to the advisory processes within WGWIDE. The work is also relevant to other ecosystem assessments done or planned to be done for the area, in particular for the Norwegian ecosystem-based holistic management plan for the Norwegian Sea and OSPAR. The output is however currently in a form where it cannot be easily be used in advisory processes. With the current revisions of the ToRs, the aim is to provide output that can be more readily be used in advisory processes, in particular through the planned work on operational products (on climate forecasts and foodweb assessments) and warning signal assessments.

## **Annex 4: Agenda of the meeting in Reykjavik 2018**

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### **Agenda of WGINOR 26 - 30 Nov. 2018, Marine and Freshwater Research Institute, Reykjavik**

#### **Monday**

10:00 Meeting opens, housekeeping, Introductions, planning (GJÓ and PA).

- Review of the TORs (GJÓ and PA).
- Content of the final report and tasks (GJÓ and PA).

11:30 Presentations:

- **Anna Olafsdottir.** Results from the 2018 International summer survey in the Nordic Seas (IESSNS).
- **Guðmundur J. Óskarsson.** The International Ecosystem Survey in Norwegian Sea (IESNS) in May 2018 and summary of WGWIDE stock assessment results of NSS-herring 2018
- **Øystein Skagseth.** Oceanographic conditions in the Norwegian Sea in 2018.
- **Benjamin Planque.** Methods for integrated trend analyses: update from the WKINTRA workshop held 28 September.

12:30 Lunch at the institute

13:30 Working session on ToRa, full assessment of the state of the ecosystem.

17:00 End of working day

#### **Tuesday**

09:00 **Kjell Rong Utne.** Results from evaluation of multispecies harvest control rules using the ENAC model.

09:45 Working session on ToRb, evaluation on multispecies harvest control rules

11:00 **Hedinn Valdimarsson.** Oceanographic conditions in the western part of the Norwegian Sea.

12:30 Lunch at the institute

13:30 Working session continued on ToRb

14:30 Excursion and end of working day

#### **Wednesday**

09:00 Working session on ToRc, ecosystem overview

12:30 Lunch at the institute

13:30 Working session on ToRc, ecosystem overview

17:00 End of working day.

#### **Thursday**

09:00 Working session on development of WGINOR in the years to come, covering:

- Methods for integrated trend analyses

- Scoping and user needs
- Types of deliverables from the group (e.g. risk assessments, management strategy evaluations etc), following up the discussion started last year.
- Development of time-series.

The session includes the presentation:

- **Benjamin Planque.** Foodweb assessments based on Chance and Necessity modelling

12:30 Lunch at the institute

13:30 Working session on revision of ToRs and working plan for the next three-year period. This includes the presentation:

- **Mimi Elizabeth Lam.** Ecological Model of the Norwegian Sea and Barents Sea: EwE Norbar Model (described in more detail in Annex 9).

17:00 End of working day

#### **Friday**

09:00 Review of report, Working on reporting and any other business

12:15 Lunch at the institute

13:00 Meeting closes.

## **Annex 5: On the further development of the approach for integrated Ecosystem Assessment in WGINOR**

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### **A. Foodweb assessment based on Chance and Necessity modelling.**

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Fish stock assessment is well developed as a tool to support fisheries management. The process of fish stock assessment can be summarized as follows: (a) compile input data on the stock and associated fishery (survey data, landings, catch-at-age, etc.), (b) fit a stock-assessment model (which is a simplified quantitative representation of population dynamics and fisheries), (c) use the model outputs to describe history of the stock and of the fishery (e.g. SSB, recruitment, F) and to forecast the possible development of the stock, conditional on fishing (e.g. projected SSB as a function of F).

In the context of IEA, a similar approach is proposed, which can be applied to foodwebs, namely 'foodweb assessment'. The approach can be summarized in a similar way: (a) compile input data on the multistocks and the associated multi-fisheries (biomasses, catches, etc.), (b) fit a foodweb model (which is a simplified quantitative representation of trophic interactions and fisheries), (c) use the model outputs to describe history of the foodweb (e.g. biomasses, trophic flows) and to forecast the possible development of the various stocks, conditional on fishing.

Multispecies models (e.g. GADGET) or foodweb models (Ecopath with Ecosim) can potentially serve as foodweb assessment models. An alternative is presented here, which is based on chance and necessity modelling (CaN, (Planque and Mullon, Submitted)). With this approach, it is possible to reconstruct plausible foodweb histories based on limited data and a small number of assumptions. The approach is transparent and can be used to support IEA in a participative modelling context (i.e. modelling being jointly performed by scientists, managers and other actors).

### **B. Scoping process in Norway**

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The scoping process in Norway has been based on three sources of information:

- 1 ) A report on knowledge needs for development of multispecies management – Fisheries Directorate, Ministry of Trade, Industry and Fisheries, Institute of Marine Research (Huse *et al.*, 2018);
- 2 ) A scoping meeting with representatives from management, industries and NGOs, held in September 2018;
- 3 ) A scoping meeting with fisheries organizations, held in October 2018.

In the report, the following issues relevant to development of EAFM/EBFM have been identified:

- Quantify predation by mackerel on herring larvae to assess influence on recruitment;
- Assess competition between mackerel and herring for *Calanus finmarchicus*;
- Assess predation of growing populations of marine mammals on herring, mackerel and krill;
- Assess effects of variation in *Calanus finmarchicus* levels on herring recruitment;
- Assess effects on the foodweb from mesopelagic harvesting.

The scoping meeting with representatives from management, industries and NGOs identified the following additional issues:

- There is a need for more precise estimates of pelagic fish stock sizes as a basis for ecosystem analyses;
- Seabirds should be included more regularly in assessments of effects on human activities (e.g. zooplankton harvesting). Also a need to better understand the causes of declines in seabird populations;
- There is a need for better knowledge of marine litter – occurrence and effects – in particular about nano plastics;
- There is a need for better knowledge of effects of variation and change in climate for ecosystem structure and processes.

The scoping meeting with fisheries organizations identified these issues:

- Is there a large effect of climate change on the population dynamics and distribution of *Calanus finmarchicus*?
- Are there changes in the distribution of *Calanus finmarchicus*? If so, does this affect distributions of the fish stocks?
- Is *Calanus helgolandicus* established in the Norwegian Sea? If so, is there an increase? And what are the expectations for this species in future?
- Is the North Sea herring moving northwards?
- What is the diet of saithe and redfish?
- What is the effect of seismic activities on distribution of fish in the Norwegian Sea?
- What are the possible effects of deep-sea mining on the ecosystem in the Norwegian Sea?

### C. A framework for repeated scoping by WGINOR

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Repeated scoping by WGINOR can be done by inviting representatives for relevant management organizations and stakeholders to a section of the yearly WGINOR meeting (e.g. a 2-hour section). Stakeholders from the host country should be invited. When done yearly, this will thus mean that scoping is done every third year in each of the countries Iceland, Faroe Islands, and Norway. The scoping sessions can be organized like this:

- 1) Brief presentation of the scope of WGINOR and the IEA work within ICES.
- 2) Presentations of key results from the work of WGINOR.
- 3) Time for representatives from management and other stakeholders to give input on issues that WGINOR may address to facilitate development of EAFM/EBFM or an ecosystem-based approach to management in general.

#### References:

- Huse G *et al.* (2018) Muligheter og prioriteringer for flerbestandsforvaltning i norske fiskerier. Fisken og havet, 7-2018.
- Planque B, Arneberg P, Handling editor: James W (2018) Principal component analyses for integrated ecosystem assessments may primarily reflect methodological artefacts ICES Journal of Marine Science 75:1021-1028 doi:10.1093/icesjms/fsx223
- Planque B, Mullon C (Submitted) Modelling chance and necessity in natural systems. ICES Journal of Marine Science.

## **Annex 6: Workshop report from Bergen**

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# **Report from the Workshop on Dynamics of the Norwegian Sea Ecosystem**

**Institute of Marine Research, Bergen, 16.-19. October**

Chairs: Per Arneberg and Eydna í Homrum



## Summary

A workshop was held in Bergen October 16-19 2018 with the aim of improving our understanding of the overall dynamics of the pelagic ecosystem in the Norwegian Sea. The workshop was a joint initiative of the ICES group WGINOR and the IMR-led research project 'EcoNorSe' and was attended by 34 participants, representing 4 countries and 6 institutions. The workshop received financial support from the Research Council of Norway.

Presentations were given on the following topics:

- Management needs, based on a scoping process run in Norway
- The scope of WGINOR and the EcoNorSe project
- Key aspects of the physical environment
- The role of the Subpolar Gyre in regulating the pelagic complex
- Primary production
- The relationship between climate variation and zooplankton communities
- Influence of the East Icelandic Current on *Calanus hyperboreus* and *C. finmarchicus*
- Recruitment dynamics of the pelagic stocks
- Mackerel, herring and blue whiting
- Trophic interactions with a focus on the three main pelagic fish stocks
- Key characteristics of the foodweb
- Trophic interactions within the pelagic ecosystem north and south of Iceland
- Climate change effects on the linkages between environmental factors, zooplankton and pelagic fish
- How multivariate time-series can inform about ecosystem processes

The discussions were centred on papers that could be written as an output from the workshop. It was agreed to work further with these papers (working titles)

1. Main physical drivers of the Norwegian Sea ecosystem
2. Effects of bottom-up and top-down processes on production at lower trophic levels in the Norwegian Sea and adjacent seas
3. Changes in the distribution of Mackerel, NSS herring and blue whiting in the Norwegian Sea during the last decades and possible factors governing these changes.

It is aimed to finalize the papers by June 2019.



## Background

A joint workshop was held between the ICES expert group, WGINOR, and the EcoNorSe project members. The aim of the workshop was to outline papers to write on the dynamics of the Norwegian Sea Ecosystem.

The workshop received financial support from the Research Council of Norway, particularly for reimbursement of travel expenses for participants not based in Bergen, Norway.

Preliminary outline-drafts were circulated by 4 lead-authors prior to the meeting.

1. Key aspects of physical environment relevant to understanding overall dynamics.
2. Direct influence of variation in physical environment on biological processes/groups at lower trophic levels.
3. Direct influence of variation in physical environment on recruitment dynamics
4. Overall synthesis, including all biological components (e.g. pelagic fish) and trophic interactions.

The meeting was structured beginning with two half days with introductory presentations on relevant topics. This was followed by two days of working in subgroups on the four planned papers.

The outlined work for the listed papers 1 and 2 was detailed during the workshop. This work followed the initial plan quite closely.

After the first afternoon in subgroup, it was decided that it was not realistic to write a paper on recruitment dynamics (paper 3) within the decided time frame. There is too little material to write a review-paper, and there is not enough manpower /time to acquire and analyse data for a new research paper.

It was decided that the scope of paper 4(which later became paper 3) was too ambitious for the available time frame, and therefore the scope was narrowed and focused as detailed in the outline of paper 3 in this report.

The group decided to aim for submission of papers in June 2019. Most likely the papers will be submitted to ICES Journal of Marine Science.

## Agenda

# Dynamics of the Norwegian Sea Pelagic Ecosystem

Workshop organized by WGINOR and the EcoNorSe project

Bergen 16-19 October 2018

Start with lunch on the 16<sup>th</sup>, end at 14:00 on the 19<sup>th</sup>

Institute of Marine Research – meeting room “Pynten”

Chaired by Per Arneberg (IMR), Eydna í Homrum (FAMRI) and Katja Enberg (UiB)

## Agenda

### 16 October

12 Lunch

13 Workshop introduction

- 13:00 Short presentation on management needs, **Per Arneberg**
- 13:10 Short presentation about WGINOR and the EcoNorSe project, **Gudmundur Oskarsson (invited speaker) and Nikolaos Nikolioudakis**
- 13:30 Short presentation on workshop structure, reporting and papers to be written (see draft list of papers below) **Eydna í Homrum**

The following time-slots are including 5 minutes for questions/discussions

13:40 Introductory talks on the physical environment

- 13:40 “Key aspects of the physical environment in the Norwegian Sea”, **Øystein Skagseth**
- 14:10 “The Subpolar Gyre regulates the pelagic complex”, **Hjálmar Hátún (invited speaker)**

14 :40 Break

15:00 Introductory talks on effects of variation in physical environment on biological components

- Primary production and zooplankton:
  - 15:00 “Relationship between climate variation and zooplankton communities” (also some slides on primary production) **Cecilie Broms**
  - 15: 30 “Influence of the East Icelandic Current on *Calanus hyperboreus* and *C. finmarchicus*” **Inga Kristiansen (invited speaker)**
- 15:50 “Recruitment dynamics of pelagic stocks in the Norwegian Sea”: **Fabian Zimmermann**
- 16:10 Further discussions on presented topics

17 End of day

### 17 October

The following time-slots are including 5 minutes for questions/discussions

09 Introductory talks on pelagic fish stocks, trophic interactions and understanding of overall dynamics of the ecosystem

- 09:00 “Mackerel in the Norwegian Sea” **Kjell Rong Utne**
- 09:20 “Herring in the Norwegian Sea” **Gudmundur Oskarsson** (*invited speaker*)
- 09:40 “Blue whiting” **Jan Arge Jacobsen** (*invited speaker*)
- 10:00 “Trophic interactions with focus on the three pelagic fish stocks” **Nikolaos Nikolioudakis**
- 10:25 “Trophic interaction within the pelagic ecosystem north and south of Iceland” **Hildur Petursdóttir** (*invited speaker*)
- 10:45 Break
- 11:00 “Climate change effects on the linkages between environmental factors, zooplankton and pelagic fish in the Norwegian Sea” **Lisa Libungan** (*invited speaker*)
- 11:20 “Foodweb of the Norwegian Sea” **Hein Rune Skjoldal** – (to be confirmed)
- 11:40 “How can multivariate time-series inform about ecosystem processes? methodological considerations” **Benjamin Planque** (*invited speaker*)
- 12:00 Further discussions on presented topics

13 Lunch

14 Break into 4 groups, working with the 4 papers

17 End of day

19 Group dinner at Wesselstuen

## 18 October

09 Short presentations of the 4 papers (to check that they are coordinated)

10:30 Group work with papers continues

12 Lunch

13 Group work with papers continues

15 Presentation of papers and discussion of them, starting with paper 4 (see below), then papers 1, 2 and 3

17 End of day

## 19 October

9 Presentation and discussion of papers continues

12 Lunch

13 Wrap up

14 End of workshop

## Draft list of papers

We aim at writing 4 papers from, reflecting the structure of the workshop:

1. Key aspects of physical environment relevant to understanding overall dynamics.
2. Direct influence of variation in physical environment on biological processes/groups at lower trophic levels.
3. Direct influence of variation in physical environment on recruitment dynamics
4. Overall synthesis, including all biological components (e.g. pelagic fish) and trophic interactions.

### **Budget, costs and funding**

#### **Budget and costs**

<b>Item</b>	<b>Budget</b>	<b>Cost</b>
Preparation of workshop	130 000	190 000
Travel and accommodation for international presenters	130 000	72 216
Travel and accommodation for national presenters	30 000	25 159
Lunch and refreshments	40 000	38 087
Sum	330 000	325 462
<b>Funding Source</b>	<b>Amount</b>	
The Research Council of Norway	100 000	
Institute of Marine Research	225 462	

### Confirmed participants and designation to groups

Name	Group	Institution
Anne Kirstine Frie	4	Institute of Marine Research
Antonio Bode	4	Instituto Espanol de Oseanografia
Benjamin Planque	4	Institute of Marine Research
Cecilie Broms	2	Institute of Marine Research
Cecilia Kvavik	4	Marine and Freshwater Research Institute, Iceland
Eneko Bachiller	4	
Eydna í Homrum	4	Faroe Marine Research Institute
Gro I. van der Meeren	4	Institute of Marine Research
Guðmundur J. Óskarsson	3,4	Marine and Freshwater Research Institute, Iceland
Hans J. Skaug	4	University of Bergen
Hein Rune Skjoldal	2, 4	Institute of Marine Research
Hildur Petursdottir	2	Marine and Freshwater Research Institute, Iceland
Hjalmar Hátún	1	Faroe Marine Research Institute
Inga Kristiansen	2	Faroe Marine Research Institute
Jan Arge Jacobsen	3,4	Faroe Marine Research Institute
Katja Enberg	3,4	University of Bergen
Kjell Rong Utne	4	Institute of Marine Research
Kjell Arne Mork	1	Institute of Marine Research
Knut Yngve Børsheim	2	Institute of Marine Research
Lisa Libungan	2, 4	Marine and Freshwater Research Institute, Iceland
Mette Mauritzen	4	Institute of Marine Research
Mimi Lam	4	University of Bergen
Morten Skogen	2	Institute of Marine Research
Nikolaos Nikolioudakis	4	Institute of Marine Research
Per Arneberg	4	Institute of Marine Research
Richard Nash	2,3	Institute of Marine Research
Webjørn Melle	2	Institute of Marine Research
Øystein Skagseth	1	Institute of Marine Research
Øyvind Fiksen	2	University of Bergen
Ina Nilsen	4	Institute of Marine Research
Fabian Zimmermann	3	Institute of Marine Research
Olav Kjesbu	3	Institute of Marine Research
Maik Tiedemann	3	Institute of Marine Research
Martina Stiasny	3	Institute of Marine Research

## Presentations

### Presentation about management needs, Norwegian perspectives

**Presented by Per Arneberg, co-chair, Institute of Marine Research, Tromsø, Norway**

Documents and a scoping process give information on several knowledge needs for management of the Norwegian Sea. A report on knowledge needs for multispecies management was prepared jointly by the Institute of Marine Research, the Fisheries Directorate and the Ministry of Trade, Industry and Fisheries and published in June 2018 (Huse et al. 2018). Identified knowledge needs relevant to the Norwegian Sea includes predation from mackerel on NSS herring and blue whiting larvae (effects on recruitment), predation on *Calanus finmarchicus* from mackerel and herring (competition), effect of variations in occurrence of *Calanus finmarchicus* on herring recruitment, predation on herring, krill and mackerel from growing populations of whales and seals and effects on the foodweb of harvest of mesopelagic species. A scoping process where stakeholders from management institutions, industry organizations and a few NGOs gave input identified the additional needs: Better assessments for the situation of seabirds, in particular a need to better understand the causes of the declines in many populations; better knowledge of occurrence and effects of marine plastic litter; better understanding of the effects of variation/change in climate on ecological processes and need for more precise stock assessments as a basis for ecosystem analyses. After the presentation was given, additional input from fisheries organizations in this scoping process has emerged. The additional knowledge needs identified here are: What is the diet of saithe and beaked redfish; is there a large effect of climate change on population dynamics and distribution of *Calanus finmarchicus*; is *Calanus helgolandicus* found in the Norwegian Sea now and what are the expected changes in the *Calanus* complex in the years to come; are there differences in the distribution of *Calanus finmarchicus* and will any such changes affect the distributions of the fish stocks; is the distribution of the North Sea Herring being shifted northwards; what is the effect of seismic exploration on the distribution of fish in the Norwegian Sea; what are the possible effects of deep-sea mining in the Norwegian Sea.

### Physical drivers of the Norwegian Sea ecosystem

**Presented by Øystein Skagseth, Institute of Marine Research, Bergen, Norway**

The purpose of this work is to present the observed variability of (bio)physical environment the Norwegian Sea, both driven by direct atmospheric forcing and by circulation changes in the subpolar North Atlantic and the East Icelandic Current. We divide this into physical forcing/variability linked to the recruitment and to the habitat / feeding condition for the adult stock.

### The Subpolar Gyre regulates the pelagic complex

**Presented by Hjálmar Hátún (*invited speaker*), Faroe Marine Research Institute**

The subpolar North Atlantic Ocean is characterized by its rich ecosystems – rapid spring blooms, vast energy-rich zooplankton stocks, huge migratory pelagic fish stocks, large seabird colonies and highly productive demersal fish stocks on the shelves

surrounding the oceanic basins. Upwelling of nutrients is the most crucial prerequisite for biological productivity, but while this fact is plainly evident at lower latitudes, its importance for the mid-latitudes has been somewhat overlooked in the literature.

The strong atmospheric jet stream, and its associated intense low pressure systems which traverse the subpolar waters, induces cooling and deep-water formation and this fuels a huge volume of water with nutrients every winter. This established the oceanographic feature called the *Subpolar Gyre* - a large body of cold and low-saline Subarctic water, which circulates anticlockwise south of Iceland and Greenland.

This presentation revolved around the Subpolar Gyre, with focus on the northeastern Atlantic. It was illustrated how the size and circulation intensity of this gyre regulates temperature, salinities, nutrient concentrations, the abundance key zooplankton species, stock sizes spawning distribution and feeding migration routes of pelagic fish stocks (blue whiting, mackerel and herring). Some speculations were also made towards the recruitment to the blue whiting stock. I have brought in large-scale indices like the *gyre index* to collectively discuss key trends in several components of this vast pelagic complex.

A simple schematic of the Norwegian Sea was presented, allowing a discussion on how key ecological indicators can be achieved from available observations and simulations. The influence from the East Icelandic Current – an issue identified and emphasized more than a century ago by Helland-Hansen and Nansen – was brought back to the arena.

### **Primary production in the Norwegian Sea**

**Presented by Cecilie Broms on behalf of Yngve Børsheim, Institute of Marine Research, Bergen, Norway**

To estimate the annual primary production in the Norwegian Sea, estimates of net primary production (NPP) from the Vertically Generalized Production Model (VGPM, Behrenfeld and Falkowski, 1997) were downloaded from [www.science.oregonstate.edu](http://www.science.oregonstate.edu). Annual primary production was estimated by integrating the production time-series from each grid cell throughout the productive season (Børsheim et al. 2014). NPP calculations with the VGPM require the following input data fields, which is given by the satellite MODIS: chlorophyll a, photosynthetically active radiation, sea surface temperature, and daylength.

The annual primary production was estimated in to areas in the Norwegian Sea: The Lofoten Basin and the Southern Basin. There was considerable interannual variation in total annual primary production in both areas. The difference between the two basins was not significant. The mean annual primary production in the Norwegian Sea was 14.3 mol C m<sup>-2</sup>year<sup>-1</sup>, and the production varied between 10.6 and 18.1 mol C m<sup>-2</sup>year<sup>-1</sup>

### **Relationship between climate variation and zooplankton communities**

**Presented by Cecilie Broms, Institute of Marine Research, Norway**

The presentation “effects of climate variations on zooplankton communities” showed some of the long-term trends and variations that has been found in plankton communities in the Northeast Atlantic with focus on the Norwegian Sea, and what environmental factors and climate variations that can influence these changes. Several studies have been carried out in the Northeast Atlantic based on data sampled with the Continuous Plankton Recorder (CPR). Beaugrand et al. (2002) documented a change in the biogeography of copepods between 1960 and 1999 where warm-water species moved poleward and Subarctic and Arctic species in among others the North Sea decreased. This change in biogeography was related to the Northern Hemisphere Temperature (NHT) and the North Atlantic Oscillation (NAO). A somewhat contradictory signal was found from CPR data in the southeastern Norwegian Sea in a to some extend overlapping period from 1949 to 1981 (Aβmus et al. 2009). In that study the large copepods *Calanus* spp and *Metridia lucens* had a constant abundance except for the last few years where a decrease was observed, while small copepods and phytoplankton strongly decreased in abundance throughout the period. Wind direction was the only environmental factor related to the change in the plankton, and a suggestion that northerly winds changed the water mass distribution so that the southern Norwegian Sea became more influenced by Norwegian Coastal water and less by Arctic water was put forward. A possible disadvantage using CPR is that the sampling is carried out only at ca 7 m depth. Long-term trends investigated from WPII-net samples indicated different trends in the southeastern Norwegian Sea (Svinøy transect) and an area close to shore in Skagerrak (Station Arendal 2) in the period 1994/1996-2012. Concerning *Calanus finmarchicus* in Skagerrak no uni-directional trend was found (ongoing study), while in southeastern Norwegian Sea *C. finmarchicus* was reduced by 50-80 percent (Dupont et al. 2017). A change in phenology of *C. finmarchicus* was found in southeastern Norwegian Sea, where the timing of the peak abundance was 4 days earlier and 3 days shorter in 2012 compared with 1996. Ongoing basin-scale studies in the Norwegian Sea indicate a decrease in the total zooplankton biomass. Analysis of long-term trends vs. year-to-year variations (detrended data) can show different results regarding which environmental factors that influence the plankton community.

**Influence of the East Icelandic Current on *Calanus hyperboreus* and *C. finmarchicus***  
**Presented by Inga Kristiansen (invited speaker), Faroe Marine Research Institute**

North of the Faroe Islands, hydrography and zooplankton have been monitored in May along the so-called Section N, which extends through Atlantic water, crosses the Iceland-Faroe Front (IFF), and into the Subarctic waters within the south-western Norwegian Sea (Kristiansen et al., 2016). Within the Subarctic region, the abundance of *C. hyperboreus* has varied consistently with the volume of Modified East Icelandic Water (MEIW) through the period 1994-2016. An abrupt reduction occurred in both variables in 2003, which have since remained lower compared to the previous years. We therefore suggest that the abundance of *C. hyperboreus* can be used as indicator species of biogeographic shifts caused by the shifting water mass boundaries. A comparable post-2003 reduction is also observed in the overwintered stages of *C. finmarchicus* (Kristiansen et al., 2016). This persistent change suggests that a portion of the overwintering *C. finmarchicus* population is advected from the Iceland Sea, together with *C. hyperboreus*. Around 2003, the zooplankton biomass, collected during the ISNES survey in May, was also much reduced within northeast of Iceland and has also remained low. This indicates that Section N may also be influenced by zooplankton changes further upstream.



Based on salinity and temperature characteristics, the eastward extension of the EIW tongue towards Section N, shows variability (Kristiansen et al., submitted). In the early 2000s, this leakage of MEIW spread far into the south-western Norwegian Sea. In 2003, the eastward extension did not cross section N. This 2003 event coincided with atmospheric changes from an anticlockwise to clockwise wind pattern, which also caused the Norwegian Sea gyre to weaken its cyclonic pattern. This has probably contributed to the pronounced oceanographic changes and likely caused the biological changes to first occur downstream at Section N, followed by further upstream the following year. Such zooplankton shifts likely impact the extensive feeding migration of the large herring stock to this region.

### **Recruitment dynamics of pelagic stocks in the Norwegian Sea**

**Presented by Fabian Zimmermann, Institute of Marine Research, Norway**

Recruitment dynamics are the combined result of environmental and ecological factors that affect the spawning stock and its reproductive output as well as the growth and survival of spawned eggs until recruitment. The physical environment is the underlying driving force that affects many of these processes and thus causes variation in recruitment, specifically through direct effects on the spawning distribution and the subsequent transport and survival of early life stages, but also as a driver of ecosystem productivity. The three major pelagic stocks in the Norwegian Sea are highly migratory and widely distributed, with spawning and nursery areas largely in waters outside the Norwegian Sea: Norwegian spring-spawning (NSS) herring spawns along the Norwegian coast, from where the eggs and larvae drift into the fjords and, the larger fraction, into the Barents Sea, whereas the spawning areas blue whiting and Atlantic mackerel are found west of the British Isle. Mackerel, however, has a much more extensive spawning distribution, stretching into the Bay of Biscay and the Iberian coast in the South and in recent years as far north as Iceland, and with an additional spawning component in the North Sea. The wide spatial and temporal spawning distribution increases the complexity of recruitment dynamics in mackerel and may explain why little is known about physical or ecological drivers. The spawning distribution itself appears to be linked mostly to bottom and mixed layer depth, while there are indications that link recruitment success to copepod production and turbulent mixing. In blue whiting, recent studies show that the spawning distribution is likely defined by temperature and salinity regimes that are determined by the Subpolar Gyre mode (Hatun et al 2005; Hatun et al 2009; Payne et al. 2012). This may also affect larval survival, as spawning location in combination with oceanographic and wind conditions determine whether larvae drift north- or southward. The direction of larval transport has consequences for the spatio-temporal overlap with zooplankton and predators, especially mackerel, which can cause substantial mortality. In contrast, the spawning distribution and larval dispersal in Norwegian spring-spawning herring is more clearly defined and comparatively well-studied. Nevertheless, the large year class variability of NSS herring has remained enigmatic, although a range of explanations have been proposed since Johann Hjort's seminal work on this stock's dynamics. Generally, it is assumed that recruitment success is strongly affected by the properties of the Norwegian coastal current, which are shaped by the windstress along the coast and freshwater inflow. This determines the conditions that early life stages experience during their drift to the nursery grounds and the spatio-temporal overlap with zooplankton abundance and possibly predation. Additional factors are likely the condition of the spawning stock

following the feeding conditions in the Norwegian Sea and predation mortality on the nursey grounds, where juvenile NSS herring typically remain for around 3 years. In conclusion, the recruitment dynamics in all three pelagic stocks are complex and far from fully understood, however, it is clear that the physical conditions and therefore the variations in ocean circulations are highly relevant to their spawning distributions and the survival of early life stages.

### **Mackerel in the Norwegian Sea**

**Presented by Kjell Rong Utne, Institute of Marine Research, Norway**

There is a high uncertainty around the estimated historic mackerel biomass. This is due to unreliable commercial catches before year 2000, short fishery independent time-series used in the assessment and contradicting trends in these series. There has been a large geographic expansion of the feeding habitat for mackerel since year 2007. A recent paper by Olafsdottir et al. (2018) indicate that this is not due to water temperature, as there are no significant changes in temperature before and after the expansion started. Indirect measurements (for instance spatial differences in weight at age) indicate that the expansion is caused by an increasing stock size and limited abundance of prey. This expansion did not happen in the 1980ies, although the mackerel stock is predicted to be at the same level at that time. The underlying cause for the limited prey abundance is not known, but can be caused by reduced production due to bottom-up driven processes, or due to increased interspecific competition with large stocks of NSS-herring and blue whiting. Recruitment of mackerel has since 2001 in average been better than recruitment in the 1990ies. The dynamics and drivers of recruitment isn't fully understood. Brunel et al. (2018) indicate that temperature is not a main driver for the spawning distribution. Bruge et al. (2016) indicate that spawning will shift northward and westward with future climate changes, but the statistical approach applied in the paper can be questioned. In recent years have there been an explosion of juvenile mackerel along the Norwegian coast, something that indicate that spawning has expanded northwestward in the recent 2-3 years. This is supported by preliminary model results of mackerel larvae drift, which indicate the egg released at the traditional spawning locations will not end up as larvae along the northern Norwegian coast.

### **Herring in the Norwegian Sea**

**Presented by Gudmundur Oskarsson (*invited speaker*), Marine and Freshwater Research Institute, Iceland**

The presentation summarized some of the relevant features and results on stock assessment and research on Norwegian spring-spawning herring, which were considered to be of relevance with respect to the objectives of the workshop. These included:

- The dynamic of the stock size, recruitment and the fisheries for the period 1950-2018, based on stock assessment and recent recruitment surveys.
- Changes in the feeding migration, spatial distribution and duration on the feeding grounds for the period 1995-2018, beside potential changes in the overwintering grounds of the stock.
- Recent studies on feeding habits and trophic interaction of the stock to other pelagic were presented, beside of providing some overview on ongoing activity in these studies.

- Recent and ongoing studies on interannual variation in body condition and reproductive potential of the stock were presented. It included a study covering the entire feeding period of the stock for 1996-2018.
- An short overview on recent and ongoing studies on stock's identity and discrimination between herring stocks, with relevance to this herring stock.

### **Blue whiting in the Northeast Atlantic**

**Presented by Jan Arge Jacobsen (*invited speaker*), Faroe Marine Research Institute**

The current system in the Northeast Atlantic is characterized by inflow from upstream areas carrying warm Atlantic Water from southwest and south into the Nordic Seas and northern basin of the North Atlantic where it meets the cold East Icelandic Current Water (EICW) from northwest forming frontal regions in the Norwegian Sea creating favourable conditions for nutrient fluxes and plankton growth, and thereby for fish preying on plankton.

The three major pelagic stocks in the Northeast Atlantic use the Nordic Seas area during their summer feeding migration phases. Post-spawning blue whiting and mackerel enter the area from the south, and post-spawning Norwegian spring-spawning herring from east. The horizontal overlap may be extensive but blue whiting is usually distributed in the deeper layers below the herring and mackerel.

Blue whiting is distributed throughout the whole area mainly confined to the shelf areas and in the deeper layers in the Norwegian Sea. The fishery for blue whiting is concentrated to the first quarter of the year, with a prespawning fishery in the Faroe-Shetland Channel, a spawning fishery west of Ireland (Porcupine Bank area) and west of the British Isles and a post-spawning fishery in the southern part of the Faroe zone in May. In recent years the main fishery has been conducted in March-April as opposed to Apr-May earlier. Also there has been a gradual decrease in the proportion taken in the latter half of the year.

The recruitment of blue whiting have been postulated to depend on the strength of the Subpolar Gyro (SPG) (Hátún et al. 2017) with high recruitment in years with a weak SPG and vice versa. The mechanism behind is the larger spawning area available (both the Porcupine Bank area and the Rockall/Hatton Bank area) due to warmer water in weak SPG situations and therefore better survival of the offspring (the causal mechanisms behind the increased survival are not known).

There might be a predation by mackerel on blue whiting larvae in the area west of the British Isles during spawning time of the mackerel (mackerel spawn later than blue whiting). There is likely an overlap between the blue whiting larvae and mackerel in the early juvenile phase of blue whiting, and pending on the locations of the spawning blue whiting, the potential predation effect is likely to vary with the aforementioned changes in the spawning areas as a results of environmental changes (Payne et al. 2012). This hypothesis has not been tested with follow-up investigations so far.

The question whether several (at least two) spawning populations of blue whiting exists in the main spawning areas has been put forward recently by Pointin & Payne (2014). To date it is not known whether this is the case.

The blue whiting recruitment seems to be characterized by two production levels evident from the recruitment plot from the 2018 assessment (ICES 2018). One such "high" level period was from around 1995 to 2005, and Hátún et al. (2017) postulated that the strength of the SPG might be the (physical) factor influencing the apparent levels in the recruitment (see above).

The geographical extent of the stock is related to stock size, when the stock is large the distributions is also extensive reaching to the shelves along Eastgreenland and north to the Troms area off Norway. Conversely when the stock is small the distribution is confined to the eastern shelves in the area.

The large changes in the spatial distribution of blue whiting has led to varying partial distributions in the various national (EEZs) and international zones with time. This has caused problems in the management of the stock, as the Coastal States have not been able to agree on a fixed share of the total allowable catch, with the result of overfishing the stock.

### **Trophic interactions with focus on the three pelagic fish stocks**

#### **Presented by Nikolaos Nikolioudakis, Institute of Marine Research, Norway**

An overview of the trophic interactions in the Norwegian Sea ecosystem was prepared and presented to the workshop participants. Based on the simplified foodweb presented initially in Skjoldal (2004), recent knowledge since then was summarized, mainly focusing on the diet and trophic interactions of the three main pelagic fish stocks, namely NEA mackerel, Norwegian spring-spawning herring and blue whiting. The diets of herring and mackerel are quite similar to both feeding mainly on calanoid copepods. Herring shifts towards larger prey in summer, showing also a more prolonged feeding period compared with our past knowledge. Blue whiting on the other hand always relies on larger prey compared to the other two species. Additionally, all species were found to have increased feeding incidence when in Arctic waters masses. The main differences in prey are also largely attributed to the differences in the vertical positioning of the three species given blue whiting's deeper positioning in the water column. The large expansion of NEA mackerel during the last decade is potentially exerting pressure on herring as they largely share the same prey fields. However, the latest modelling simulations support that the three species are able to coexist in the area under the current plankton availability. Moreover, the total consumption of zooplankton appears to exceed previous estimates, with herring and mackerel requiring x10 and blue whiting x6, their biomass in zooplankton prey, respectively. Another important aspect that was considered was the potential impact of mackerel's overlap with early life stages of herring, that remains understudied, as well as the impact of higher trophic level predators (e.g. marine mammals, seabirds) on the biomass of the three stocks. Considering all the above, the questions to be addressed to synthesize the existing knowledge were discussed among the workshop participants.

#### **Foodweb of the Norwegian Sea**

**Presenter: Hein Rune Skjoldal**

The foodweb in the Norwegian Sea can be regarded as both simple and complex. It is simple in the sense that there are relatively few dominant or key species which convey much of the energy flow in the system. It is complex because there are many connections and combinations of routes the energy flow may take on its way from sunlight to top predators and human harvest in fisheries. We measure the total complex of zooplankton as dry weight biomass in three size fractions. The (predominantly) herbivorous *Calanus* species dominate the mesozooplankton biomass, which constitute food for the three species of planktonktivorous pelagic fish (herring, mackerel, blue whiting). Density-dependent interactions between zooplankton as food, and growth and condition of the pelagic fish as predators, are important to address in analysis of the dynamics of the Norwegian Sea ecosystem.

Some examples on variation of zooplankton biomass in the Barents Sea were presented. For this ecosystem, zooplankton biomass in three size fractions and their total sum have shown temporal and spatial patterns in relation to climate variability and change (the Barents Sea has warmed by nearly 2°C since 1980) and fluctuations in the capelin stock. Similar analysis should be done with size-fractioned biomass data from the Norwegian Sea. The largest size fraction (>2 mm) has shown a recent decline in the Barents Sea, which may be an advected signal from the upstream Norwegian Sea reflecting increased predation on large zooplankton by pelagic fish in this ecosystem.

**Trophic interaction within the pelagic ecosystem north and south of Iceland**

**Presented by Hildur Petursdóttir (*invited speaker*), Marine and Freshwater Research Institute, Reykjavík, Iceland)**

The waters south and north of Iceland vary greatly both oceanographically and biologically with the rather stable and warm Atlantic waters south and west of Iceland and the more variable and cold Arctic and Subarctic waters, north and east of Iceland. The aim of this study was to increase the knowledge of the role of *Calanus* copepods and trophic relations of the key components of the oceanic ecosystems south-west (over the Reykjanes Ridge) and north (in the Iceland Sea) of Iceland. The trophic relationships and energy transfer to higher trophic levels were estimated by using fatty acid trophic markers, by comparing fatty acid profiles among species and by applying stable isotopes of carbon and nitrogen. The energy rich *Calanus* species are key links between primary producers and higher trophic levels in the Icelandic waters. The *Calanus* species dominate the zooplankton biomass around Iceland and their markers (20:1n9 and 22:1n11) are found in high amount in animals at higher trophic levels. *Calanus finmarchicus* plays important role as a forage species in the Atlantic water south-west of Iceland while its high importance is replaced by the larger lipid rich *C. hyperboreus* in the Arctic and Subarctic waters north of Iceland. Although *Calanus* based foodweb is the main driver in both areas, there exist a pathway where *Calanus* species are of less importance and the energy is channeled via euphausiids to higher trophic levels. Around four trophic levels were observed in the two oceanic ecosystems where adult fish occupied the highest trophic levels. Over the Reykjanes Ridge vertically migrating mesopelagic fish, in pronounced deep-scattering layers, are actively bringing energy to

deeper layers by feeding on *C. finmarchicus* in the upper layers. In the Iceland Sea comparable deep-scattering layers were not observed.

### **Climate change effects on the linkages between environmental factors, zooplankton and pelagic fish in the Norwegian Sea**

**Presented by Lisa Libungan (*invited speaker*), Marine and Freshwater Research Institute, Reykjavík, Iceland**

The ocean ecosystem east of Iceland, the western part of the Norwegian Sea, is characterized by dramatic conditions, where cold and low saline polar currents from the north meet warm and saline currents from the south. The Marine and Freshwater Research Institute in Iceland has monitored the oceanic region east of Iceland in detail for the past decades with regards to hydrography, zooplankton and pelagic fish. Here, we focus on two oceanic subregions east of Iceland over a 22 year period (1995-2017) where the sea temperature was higher during the latter half of the period. We attempt to answer the following questions: (1) Has the species composition, abundance and development of zooplankton changed over the past 22 years (1995-2017)? (2) Are there interactions between environmental factors, development and abundance of zooplankton and the abundance and migration pattern of herring? (3) Does the composition and abundance of zooplankton in the ocean reflect the food items which herring prey on?

The results of this study will provide a novel understanding on the linkages between the migration behavior and feeding ecology of herring and the zooplankton community structure. Increased knowledge of zooplankton, which play a vital role in marine foodwebs and their interactions with the environment and inhabiting pelagic fish stocks, is fundamental to predict changes in the marine ecosystem by using ecosystem models.

### **How can multivariate time-series inform about ecosystem processes? Methodological considerations**

**Presented by Benjamin Planque (*invited speaker*), Institute of Marine Research, Norway**

Apophenia is the ‘universal human tendency to seek patterns in random information’. Although critical for human adaptation in the face of unknown – yet recognizable – circumstances, apophenia can be a serious problem when investigating patterns in complex ecological datasets.

Principal Component Analysis (PCA) has been the most common multivariate analysis used for trend analysis in marine integrated ecosystem assessments (IEA), and the method has been used widely in ICES IEA groups to summarize the dynamics of marine ecosystems. In a multivariate time-series simulation study, Planque and Arneberg (2018) showed that the patterns revealed by PCA could likely have emerged by chance, a clear case of apophenia. Therefore, the results of PCA analyses, though not ‘wrong’ were uninformative and the conclusion of this study is that outputs from PCA provide very little insight into the marine ecosystem status, trajectory and functioning.

IEA groups need to be equipped with methods that can provide better insight into how marine ecosystems function, the drivers of their changes and their possible future trajectories. Multivariate Autoregressive Models (MARs) - including Dynamic Factor Analysis (DFA) - and Structural equation modelling (SEM) are possible candidates.

The performance of these numerical methods can be assessed *a priori* by checking that they are appropriately used, following their underlying assumptions and domain of application. However, it is necessary to evaluate the methods performance for specific application to large marine ecosystems datasets. It is proposed that this can be achieved by using specifically designed simulated datasets. This simulation-based evaluation follows the approach used by Planque and Arneberg (2018) and has been used in other context for the evaluation of Multivariate Auto Regressive Models (MARs, Certain et al., 2018) or the retrieval of causal relationships from multiple time-series (Runge 2018). It is also consistent with earlier work by ICES (1993) and NOAA (Anonymous, 1998) for evaluating the performance of stock assessment models. The ICES Working Group on Integrated Trend Analyses in Support to Integrated Ecosystem Assessment (WKINTRA) is working on this specific topic.

Once the methods are evaluated on appropriate datasets, they can hopefully be used to inform about ecosystem processes.

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## Outlines of planned papers

### Paper 1: Tentative title; Main physical drivers of the Norwegian Sea ecosystem

#### East Icelandic Current

- Define the characteristic of the EIC based on the Icelandic sections  
Invite: Hedin: T,S, Nitrat, silikat analyse av Islandshavet (kontakt: Øystein/  
Hjalmar Island midt nov)
- Combine with hydrographic section FaroeN and Svinoy section to resolve the  
influence in the sothern Norwegian Sea.

Hjalmar/Inga: measured of MEIW *Time: End of november*

Kjell Arne: Svinøy *Time: End of november*

- From gridded hydrographic data (May) perform volumetric analysis: defini-  
tion of water masses for discussion

Kjell Arne/Hjalmar: basert på snittanalyse

#### Biological relevance

- Import of cold water zooplankton
- Import of nutrient rich water

#### Frontal position in Norwegian Sea/ Interface between Arctic/Atlantic water

- Frontal position can be calculated from: hydrographic sections, Hjalmar / Kjell  
Arne koordinerer: *Time: End of november*
- Spatially: ssh (EKE, variance of ssh), ssheof analysis, Øystein/Leon *Time: End  
of november*
- hydrographic gridded May data, (avventer -
- satellite SST, mulig å kontakte Peter Miller (2.runde)
- nutrients (norske data odv,ok) 1994-2018: *andre fase*
- andremuligheter ..

#### Biological relevance

- Elevated production,
- A border between Atlantic (dessert) and Subarctic waters
- Zooplankton / Fish
- 

#### The Norwegian Sea gyre circulation

- From satellite ssh maybe combined with hydrographic data: Øystein/Leon  
*End of november*
- Overflow series as index of the gyre,: Hjalmar

- Atmospheric forcing of the gyre, area integrated windstress curl (model): Øystein/Leon
- NEMO bottom currents; sml mot ADCP Farø : *End of Nov.* Hjalmar,
- evt koble NEMO felter med Norwecom
- Floats (ARGO, RAFOS?)

#### Biological relevance

- Norwecom simulations

## **Paper 2: Effects of bottom-up and top-down processes on production at lower trophic levels in the Norwegian Sea and adjacent seas**

Authors: Cecilie Broms, Hein Rune Skjoldal, Hildur Petursdottir, Inga Kristiansen, Knut Yngve Børsheim, Lisa Libungan, Morten Skogen, Richard Nash, Webjørn Melle, Øyvind Fiksen (in random order)

**Keywords:** Norwegian Sea, physical variations, zooplankton, primary production

### **Abstract**

#### **1. Introduction**

The zooplankton biomass and abundance of *Calanus* spp. in the Norwegian Sea has been strongly reduced the last two decades. Basin-scale studies have shown a decreasing long-term trend of the total zooplankton biomass in all parts of the Norwegian Sea (WGINOR annual report, 2017; Zuur et al., in progress). Studies in the southern Norwegian Sea have found a sharp decrease in *Calanus* spp. both in eastern and western areas (Kristiansen et al., 2016, Dupont et al., 2017).

Several studies have suggested that variations in the subpolar gyre influence the biological productivity in the Northeast Atlantic, and that inflow of Arctic water into southwestern Norwegian Sea influence the zooplankton community (Hátún et al., 2016, Kristiansen et al., 2016). A reduction in zooplankton biomass, in *Calanus finmarchicus* and *C. hyperboreus* abundance, and a phenological shift in *C. finmarchicus*, have been observed in southwestern Norwegian Sea and linked to reduced inflow of the cold and less saline East Icelandic Water of Arctic origin from the west (Kristiansen et al., 2016; Kristiansen et al., submitted).

Simultaneous as the zooplankton biomass in the Norwegian Sea is reduced, the total stock size of the pelagic planktivorous NSS herring, NEA mackerel and blue whiting, is at a historic high level. Their annual consumption of zooplankton has been estimated to 135 million tonnes, higher than previously assumed. It has been suggested that the biomass of pelagic fish in the Norwegian Sea have been close to or above the carrying capacity for some time, based on, among others, *Calanus* spp. production-estimates of 290 million tonnes (Skjoldal et al., 2004; Huse et al., 2012). Due to their high abundance they can potentially have a strong ecological impact on the ecosystem.

The main aim of this study is to identify key processes influencing the production in the Norwegian Sea and adjacent seas. To identify important processes influencing the plankton biomass and production, both bottom-up and top-down processes are examined.

The bottom-up hypotheses are:

1. Is the inflow of Arctic water into the southern Norwegian Sea governing the zooplankton production?

In open sea areas, the consumption of nitrate is directly related to the amount of phytoplankton produced within a growing season. Thus, an assumption for the first hypothesis is that Arctic water flowing into the Norwegian Sea contains more nutrients than Atlantic water and thus will increase the nutrient concentrations in this area. If this assumption is not fulfilled, other processes linked to the inflow of Arctic water and

a change in the position of the Arctic front must result in increased nutrient concentrations. The present paper and paper 1 will examine the nutrient concentrations in different water masses in the Norwegian Sea.

Because the nutrient situation in the southern Norwegian Sea is not yet clear, a second hypothesis is put forward to challenge the first hypothesis:

2. The mixing of Atlantic and Arctic water masses in the Norwegian Sea gyres is governing the plankton production in the Norwegian Sea.

Questions raised are: Can circulation within the Norwegian Sea gyre and Lofoten gyre influence the plankton production. Will increasing strength of the gyre circulation lead to increased mixing of water masses, increased upwelling and increased production? Low and high gyre index periods will be compared.

The top-down hypotheses are:

1. Predation by pelagic fish will influence the zooplankton biomass and production.

To examine this hypothesis, Norwecom will run with large (maximum historic SSB) observed and small (10%, 50% of the large) fish biomass. Objective: Does one see sign in the model of top down control.

2. Increased predation on zooplankton late in the growth season will not to the same extent influence the zooplankton production.

It has been suggested that predation on the overwintering generation of *Calanus* spp. (G0) will have stronger influence on the *Calanus* production compared to predation on the new generation (G1). To examine this hypothesis, Norwecom will run with large herring and small mackerel biomass, and small herring and large mackerel biomass. Mackerel are entering later in the season, and they are/can also be parameterized in the model to eat C2-C3, which herring don't. Are there differences in the response? Is there an effect on *Calanus* production if the fish eat young vs. old prey seen from a bioenergetic point of view?

Additionally, we will examine if the fish condition factor/length growth increase when zooplankton production is high, using a Growth model where covariates are included, and the effects of the covariate examined.

The paper may also consider the following (but this needs to be discussed):

- Do zooplankton communities/areas with high predation contain less of the larger zooplankton groups
- Grazing by zooplankton on phytoplankton
- Can the strength of the circulation in the Norwegian Sea gyre influence retention of zooplankton/*Calanus*

## 2. Material and Methods

## 2.1 Overview description of surveys and data

In the present study, data from the period 2008 to 2018 have been examined. Each year two ICES coordinated ecosystem surveys have been carried out in the Nordic Seas: IESNS and IESSNS surveys. Several countries and research vessels participated in the international surveys, and data are stored in the PGNAPES database hosted by Faroe Islands. The IESNS (International Ecosystem Survey in the Nordic Seas) surveys are performed within approximately 5 weeks, from late April to early June, with some variations in the survey-period between years. The aim of these surveys is to cover the whole distribution area of the Norwegian Spring-spawning Herring (*Clupea harengus*) with the objective of estimating the total biomass of the herring stock, in addition to collect data on plankton and hydrographical conditions in the area. The IESSNS (International Ecosystem Summer Survey in the Nordic Seas) surveys are performed within approximately 4 weeks from early July to early August, however the timing of the surveys varies with some days between years. The main object is to provide annual age-disaggregated abundance index with an uncertainty estimate for the North East Atlantic mackerel (*Scomber scombrus*). A secondary aim of these surveys is to study the spatial distribution of mackerel in relation to other abundant pelagic fish stocks and to environmental factors. The present study has used data on hydrography, nutrients, zooplankton and pelagic fish from these surveys. In addition, data on inflow of Arctic water into the Norwegian Sea, data on the Norwegian Basin gyre and Lofoten Basin gyre and mixing of Atlantic and Arctic waters in the Norwegian Sea, satellite data, and output from the NORWECOM.E2E model, all from the same period 2008 to 2018, have been collected.

## 2.2. Arctic front

(Input from paper 1)

## 2.3. Norwegian Sea gyre indexes

(Input from paper 1)

## 2.4. Nutrients

Water samples for determination of nitrate and silicate were collected at a total of xxx stations by vertical casts using a CTD with water bottles mounted. Laboratory analyses of nutrients were performed according to (ref).

## 2.5. Satellite data and phytoplankton production

Estimates of net primary production (NPP) from the Vertically Generalized Production Model (VGPM, Behrenfeld & Falkowski, 1997) were downloaded from [www.science.oregonstate.edu](http://www.science.oregonstate.edu). Annual primary production was estimated by integrating the production time-series from each grid cell throughout the productive season (Børsheim et al., 2014). NPP calculations with the VGPM used the input data fields chlorophyll *a*, photosynthetically active radiation (PAR), sea surface temperature and daylength, all given by the satellite MODIS (ref).

## 2.6. Zooplankton biomass

A total of xxx zooplankton samples were collected by the zooplankton net WP2(0.25m<sup>2</sup> mouth area) from 200 m to the surface. Whenever bottom depth was shallower than 200 m, samples were collected from bottom to surface. The WP2 used on the Norwegian surveys had 180 µm mesh, and the WP2 used on the Icelandic and Faroese surveys

had 200 µm mesh. The samples were oven-dried at 65 °C for a minimum of 24 hours to obtain dry-weight.

## 2.7. NORWECOM.E2E model

The model is a coupled three-dimensional ecosystem model with modules for several trophic levels. A hydrographical model with fields of temperature, salinity and currents is used as input to all other modules. A phytoplankton model (Skogen et al 1995) provides prey fields to an individual based *Calanus finmarchicus* model (Hjøllo et al 2012), which then provide prey fields for the pelagic fish individual based models. The model is fully coupled, which means that all modules are run simultaneously, and consumed individuals are removed from the model system immediately. The pelagic fish included is Norwegian Spring-spawning (NSS) herring, mackerel and blue whiting (Utne et al 2012). All life stages are included for the pelagic fish, from spawning, larvae, juvenile and adult fish. The model is suited to study the potential effect of predation from pelagic fish on zooplankton production and abundance, due to the direct and immediate coupling between pelagic fish and *C. finmarchicus*.

## 3 Results

## 4 Discussion

## 5 References

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**Paper 3 – Tentative title: Changes in distribution of Mackerel, NSS herring and blue whiting in the Norwegian Sea during the last decades and possible factors governing these changes**

1. Put together data on distribution changes of the three pelagic species (including vertical distribution) – must be formulated as a hypothesis
2. Identify further questions/hypotheses
3. If possible, test some of these hypotheses
4. Who will do what and when:

Data will be put in PGNAPES database

Possible Hypotheses:

- The water masses of the Modified East Icelandic current affect the distribution of pelagic stocks in the Norwegian Sea. Note (we are thinking about the following characteristics: extent of the water masses, temperature, salinity, nutrients, height of the water mass)
- Hydrographic conditions affect distribution of pelagic fish in the Norwegian Sea

Distribution maps: Nikos

Plan:

	Norway	Deadl.	Faroes	Deadl.	Iceland	Deadl.
Survey data	Fabian	31.12.18	Eydna	31.12.18	Gudmundur	31.12.18
Catch data	Joint task, must get permission to use, Eydna and Gudmundur, 31.12.18 Old mackerel catch data (RU), Hjalmar? ,31.12.18?					
EU survey data	Eydna and Gudmundur, 31.12.18					
Making maps of distributions	Nikos 15.01.19					
Identify further questions	Nikos and Fabian 31.01.19 Exchange results with paper 1 28.02.19 Draft with results and some thoughts on interpretations/further questions 30.03.19 Feedback from group					

Finalize paper	Fabian and Nikos 15.05.19 New draft, more complete text 30.06.19 Paper submitted
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## **Annex 7: Ecosystem overview for the Norwegian Sea**

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### 3.1 Norwegian Sea ecoregion – Ecosystem overview

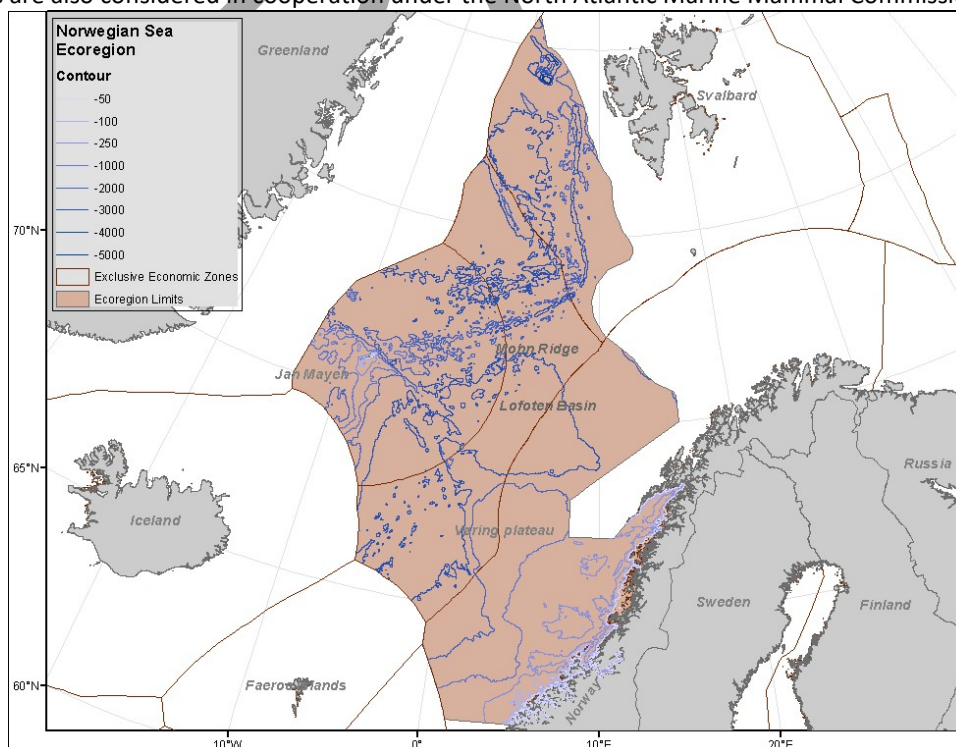
#### Ecoregion description

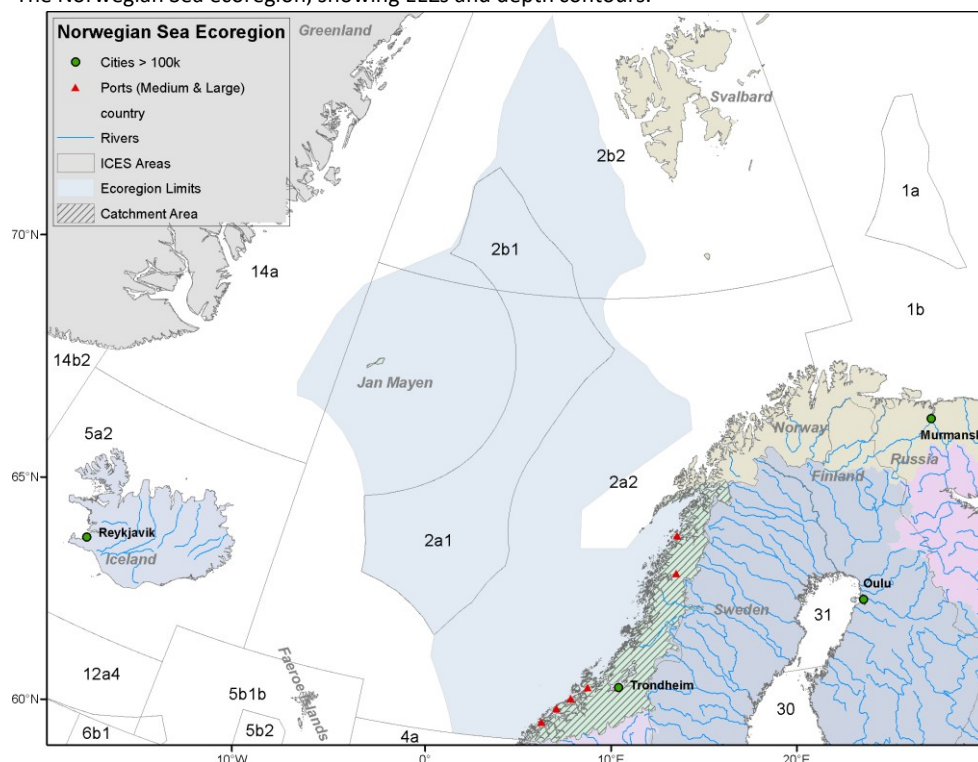
The Norwegian Sea, the Greenland Sea, and the Iceland Sea comprise the Nordic seas, which are separated from the rest of the North Atlantic by the Greenland–Scotland Ridge. The Norwegian Sea (NwS) connects with the Northeast Atlantic Ocean to the southwest, the Icelandic Waters ecoregion and Greenland Sea to the west along the edge to the shallower Iceland Sea between the Faroe Islands, and northwards to Jan Mayen. To the south, it borders to the shallower North Sea along the 62°N parallel between Norway and the Faroe Islands, and to the northeast with the shallower Barents Sea (Figure 1).

The Norwegian Sea covers more than 1.1 million km<sup>2</sup>, consisting of two deep basins (between 3000 and 4000 m deep), the Norwegian Basin and the Lofoten Basin, separated by the Vøring plateau (between 1000 and 3000 m deep). The Norwegian Sea is separated from the Greenland Sea to the north by the Mohn Ridge. To the west, the basin slope forms the transition to the somewhat shallower Iceland Sea. The upper ocean of the Nordic seas consists of warm and saline Atlantic water to the east, and cold and fresh polar water from the Arctic to the west.

The Norwegian and Barents seas are transition zones for warm and saline waters on their way from the Atlantic to the Arctic Ocean. The major current, the Norwegian Atlantic Current (NwAC), is a poleward extension of the Gulf Stream and the North Atlantic Current that acts as a conduit for warm and saline Atlantic water from the North Atlantic to the Barents Sea and Arctic Ocean.

The fisheries in the Norwegian Sea ecoregion are managed by Norway and by coastal states, with some fisheries managed by the North East Atlantic Fisheries Commission (NEAFC). Responsibility for management of salmon fisheries rests with the North Atlantic Salmon Conservation Organization (NASCO), and for large pelagic fish with the International Commission for the Conservation of Atlantic Tunas (ICCAT). Fisheries advice is provided by the International Council for the Exploration of the Sea (ICES). Environmental issues are managed by Norwegian agencies and through OSPAR, with advice being provided by Norwegian agencies, OSPAR, and ICES. International shipping is managed under the International Maritime Organization (IMO). The International Whaling Commission (IWC) has regulations for the conservation and harvest of whales. Marine mammal issues are also considered in cooperation under the North Atlantic Marine Mammal Commission (NAMMCO).



**Figure 1** The Norwegian Sea ecoregion, showing EEZs and depth contours.**Figure 2** Catchment area for the Norwegian Sea ecoregion, showing major cities, ports, and ICES areas.

### Key signals within the environment and the ecosystem

Water temperatures, both at the surface and in deeper waters in the Norwegian Sea have been above the long-term trend since around the beginning of the 2000s, peaking in 2007 at almost 1.5°C above the long-term mean at water depths of 50–500 m. Though the 2014 level was near and slightly above and the 2015 level at and below the long-term mean, the temperature trend is still positive because of inflow of Atlantic waters at the western entrance. The heat content of Atlantic water in the Norwegian Sea has been above the long-term mean since 2000.

The decrease in the zooplankton biomass index observed during the last decade for the whole Norwegian Sea has stopped. The index is by 2018 at the long-term mean.

Norwegian spring-spawning herring *Clupea harengus* has not produced a strong year class after the productive period of 1998–2004, causing declining stock size since 2010. Individual growth rate has been relatively high in later years. Stock size and summer feeding area of mackerel *Scomber scombrus* has increased the last decade, but estimated stock size declined from 2017 to 2018. There are indications of shifts in both spawning and nursery grounds. Individual growth varies and is related to mackerel density for all age groups.

Blue whiting *Micromesistius poutassou* biomass increased for several years after 2011 but declined during the last year. Several strong year classes have been produced during the last years, but the 2016 and 2017 year classes are expected to be poor.

Atlantic bluefin tuna *Thynnus thynnus* has since around 2013 returned to Norwegian waters and may increase predation of pelagic fish.

The breeding populations of kittiwake, Atlantic puffin, and guillemot in seabird colonies along the Norwegian coast has declined since monitoring started in 1980. The causes of the declines are not completely known. The situation for seabirds in the Faroes is similar to that in Norway, but the declines have been less drastic.

### Pressures

The NwS is influenced by human activity; historically involving fishing as well as the hunting of marine mammals. More recently, human activities also involve transportation of goods, oil, gas, and tourism, with contaminants coming from

outside the boundaries of the ecoregion.

Human-induced climate change and ocean acidification may have a large influence on the NwS in future.

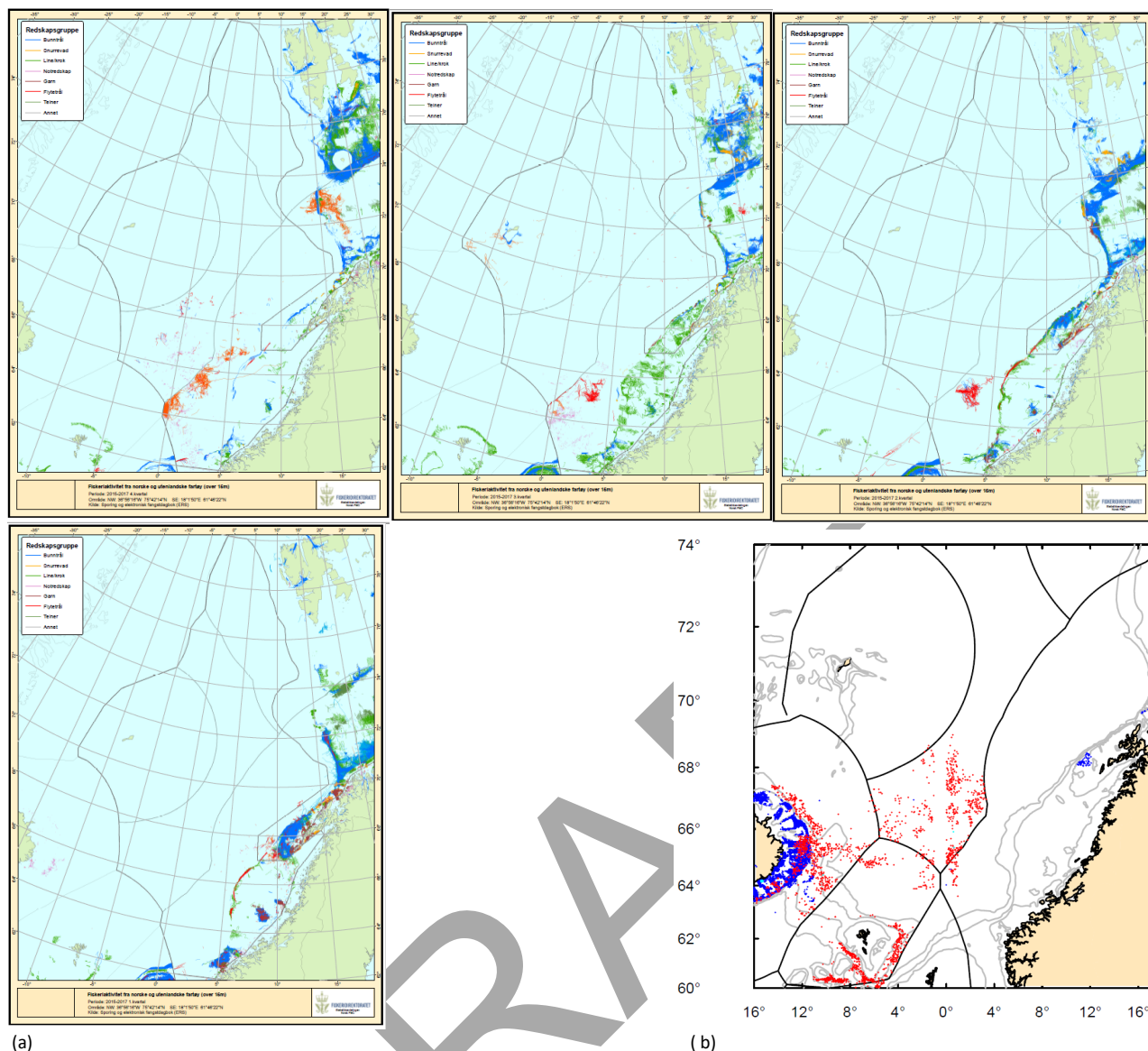
Changing distributions of valuable fish stocks (e.g. mackerel and NSS herring) lead to international disputes on harvest rights and quota sharing. It may also lead to changes in spawning success and to changes in migration patterns and ecological cascades with unknown outcome. The main pressures described below are defined in the ICES glossary of human pressures.

## See tables for scaling in appendix

**Figure 3** Norwegian Sea ecoregion overview with the major regional pressures, human activities, and state of the ecosystem components. The width of lines indicates the relative importance of individual links (the scaled strength of pressures should be understood as a relevant strength between the human activities listed and not as an assessment of the actual pressure on the ecosystem).

Pelagic fishing by multinational fleets is the major activity in the ecoregion. The number of fishing vessels is declining while the sizes of the vessels are increasing. The Norwegian commercial fleet has the highest fishing activity in the shelf area, particularly along the coast of Norway and along the continental shelf edge (Figure 4a and 4b). Icelandic vessels operate mainly with pelagic trawl in the ecoregion (Figure 4c). Other fisheries in the ecoregion are predominantly pelagic fisheries targeting NSS-herring, mackerel, and blue whiting.

Bottom trawls are regulated along the Norwegian continental slope through closed areas to avoid extended damage on fragile and vulnerable benthic communities and reef-building organisms.

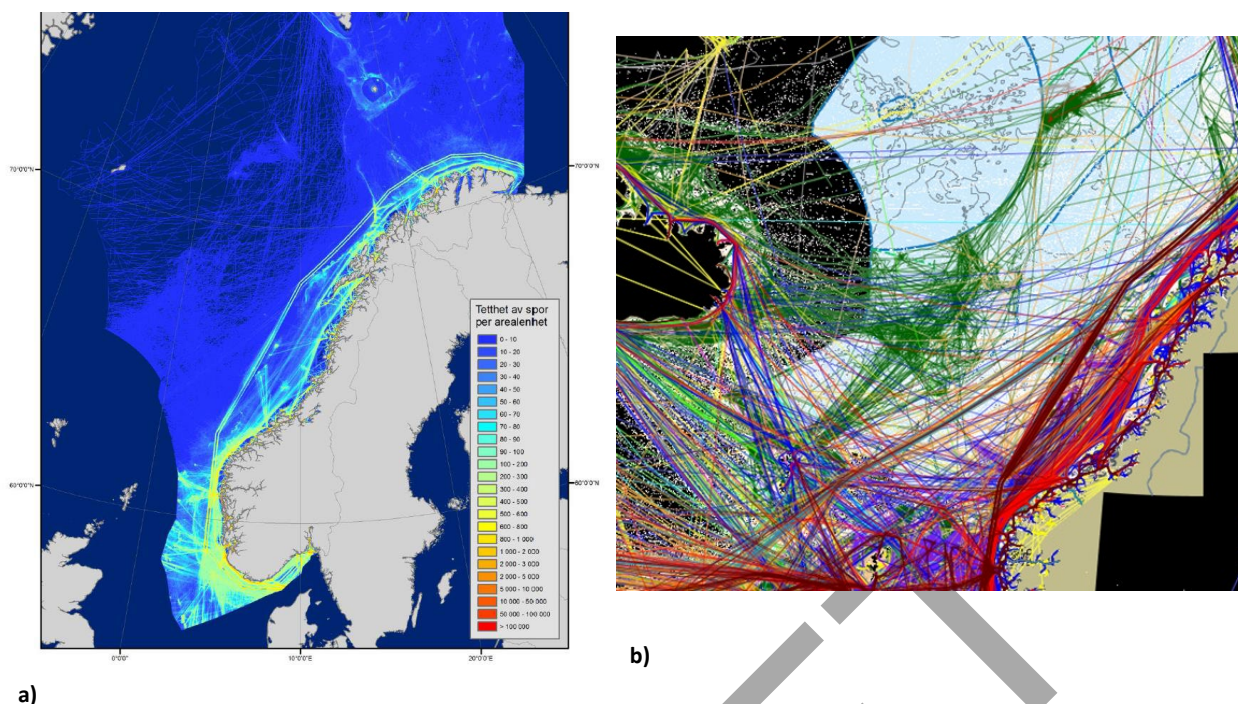


**Figure 4** Representation of fishing activity in the Norwegian Sea by (a) Norwegian and foreign fishing commercial fleets (larger than 15 m) and fishing vessels used for research purposes for each quarter, from 2015 to 2017, as reported through vessel monitoring systems (VMS) to Norwegian authorities (Sources: Norwegian Directorate of Fisheries, <http://www.fiskeridir.no/English>); and (b) the Icelandic fishing fleet in 2018 with midwater trawls (red dots), bottom trawls (blue dots) and purse-seine fishery (green dots, very few east of Iceland)

The oil- and gas-related activities are managed through governmental licences (figures 8–9 below). Seismic investigations occur annually and are prohibited in the Norwegian sector during the spawning periods of Northeast Atlantic (NEA) cod *Gadus morhua* and NSS herring.

Non-fishing marine traffic shows a slightly increasing trend, in particular in tourist traffic. Most ships follow the main traffic lanes near the coasts (Figure 5)





**Figure 5** a) Density of vessels in Norwegian waters, 2017 (AIS data) and b) Density plot for vessel (including fishing vessels and other vessels less than 1k GT) movements (AIS-data) in the Norwegian Sea for July through August 2018. The traffic seen in international waters in the centre of the ecoregion is predominantly fishing vessels. (Source: <https://havbase.no/> The Norwegian Coastal Administration, <https://www.kystverket.no/en>)

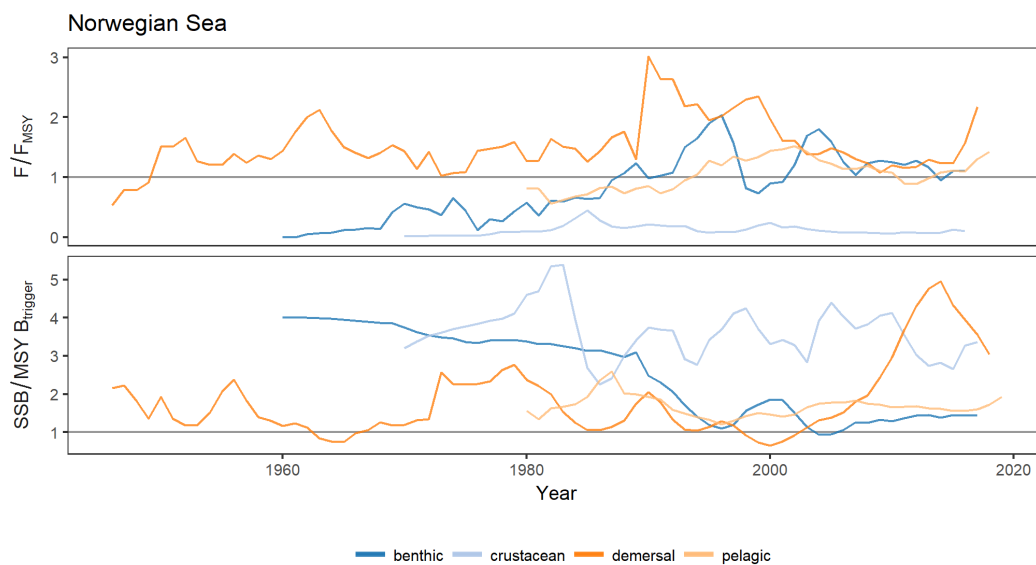
### Selective extraction of species (including non-target catch)

Fishing is considered the human activity that currently puts most pressure on the Norwegian Sea during normal activities, due to the wide area, depth and time through the year it is pursued. Every fishery has some direct impact on the ecosystem where it takes place. The level of pressure depends on how much of a stock is harvested, how it is harvested, and the trophic level to which the stock belongs. For various reasons, such as natural fluctuations, climate change, and high level of fishing pressure, certain fish stocks are not in a very healthy condition, and are therefore particularly vulnerable to even small increases in human pressures. Such species include redfish (*Sebastes marinus* and *S. mentella*) and coastal cod. Other species — such as blue whiting and Greenland halibut — are also considered to be vulnerable (NMCE, 2009). Fisheries, being the most widespread and continuous pressure in the region remains the top human pressure in the region.

Regulations established in 2011 have restricted the use of bottom trawls in areas with coral reefs and at depths exceeding 1 000 m. Some bycatch of seabirds and marine mammals is known to occur, but numbers have not been quantified. Only minke whales are exploited in the NwS.

A Norwegian hunt for minke whales is conducted in the Norwegian Sea, Barents Sea, North Sea, and the Jan Mayen area. Quotas are set in accordance with IWC's Revised management procedure and the total annual catch has ranged between 450 and 750 animals in all waters. Survey population estimates are provided every six years and have shown the population to be stable over the past five survey cycles.

A small trial commercial fishery (< 1000 tonnes annually) for *Calanus finmarchicus* has been developed along the Norwegian coast for more than a decade. Norway is currently considering to upscale this fishery for offshore parts of the NwS.

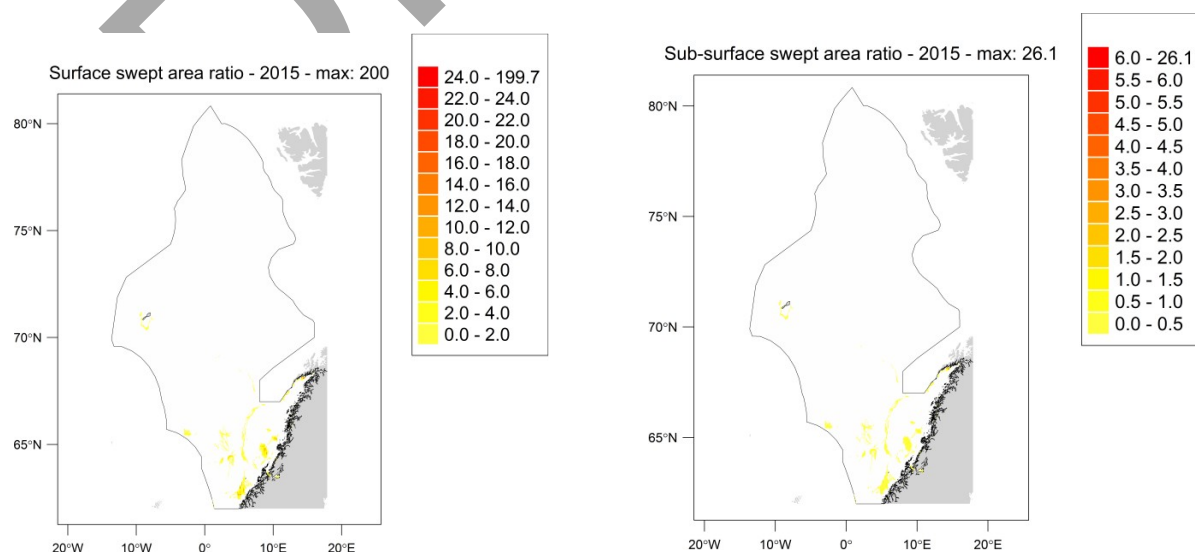


ICES Stock Assessment Database, November/2018. ICES, Copenhagen

**Figure 6** Time-series of average of relative fishing mortality ( $F$  to  $F_{MSY}$  ratio) for Northeast Atlantic mackerel (Mac-nea), Norwegian spring-spawning herring (Her-noss), and blue whiting (WHB-comb), and for SSB/ to  $MSY B_{trigger}$ , based on ICES 2018 assessments.

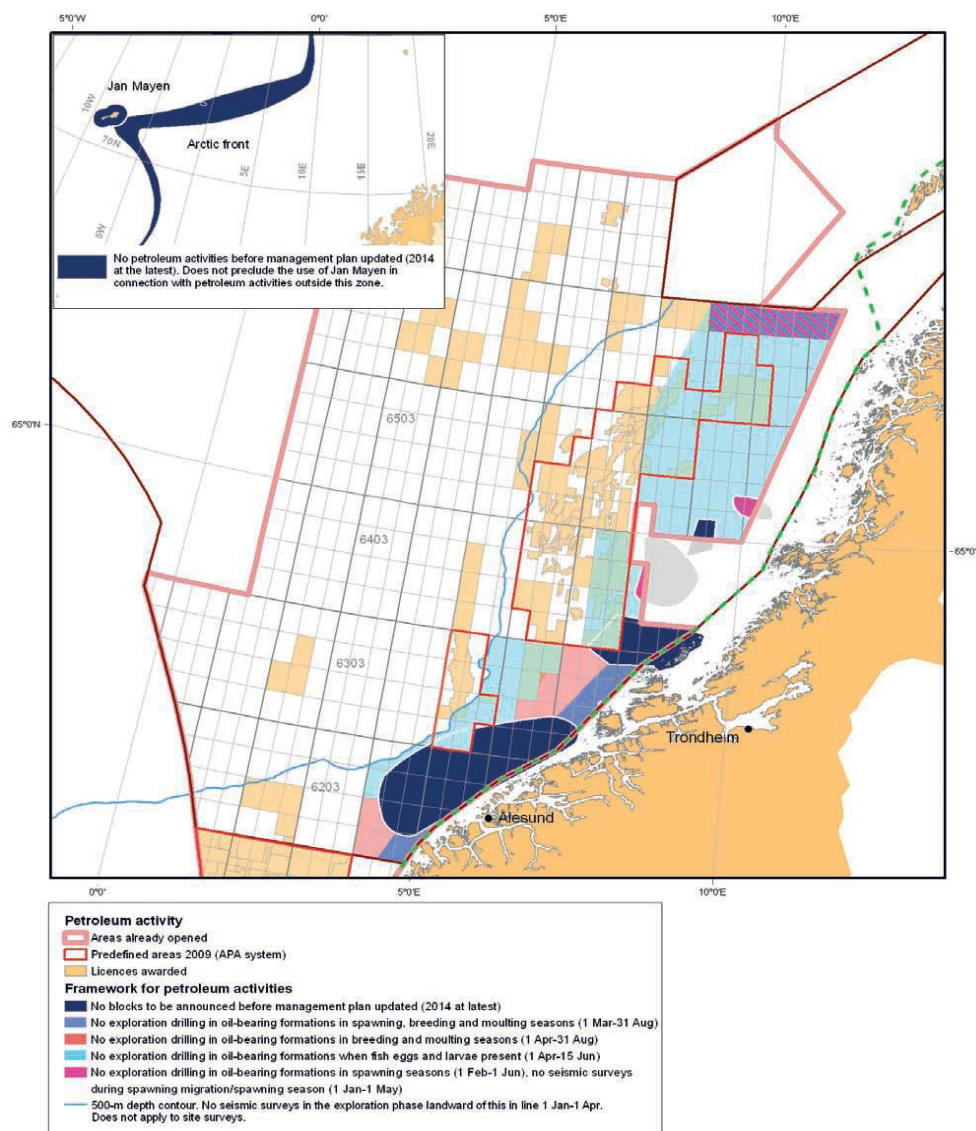
## Abrasion

Abrasion occurs from towed bottom-contacting gear with some damage to benthic organisms and habitats. Relatively little such gear is used in the NwS, mainly on the shelf in the southern part of the ecoregion (Figure 7). Some abrasion can occur near offshore oil and gas operations – these also are limited in extent and numbers in the NwS.



**Figure 7** Surface and subsurface abrasion pressure expressed as the swept-area ratio obtained from VMS data from 2015 in the Norwegian Sea ecoregion.

Coral reef areas are protected from bottom fishing. Relatively large areas are closed to petroleum-related activities in the Norwegian EEZ, in particular at the Møre plateau (Figure 8).



**Figure 8** Framework for petroleum activities (announcement of blocks, exploration drilling, seismic surveying). (Source: Norwegian Ministry of the Environment, 2009.)

## Underwater noise

Underwater noise masking the acoustic communication between marine animals, mammals, fish and in-vertebrates, as well as abilities to navigate and hunt in some species. Forceful noise levels, from seismic activity, military sonars and detonations may afflict damage directly to animals and lead to behavioural responses.

## Introduction of contaminating compounds

The NwS remains relatively clean with low pollution levels compared to marine areas in many industrialized parts of the world. The Norwegian management plan covers pollution with several indicators, including sources from outside the ecoregion as well as from the oil and gas industry.

Petroleum activities and maritime transport in the Norwegian Sea represent a risk of accidents which could result in oil spills. Regular updating of the legislation for both industries means that operators must meet higher and higher standards; thus, reducing the probability of accidents. In general, the probability of a small spill is



higher than that of a large spill. Potential consequences of different types of accidental events are closely linked to: where they occur and the scale; the type of oil; weather conditions; time of year; and how likely the spill is to affect vulnerable species and habitats. In addition, species and habitats which are known to be vulnerable to oil are generally found in larger numbers (or at higher densities) in coastal areas; the distance to shore is, therefore, another important factor in evaluating potential consequences of a spill. Permitted operational discharges from maritime transport make a relatively small contribution to the cumulative effects on the Norwegian Sea ecosystem. Discharges of waste are believed to have insignificant effects on marine mammals and the shoreline, and up to moderate effects on seabirds. Discharges of oil are estimated to have insignificant effects on seabirds. Operational discharges from petroleum activities are generally so strictly regulated that they are only considered to have more local effects, which are believed insignificant for the Norwegian Sea ecosystem as a whole. Nevertheless, there is uncertainty regarding the potential long-term effects of produced water discharged from petroleum activities (NMCE, 2009). What is present and constant, are the structures placed in the sea and on the sea bottom, providing artificial hard-bottom and fish refuge, which in several ways change the food web and the biodiversity locally (Hovland, 2012). Therefore, this pressure is kept among the top-five pressures in the region.

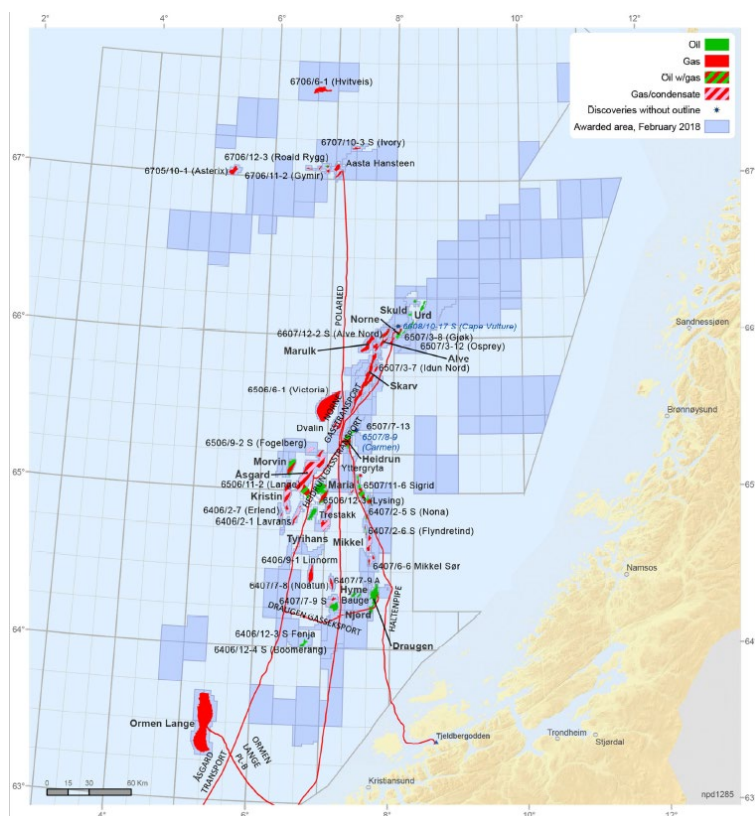
Releases of NO<sub>x</sub>, CO<sub>2</sub>, and pollutants (oil releases to the sea, greenhouse gases, organic acids (declining), phenols, PAH, radioactive compounds) in produced-water from the petroleum activities are fairly stable, or in some cases slowly rising.

River run-offs are negligible.

### **Smothering and substratum loss**

This pressure derives both from towed bottom-fishing (Figure 7) and from oil and gas infrastructure development (Figure 9). Oil and gas extraction continues to develop in the NwS. Currently offshore development is limited in the Norwegian economic zone.

Bottom trawling has direct impacts on benthic species and communities, and varies with the intensity of trawling and other physical disturbance of the seabed, including discharges of drill cuttings from oil exploration and production drilling, have negative impacts, particularly on cold-water corals (Ragnarsson et al. 2016). However, due to the limited area open for bottom trawls and petroleum-related activities, the impact is considered to have more local and less significant impacts on the Norwegian Sea ecosystem as a whole. Operators are required to ensure that petroleum activities do not damage corals or other valuable benthic communities. In particularly chosen valuable and vulnerable areas, mainly cold-water corals, bottom trawling and new locations for oil- and gas drilling are to be regulated and restricted to avoid damage from smothering. Although the impact is local, the consequences are strong and the long-lasting, so this pressure is kept among the top-five pressures in the region.



**Figure 9** Overview of petroleum activities in the Norwegian Sea (Source: Norwegian Petroleum Directorate, <http://www.npd.no/en/>).

### Nutrient and organic enrichment

Aquaculture production is increasing along the coasts and in fjords of the NWS. Several commercial fish farms are producing salmonids (salmon, trout) and shellfish. With aquaculture activities the increase in nutrients and enrichment can cause problems locally, but this does not impact the open ocean of the NWS.

Inputs from river run-offs are negligible.

### Marine litter

The background density of litter in Norwegian Sea is 279 items/km<sup>2</sup> and highest densities were found close to coast and in canyons. Most of the litter originated from the fishing industry and plastic was the second most common litter. Background levels were comparable to European records and areas with most littering had higher densities than in Europe (Buhl-Mortensen & Buhl-Mortensen, 2017).

The level of marine litter is increasing (Pham et al., 2014; Galgani et al., 2015;) and new research show it may have more impact, particularly on species mistaking plastic item for food, and is therefore selected as one of top-five pressures in the region.

### Other pressures

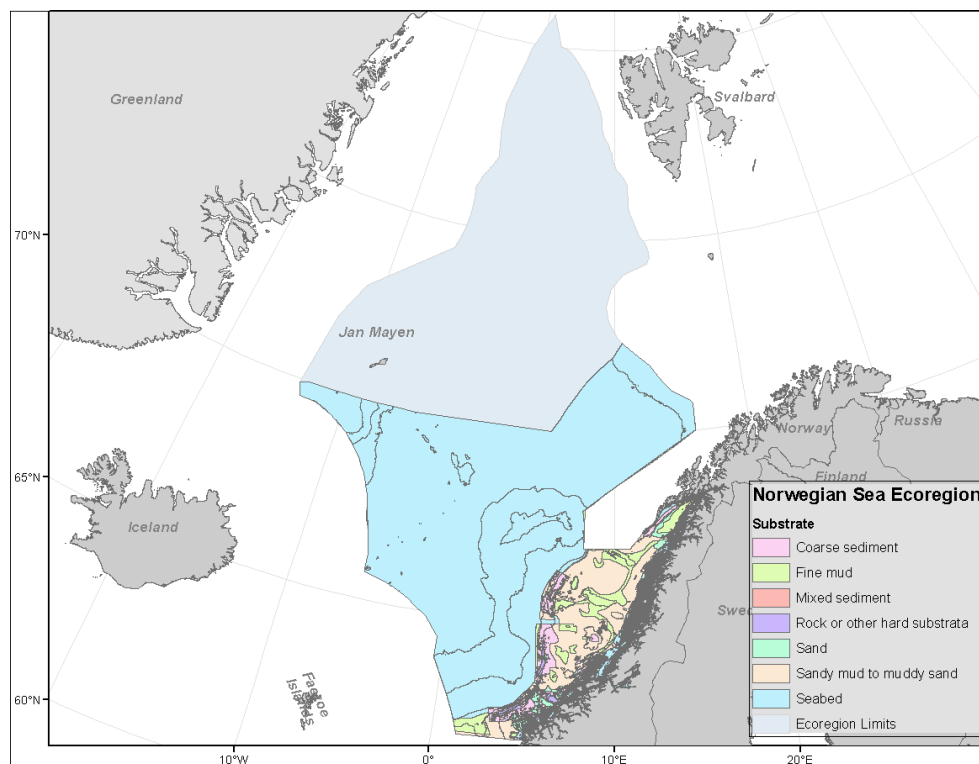
Introduced species are all pressures within the ecoregion, but their effects are considered to be of minor importance.

## State of the ecosystem

### Habitats (substratum)

The substrates within the coastal NWS have been mapped by the MAREANO project. This mapping is confined mostly to the Norwegian continental shelf and slope. The majority of the shelf consists of fine muds and sandy

muds, with coarser sediments on the shelf slope (Figure 10). MAREANO has located several vulnerable habitat locations, including coral and sponge communities. There is little information from the deep-water areas.



**Figure 10** Major substrates in the Norwegian Sea ecoregion (compiled by EMODNET seabed habitats; [www.emodnet-seabedhabitats.eu](http://www.emodnet-seabedhabitats.eu)).

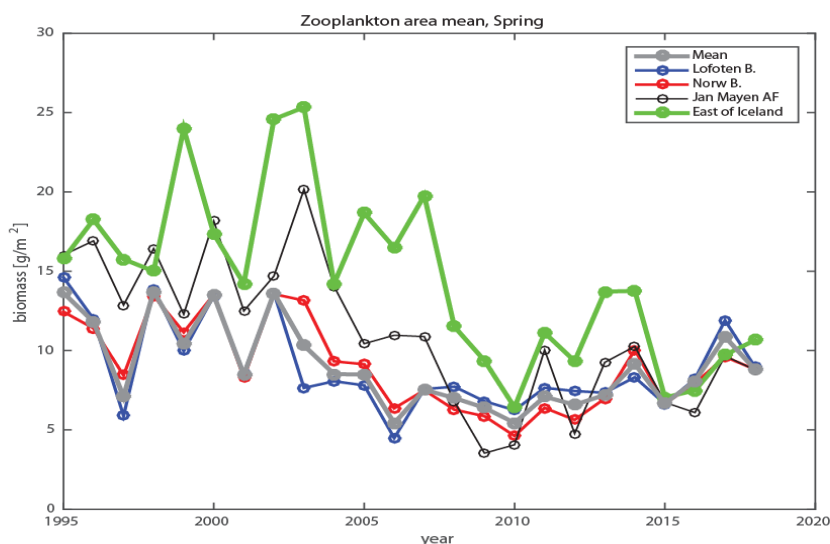
### Productivity (phytoplankton)

Biomass varies between years, but no trends have yet been detected. The North-Atlantic subpolar gyre (SPG) variability can affect bloom dynamics in the Norwegian Sea. A pre-bloom silicate decline was registered throughout the winter mixed layer in the period 1990-2015. The decline is attributed to natural multi-decadal variability through decreased winter convection depths since the mid-1990s, a weakening and retraction of the SPG and an associated increased influence of nutrient-poor water of subtropical origin (Hátún et al., 2017).

### Plankton

The high-latitude ecosystem of the Norwegian Sea consists of areas with different physical regimes, and the length of productive season and intensity of biological production varies among these areas. In the east–west direction the Norwegian Sea can be divided into Norwegian coastal, Atlantic, and Arctic habitats, which is reflected in the zooplankton species composition. One of the most important zooplankton groups in the Norwegian Sea is the genus *Calanus*, both in numbers and biomass. In the Norwegian coastal and Atlantic habitats *C. finmarchicus* dominates the zooplankton biomass in spring and summer, and *C. helgolandicus* is also found in southern and eastern parts of these habitats. In the Arctic habitat *C. hyperboreus* is important. Of other species, the krill *Thysanoessa inermis*, *T. longicaudata*, and *Meganyctiphanes norvegica* are widespread, the latter especially in the warmer Atlantic and coastal habitats. The amphipod *Themisto libellula* is abundant in the Arctic, and *T. abyssorum* in the Atlantic habitats. The seasonal pulse of zooplankton production starts in southern and eastern parts of the Norwegian Sea, with a time delay towards the colder areas in the western and northern parts.

Zooplankton biomass has shown considerable fluctuations over the period 1995-2018 (Figure 11). From high levels during the early 2000s, the zooplankton biomass index declined until 2010. Since then the index has increased and is currently around the long-term mean.



**Figure 11** The annual mean dry weight of zooplankton biomass (g dw m<sup>-2</sup>), sampled with WP2 in the upper 200 m of the water column, in 4 sub-areas (defined in Figure 6.4.1) for the period 1995–2018.

## Benthos

Biological production is high in the shallow bank areas on the continental shelf. Major cumulative environmental effects from human activities are considered to impact corals, sponges, and other benthic fauna (NMCE, 2009). Reef-building organisms, like sponges and cold-water corals are protected on designated vulnerable marine ecosystems (VMEs). Cold-water corals are generally found at depths of 200–500 meters. Reefs found thus far on the continental shelf include Sula — the largest known cold-water coral reef.

## Fish

The fish community in the Norwegian Sea is dominated by three pelagic species Norwegian spring-spawning (NSS) herring, northeast Atlantic mackerel, and blue whiting (Figure 12). Some of the main recent changes in the ecosystem is therefore growth and expansion of the mackerel stock and the decline in the herring stock. The spawning stock biomass of NSS herring is estimated at 3.9 million tonnes in 2019 (ICES 2018a), which is above the precautionary level ( $B_{pa}$ ) of 3.184 million tonnes. The herring stock has declined since 2010, mainly due to poor recruitment since 2004. The largest year classes since 2004 (the year classes from 2006, 2009 and 2013, respectively) were close to average size over the period 1988–2016. The newest information from the surveys in the Barents Sea (ICES 2018b) indicate that the 2016 year class is stronger. A consequence of the poor recruitment is that the stock is composed of relatively large number of old fish (age 12+). Concurrently to a declining stock size, individual growth rate has been relatively high in later years. A new management strategy was adopted by the coastal states in 2018 that is accordance with of precautionary approach and has the target fishing mortality ( $F_{mgt}$ ) of 0.14 (ICES 2018c).

The mackerel population increased between 2002 and 2014, but decreased slightly in 2015. Recruitment has been increasing since late 1990s with two strong cohorts (2002 and 2006). The 2011-year class is probably well above average, whereas the 2013-year class appears to be the weakest since 2003. There was a sharp reduction in the fitness and growth of individual mackerel individuals between 2005 and 2013: the average 4-year-old mackerel in 2005 weighed as much as the average 8-year-old mackerel in 2013 (Olafsdóttir et al. 2015). This is likely due to an increased population size where increased biomass leads to reduced food availability for individuals. The spawning-stock biomass (SSB) of mackerel has declined since it was at maximum around 2015 (ICES, 2018a). There have been several strong year classes of mackerel in recent years (Jansen, 2016; ICES, 2018a).

The blue whiting stock increased during the 2010–2014 period, and in 2015 was at a level to be harvested sustainably. The 2015 stock assessment reported a sharp reduction in size of the historic spawning population, mainly due to low abundance indices on the spawning grounds from 2015 survey data. SSB of blue whiting has increased since 2011, but the estimated biomass de-creased from 2018 to 4.3 million tonnes in 2019 (ICES 2018a). Blue whiting has produced several strong year classes in recent years, but the 2016 and 2017 year classes

are expected to be poor (ICES 2018a). The blue whiting stock is currently dominated by 3-5 year old individuals.

There are strong indications for interspecific interaction regarding food among NSS-herring, blue whiting and mackerel (Huse et al., 2012). The increasing stock of mackerel may have an advantage in the interaction with the declining stock of NSS herring, because mackerel stomach fullness index was higher (Langøy et al. 2012; Debes et al., 2012; Óskarsson et al., 2015; Bachiller et al., 2016; 2018); additionally, the diet composition of herring was different from previous periods when the mackerel stock size was smaller.

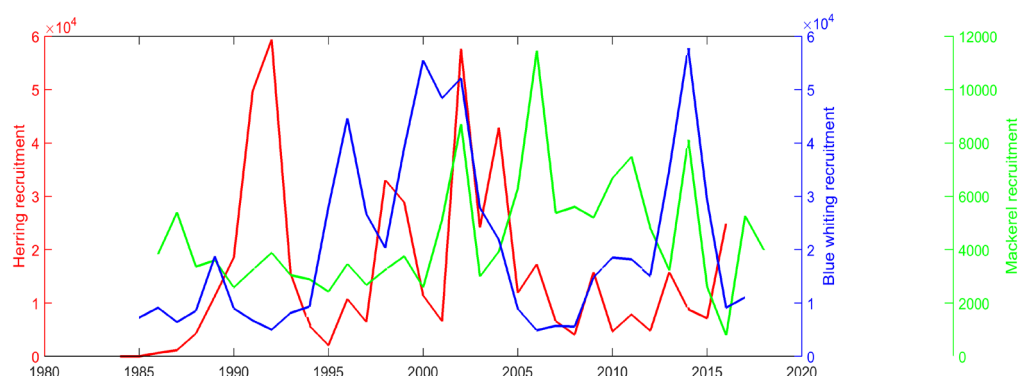
Atlantic bluefin tuna (*Thynnus thynnus*) has now returned to Norwegian waters, and are once again re-establishing their traditional annual feeding migration pattern. Schools of bluefin tuna are distributed into the Norwegian Sea and along the Norwegian coast as documented in previous decades. A positive sign of the stock rebuilding is now visible in northern waters due to numerous sightings where sightings of small to large aggregations/schools have been recorded in Norwegian waters, first in 2013 and in particular since 2016.

Unaccounted mortality of herring and mackerel due to fish crowding within, and their subsequent release (slipping) from, purse seines nets is a problem. IMR collaborates with the fishing industry and the Directorate of Fisheries to find “best practices” for slipping fish from nets. The goal is to reduce both fishing mortality and the level of conflict between the industry and enforcement authorities (Bakketeig, et al., 2016).

Greenland halibut is widely distributed in the Barents Sea, but is also found along most of the continental slopes in the Norwegian Sea. In the Svalbard region, juvenile Greenland halibut may be observed as far west as Iceland. This could indicate that Greenland halibut populations in the Barents Sea and in the southern Norwegian Sea are more closely related than previously anticipated (Bakketeig, et al., 2016).

The silver smelt (white salmon) population in Norwegian waters appears stable, but the structure of the entire Northeast Atlantic populations is unclear.

The spawning stock for deep-sea redfish has increased six-fold over the last twenty years (Bakketeig, et al., 2016).



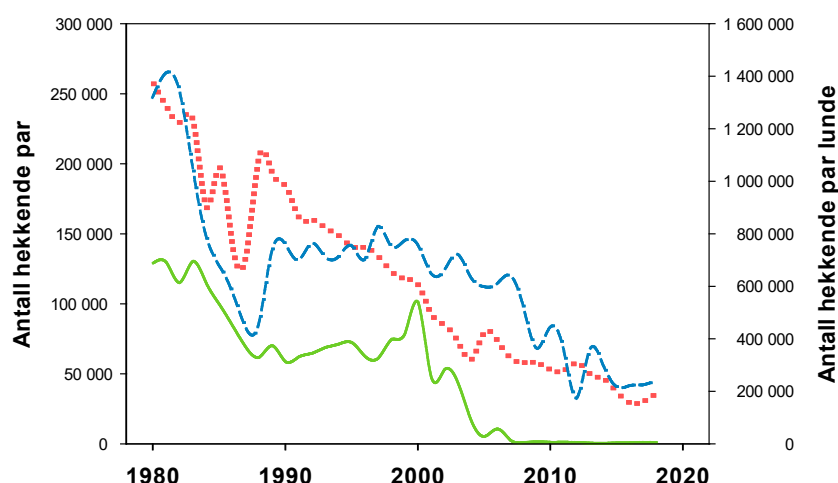
**Figure 12** Year class strength (i.e. recruitment) of Norwegian spring spawning herring, blue whiting and mackerel over 1986-2018 based on the most recent assessments (ICES 2018a). The herring and blue whiting recruitment is of 2 and 1 years old, and these have therefore been moved 2 and 1 years back in time, respectively.

## Seabirds

The total population size of seabirds breeding on the coasts of the Norwegian parts of the Norwegian Sea in 2013 was estimated based on the latest counts in all areas (Anker-Nilssen et al., 2015), which for the mainland were also adjusted for trends in numbers at the monitored colonies (Fauchald et al., 2015). Insufficient data did not allow such calculations for northern fulmar and black guillemot, but we have subjectively adjusted the estimate for the former to account for some very apparent recent declines. The SEAPOP programme aims to publish annual updates of national and regional population estimates on [www.seapop.no](http://www.seapop.no) in 1-2 years.

The total number of seabirds breeding in the Norwegian parts of the Norwegian Sea was recently estimated at 1 270 000 pairs, of which 870 000 pairs of 20 species were breeding along the mainland coast and 400 000 pairs of 15 species were on Jan Mayen. Most populations have decreased steeply over the last decade (mean trend  $-5.8\% \text{ year}^{-1}$  in 2005–2015), and many have decreased almost constantly since monitoring started three to five decades ago (see e.g. Figure 13). No single factor explains all these trends; however, long-term breeding failures for species feeding in pelagic waters such as Atlantic puffin *Fratercula arctica*, black-legged kittiwake *Rissa*

tridactyla, common guillemot *Uria aalge*, and Northern fulmar *Fulmarus glacialis* indicate that much of the problem along the mainland coast is related to drastic changes in the availability of 0-group fish (especially herring), and also linked to variations in ocean climate.



**Figure 13** Development in the breeding populations of black-legged kittiwake, common guillemot and Atlantic puffin in the Norwegian part of the Norwegian Sea in the period 1980–2018.

### Marine mammals

Two species of seals are present year-round in coastal waters, harbour seal *Phoca vitulina* and grey seal *Halichoerus grypus*, with a further five pinniped species as infrequent visitors.

The abundance of harbour seals in central Norway has decreased since the late 1990s, mainly from hunting, but abundance is now increasing. Surveys of grey seals have shown a 50–60% reduction in pup production between 2007–2008 and 2014–2015 in mid-Norway, probably as a result of increased bycatches in gillnet fisheries for monkfish *Lophius piscatorius* and cod.

Twelve cetacean species are commonly observed in Norwegian waters, either on a year-round basis or as seasonal visitors in the productive summer season. The numbers of minke whales in the northeast Atlantic (including the Norwegian Sea) are stable overall (2007–2013). However, a general displacement of minke whales and other baleen whales towards the northeast implies a shift from the Norwegian Sea to the Barents Sea.

### Non-indigenous species

No species are found in the Norwegian Sea are considered invasive, but the comb jelly *Mnemiopsis leidyi* is occasionally registered in zooplankton samples (most recent record in 2014), usually in warmer periods.

### Threatened and declining species and habitats

**Table 1** Threatened and declining species in the Norwegian Sea, according to OSPAR.

SCIENTIFIC NAME	COMMON NAME
INVERTEBRATES	
<i>Nucella lapillus</i>	Dog whelk
SEABIRDS	
<i>Larus fuscus fuscus</i>	Lesser black-backed gull
<i>Pagophila eburnea</i>	Ivory gull
<i>Rissa tridactyla</i>	Black-legged kittiwake
<i>Uria lomvia</i>	Thick-billed murre (or Brünnich's guillemot)
FISH	
<i>Anguilla anguilla</i>	European eel
<i>Cetorhinus maximus</i>	Basking shark
<i>Dipturus batis</i>	Common skate
<i>Lamna nasus</i>	Porbeagle



<i>Petromyzon marinus</i>	Sea lamprey
<i>Salmo salar</i>	Salmon
<i>Squalus acanthias</i>	[Northeast Atlantic] spurdog
MARINE MAMMALS	
<i>Balaenoptera musculus</i>	Blue whale
<i>Eubalaena glacialis</i>	Northern right whale
<i>Phocoena phocoena</i>	Harbour porpoise

**Table 2** Threatened and declining habitats in the Norwegian Sea, according to OSPAR.

HABITATS
Coral gardens
Deep-sea sponge aggregations
Intertidal mudflats
<i>Lophelia pertusa</i> reefs
<i>Modiolus modiolus</i> beds
<i>Ostrea edulis</i> beds
Seamounts
<i>Zostera</i> beds

## Sources and acknowledgments

The content for the ICES regional ecosystem overviews is based on information and knowledge generated by the following ICES processes: Workshop on Benchmarking Integrated Ecosystem Assessment (WKBEMIA) 2012, ACOM/SCICOM Workshop on Ecosystem Overviews (WKECOVER) 2013, Workshop to draft advice on Ecosystem Overviews (WKDECOVER) 2013, and the Advice Drafting Group to finalize draft Ecosystem Overviews (ADGECO) 2017, which provided the theoretical framework and final layout of the documents. ICES Working Group on the Integrated Assessments of the Norwegian Sea (WGINOR) contributed to the main sections of this overview including information from several ICES working groups, report of the Norwegian Environment Agency (2014), and the Norwegian management plan as reported by the Norwegian Ministry of the Environment (2009). The following working groups directly contributed to draft the subsections on the state of the ecosystem components: Working Group on Zooplankton Ecology (WGZE), Working Group on Marine Mammal Ecology (WGMME), Working Group on Introductions and Transfers of Marine Organisms (WGITMO), and the Joint Working Group on Seabirds (JWGBIRD). References have been removed from the text for clarity and can be found below.

Those maps and GIS products, produced by the ICES Secretariat, used data from:

1. Exclusive Economic Zones. *Marineregions.org* (VLIZ).
2. Depth contours. *General Bathymetric Chart of the Oceans* (GEBCO).
3. Ecoregions. *International Council for the Exploration of the Sea* (ICES).
4. Ports. *Norwegian Institute of Marine Research* (IMR).
5. Cities. *World Cities* (ESRI).
6. Rivers. *WISE Large rivers and large lakes*. European Environment Agency (EEA).
7. ICES Areas. *International Council for the Exploration of the Sea* (ICES).
8. Catchment Area. *European Environment Agency* (EEA). *European Topic Centre on Inland, Coastal and Marine waters* (ETC/ICM).
9. Substrate maps. EU EMODNET seabed habitats; [www.emodnet-seabedhabitats.eu](http://www.emodnet-seabedhabitats.eu).

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## Appendix

### Tables for scaling of the pressures

**Table 7.1** Pressure selection.

Pressure	Probability of occurrence	Magnitude (low = 1, high = 3)	Total
Selective extraction of species	3	3	6
Smothering	2	1	3
Off-shore structures/oil and gas	2	2	4
Underwater noise	3	2	5
Marine litter	3	2	5
Introduction of contaminating compounds	3	1	4

*Selecting the five first pressures for the next tables, as contamination is mostly long-transported and not produced within the region. Smothering is limited to shelf areas and have a smaller Total score, but may become a stronger link if deep-sea mining is initiated in the future.*

**Table 7.2** Defining the relationship between pressure and main human activities.

Pressure	Human activity	Strength of link
Selective extraction of species	fishing	3
Smothering	fishing	2
	drilling	1
	deep-water mining (planned)	...
Off-shore structures (oil and gas)	physical drilling structures and pipe-lines	1
Underwater noise	shipping	2
	Seismic investigations	2
	Military exercises, sonar	2
Marine litter	fishing	3
	shipping	1
	Long-transportation from land-based sources	3

**Table 7.3** Defining the relationship between pressure and the state of the ecosystem.

Pressure	Ecosystem component	Strength of link	Examples of literature
Selective extraction of species	foodwebs	2	Utne et al. 2012; Bachiller et al. 2018
	benthos	1	Buhl-Mortensen et al. 2013
	fish	3	Dragesund et al. 1997; Skaret et al. 2015 ; Payne et al. 2012.
	seabirds	1	Fangel et al. 2015; Grémillet et al. 2018.
	marine mammals	1	
Smothering	habitat	1	Ragnarson <i>et al.</i> , 2016
	benthos	1	
Off-shore Structures (oil and gas)	benthos	1	Hovland, 2012
Underwater noise	fish	2	Kvadsheim <i>et al.</i> , 2017, and references within this report Rosenbaum & Southall 2017
	marine mammals	2	
	zooplankton	2	
Marine litter	Zooplankton	1	Buhl-Mortensen, Buhl-Mortensen, 2017. Pham, et al. 2014
	fish	2	
	seabirds	3	
	marine mammals	2	

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## Annex 8: Exploring ecosystem effects of changing harvest control rules for mackerel in the Norwegian Sea Ecosystem

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By Kaplan and Hansen (to be submitted)

### Objective

If we change the harvest control rule (HCR) for mackerel to take into account the zooplankton levels, will there be an ecosystem response, and how will the stock and the catches respond to such HCRs, compared to 'ordinary' broken stick HCR?

### Introduction

The Norwegian sea is dominated by the warm, saline Atlantic water flowing northwards along the shelf break, the Norwegian Atlantic slope current. Close to the coast, the water masses are less saline, driven by the Norwegian Coastal Current.

Three pelagic fish stocks are dominating; the mackerel, Norwegian spring-spawning herring and blue whiting. These three overlap to some degree, both in distributions and in favorite prey. One of the main food sources for the pelagic fish in the Norwegian sea is the copepod *Calanus Finmarchicus*, and it has been suggested that high mackerel abundance/biomass drives the total amount of *C. finmarchicus* down, leaving less food for the other species.

The Atlantis framework is created to evaluate 'what if' scenarios, and one version (hereafter NoBa) is developed for the Nordic and Barents Seas, including the Norwegian sea. It covers the 4 million km<sup>2</sup> by 60 polygons and represents the ecosystems by 57 components. The components are connected through a complex diet matrix, defining the availability of prey to a predator.

Here, we use NoBa to explore six different harvest control rules, and their effect on the stock, catches and the ecosystem responses.

### Models and methods

The NoBa model was run for the period 2004-2068, applying daily forcing of temperature, salinity and currents from a Regional ocean modelling system (ROMS). For the historical period (2004-2016), levels of fishing mortality for all components but mackerel was calculated from ices assessment reports (ICES 2017a, ICES 2017b). From 2017 and onwards, a representative average fisheries mortality was applied, calculated from fisheries mortality rates over the last decade. For mackerel, the maximum sustainable yield was calculated from NoBa. To estimate the MSY level, multiple simulations are being performed, and the MSY level is taken where catch/biomass peaks.

In total, six different harvest control rules were tested out for mackerel (Table 1, Figure 1). For each of the control rules, we have added variability by changing the shape of the time-series of annual mesozooplankton concentrations. This is done by using the estimated concentrations from the May cruise (Cecilie Broms, pers comm) performed by the IMR, and shifting this time-series by two years. The flat MSY scenario will apply the  $F_{MSY}$  for the mackerel stock during the whole simulation. The second HCR implemented was a simple broken stick HCR, where the level of fisheries mortality is being decreased linearly when the mackerel biomass reaches a defined precautionary level. Above the precautionary level, the fishing pressure will be at the  $F_{MSY}$  level. Finally, we applied an ecosystem harvest control rule for the mackerel stock. This means that when the mesozooplankton biomass reaches a certain level (representing average or 0.5 x

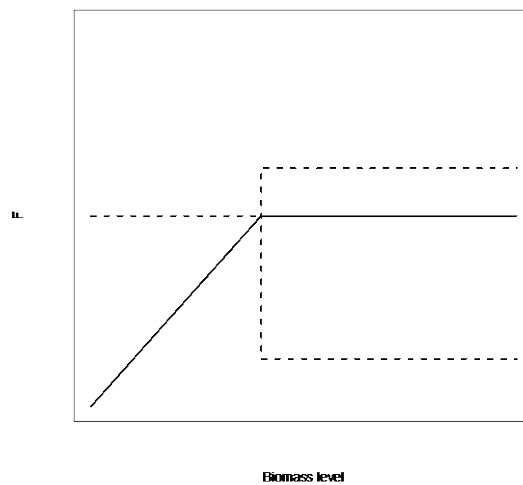
average level), the fishing mortality on mackerel changes. For this rule in particular, we operate with two theories:

When the biomass of the key prey drops below a given threshold, the prey availability of mackerel decreases, hence the fishing pressure should be released as the condition in the stock is likely to decrease.

When the biomass of the key prey drops below a given threshold, the prey availability of mackerel and other stocks in the Norwegian Sea decreases, hence the fishing pressure should be increased to avoid a decrease in the condition of the stock, as there is not enough food to feed them all.

**Table 1: Overview of simulations performed with the different harvest control rules. All in all, 84 simulations have been performed. The ecosystem harvest control rule will either increase/decrease the fishing mortality when the level of zooplankton biomass has been reached.**

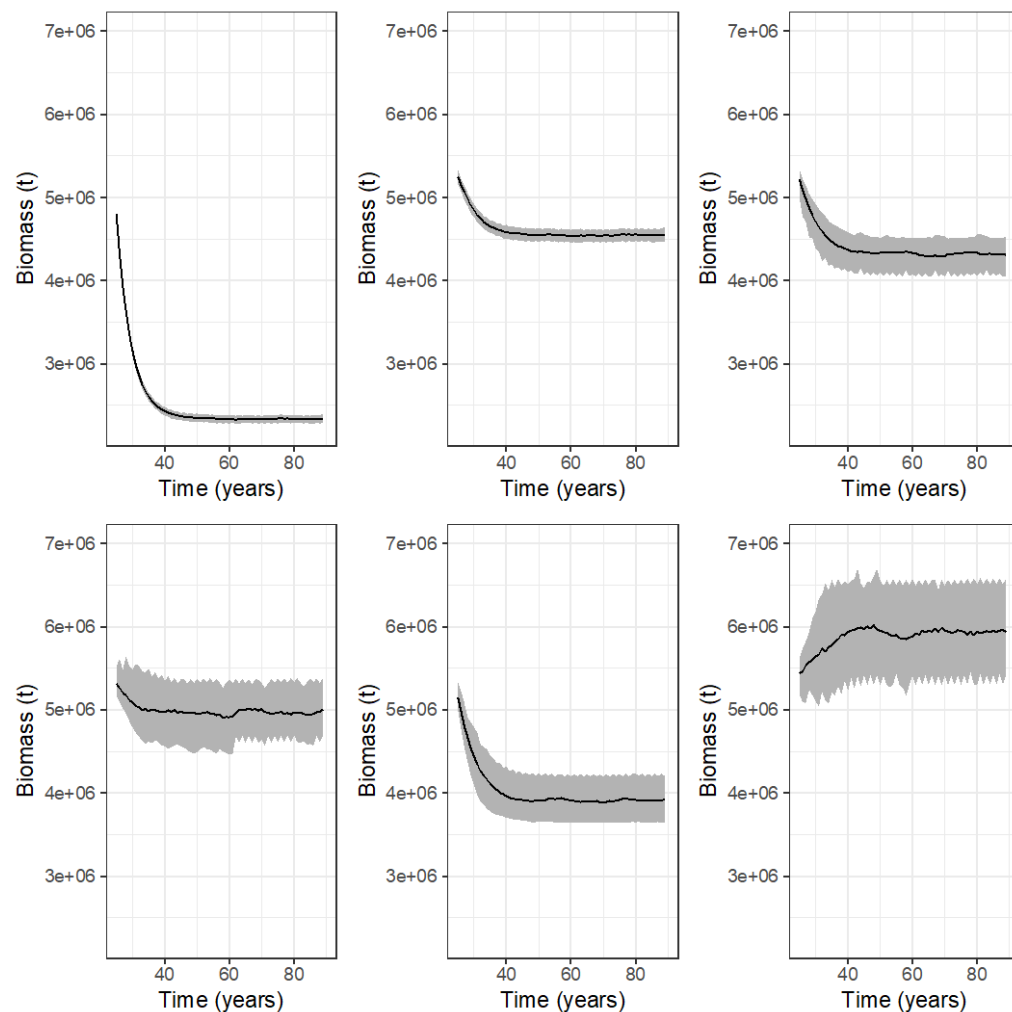
Harvest control rule	Species	Forcing	Decrease/Increase F at low zoop. Biom.	Level of zoop. Biom when increase/decrease	Nr. Sims
Flat MSY F	Mackerel	Zooplankton biomass	-		14
Simple broken stick	Mackerel	Zooplankton biomass	-		14
Ecosystem broken stick	Mackerel	Zooplankton biomass	Increase	0.5	14
Ecosystem broken stick	Mackerel	Zooplankton biomass	Decrease	0.5	14
Ecosystem broken stick	Mackerel	Zooplankton biomass	Increase	0.25	14
Ecosystem broken stick	Mackerel	Zooplankton biomass	Decrease	0.25	14



**Figure 1:** Examples of the shapes of the HCRs applied for mackerel. The dashed lines to the right in the figure are not the real shape of the ecosystem HCRs, but indicate the F level when the zooplankton biomass reaches a defined level. When the zooplankton biomass is above this level, the catches will follow the standard broken stick HCR.

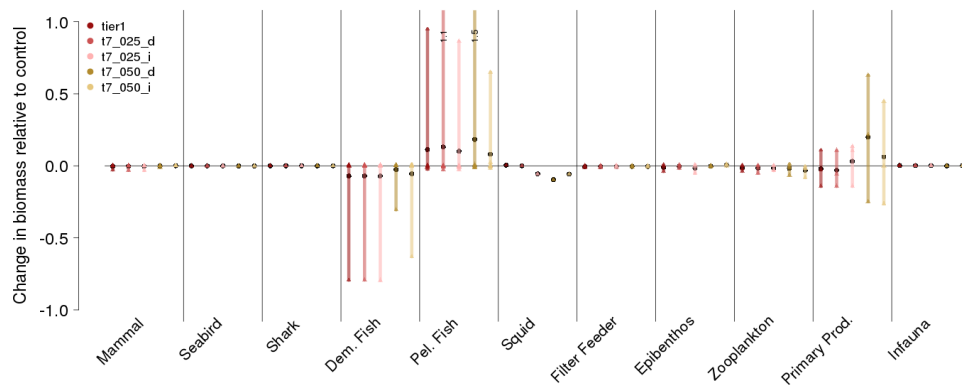
## Results

Mackerel biomass varied with over 3 million tonnes between the scenario with the strictest rule, compared to the scenario that applies the highest catch rates (Figure 2). There is higher variability of the scenarios with ecosystem HCRs, as expected due to the variability added by shifting the zooplankton biomass time-series. The variability in the stock itself is low, something we've also seen for e.g. herring. This might be an artefact with the model system, explained by the lack of an appropriate recruitment option for small pelagic fish. There is in general less than 5% change in condition in mackerel (all cohorts) for the six different scenarios, hence the differences in biomass between the scenarios was driven by changes in the numbers.



**Figure 2: Biomass development in the mackerel stock for the six different scenarios. Top (left to right): Flat  $F_{MSY}$ , broken stick (tier 1), broken stick with ecosystem interaction: increase  $F$  when zooplankton biomass drops below 50% of average level. Bottom (left to right): broken stick with ecosystem interaction: decrease  $F$  when zooplankton biomass drops below 50% of average level. The two are also broken stick with ecosystem interaction, the first increases  $F$  when the level drops below 50%, the second decreases  $F$  when the zooplankton level drops below 50%. The variability of the biomass levels increases significantly for the ecosystem harvest control rules.**

Catches for mackerel are highest for the scenario where we apply a flat  $F_{MSY}$  HCR on the stock. The variability of the catches are also at their lowest for this HCR and for the ordinary broken stick rule. When the ecosystem considerations are taken into account, the variability of the catches increase. For the two HCRs where the  $F$  is increased when the biomass drops below a given threshold, the lower limit of the catches is at approximately the average level of the catches resulting from ordinary broken stick harvest control rule. When  $F$  is decreased when the zooplankton biomass drops below a given limit, the catches has a much larger variability, ranging from close to 0 to the average level of the broken stick catches.



**Figure 3: Ecosystem responses to changes in harvest control rules, excluding zooplankton biomass forcing.**

Considering the effects on the ecosystem level, we decided to use the same approach as in Olsen *et al.*, 2018, by gathering the components in guilds. The results from HCR 2-6 was compared to the results from the scenario applying a flat  $F_{MSY}$  for the last 20 years of the simulations. The only guilds showing a relatively strong response to changes in the harvest control rules, are demersal fish, pelagic fish and primary production. In the demersal fish guild, the component causing the strong responses is haddock. This is a species that we are aware of from other scenarios performed with NoBa, and which is extremely sensitive to changes in the other components of the system. The changes in the phytoplankton is caused by the large phytoplankton, which is indirectly linked to mackerel through zooplankton. The only species varying to a noticeable level in the pelagic fish guild, is the mackerel.

### Discussion/Conclusions

As we've seen for other components in the system, changes made to a single component does not impact the ecosystem structure excessively. This indicates a strong buffering effect in the system, something also seen in the real ecosystem. However, that does not mean that it's not important. With a difference of close to 3 million tonnes in mackerel biomass between the scenarios, the changes in harvest control rules would have a huge impact on that component and on the fisheries that are associated with the stock. Adding an ecosystem component in the harvest control rule adds a lot of variability to the catches. Between the flat  $F_{MSY}$  scenario and the broken stick ecosystem HCR decreasing the harvest when the zooplankton biomass drops below 50%, there is a 78% difference in total catches over the simulation period. It is unfortunate for the results of the scenarios that by forcing the biomass level of mesozooplankton, we turn off the feedback loop between these two, as it would have been extremely interesting to investigate how this would work, and also its effect on the other components. However, within the study, we had 6 simulations that were run without this forcing, and neither of these showed any large ecosystem effects either. Still, without the added variability, it is difficult to conclude that this would have been the case for all scenarios.

Mackerel is a migrating species within NoBa, leaving the model domain for larger parts of the year. Therefore, the fishing mortality was only applied during summertime, decreasing the realized  $F$  to a level of roughly 0.15. This is something that should be further explored. The predation link between herring and mackerel is also lacking. The reason for this is that Atlantis does not explicitly resolve the larvae period, making it



difficult to force the predation link between these two due to lack of overlap at a later stage.

The ecosystem HCRs tested here are rather extreme and leads to large changes in the catches between years, something that would be unfortunate if it existed in the real ecosystem, due to the low predictability of the income from catches. However, it is interesting to see how the mackerel stock changes due to the differences in the HCRs. From a biomass perspective, it is clear that for the mackerel stock isolated, a flat  $F_{MSY}$  would be a poor choice of HCR. A broken stick HCR would lead to much higher biomasses, although decreasing the catches over the simulation period by roughly 30%.

We will continue to explore the effects of the HCRs on the stock and on the ecosystem, by among other changing the recruitment option, and adding predation link between mackerel and herring.

## Annex 9: Ecological Model of the Norwegian Sea and Barents Sea: EwE Norbar Model

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Mimi E. Lam and Tony J. Pitcher

An ecosystem simulation model covering the large marine ecosystem of the Norwegian Sea and Barents Sea has been developed using Ecopath with Ecosim (EwE) (Skaret and Pitcher, 2016). This EwE 'Norbar' model has 58 functional groups to represent the marine food web and its dynamics, including the pelagic fish species, their prey and predators. Norbar was validated against time series abundance data from 1950–2000. The Norbar model is being updated within a value- and ecosystem-based management approach (VEBMA; Lam *et al.*, in review) for the Norwegian spring-spawning herring (NSSH) fishery (Lam, 2016). Recent information on primary production, species abundances, catches, discards, fleet structure, and quota shares are being incorporated. Norbar is being refitted to updated survey, catch, and stock assessment time series data of species abundance, including Bluefin tuna, resurgent in the North Atlantic.

The updated Norbar model is being used to examine Norwegian Sea and Barents Sea ecosystem interactions. It is also being used as a heuristic gaming tool to examine the ecosystem consequences of fisheries management and policy options related to the major pelagic fish species: namely, NSSH, mackerel, blue whiting, and capelin. Encouragingly, Norbar model  $F_{MSY}$  calculated for the main pelagic stocks and their predators (Northeast Arctic cod, coastal cod, haddock, and saithe) are close to the present ICES single-species  $F_{MSY}$  values. Preliminary simulations suggest that the set of  $F_{MSY}$  across these forage fish and predatory fish species are compatible with sustainable fisheries, a finding that cannot be assumed everywhere.

Using the EwE Management Strategy Evaluation (MSE) module (Surma *et al.*, 2018b), and a recent more flexible MSE algorithm (Mackinson *et al.*, 2018, Siple *et al.*, 2018), the ecological impacts and policy tradeoffs of alternative NSSH fishery management scenarios and harvest-control rules will be identified. This ecological modelling approach will be combined with a participatory approach to explicate the knowledge, values and preferences of the principal stakeholders concerned with the NSSH fishery, namely, fishers, scientists, conservationists, managers, policymakers, and civil society. This integrated VEBMA approach considers the diverse values and ecosystem interactions in NSSH fishery management to explore the policy implications of alternative fishery management scenarios.

Multi-model comparisons (Forrest *et al.*, 2015) of ecological (EwE), agent-based (NORWECOM), and end-to-end (Atlantis) models are underway to examine ecosystem interactions and fisheries management within the Norwegian Sea. Specifically, we will compare EwE Norbar model outputs with those from NORWECOM to examine top-down effects of the pelagic fish stocks on zooplankton abundance, as well as with the NoBa Atlantis model to compare MSE results for the NSSH fishery. Extensions of the EwE Norbar model include spatializing it within Ecospace, utilizing spatial catch and survey data, and reconfiguring it based on energy, rather than biomass, to better understand the role of forage fish in marine ecosystems (Surma *et al.* 2018a). These ecosystem models and their spatialized versions will be particularly fruitful in future work using the seascape concept to link oceanographic patterns, ecological processes and management objectives of the pelagic fish stocks in the Norwegian Sea and Barents Sea.

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