WORKING GROUP ON THE INTEGRATED ASSESSMENTS OF THE NORWEGIAN SEA (WGINOR; outputs from 2020 meeting)

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i Executive summary

The task of the Working Group on Integrated Ecosystem Assessments for the Norwegian Sea (WGINOR) is to advance the understanding of the Norwegian Sea ecosystem and to develop an operational approach for integrated ecosystem assessment (IEA) that is applicable to management. This includes research on functional connections within the ecosystem, compiling relevant time series and develop models suitable for IEA. The current report contains the results from the second meeting of a 3-year term which has six Terms of Reference (ToRs).

An interim assessment of the ecosystem (ToR A) shows that since 2016 the water has become fresher and cooled slightly. Primary production has been higher the last 7 years than previously, while zooplankton biomass remains low as it has since 2003. Biomass of the major pelagic stock shows a declining trend and the decline in seabird populations have continued.

Further development of the IEA approach include work with classification of trends in time series of physical and biological ecosystem components (to be used for communication) and warning signal analyses based on trend estimation and an outlier detection analysis of the same time series (ToR A). Work has also been done on a framework for forecasting ocean climate based on statistical models (ToR C) and a foodweb based model assessment with hindcast and forecast properties using a chance and necessity modelling approach (ToR D), and a plan has been made for a framework for exploring multispecies harvest control rules for pelagic fish (ToR B). Further work on these issues will be done in the years 2021-2023 through the research project "Sustainable multispecies harvest from the Norwegian Sea and adjacent ecosystems" at the Institute for Marine Research (Norway).

Work on revising the Norwegian Sea ecosystem overview (EO) was continued (ToR F). A workshop involving experts external to WGINOR will follow up this.

Science highlights from the meeting includes two model-based studies, one on harvest patterns in zooplankton fisheries and another exploring the population and ecosystem effects of changes in harvest control rules of two target species; mackerel and hake; in the Norwegian Sea and the California Current system

ii Expert group information

Expert group name	Working Group on Integrated Ecosystem Assessments for the Norwegian Sea (WGINOR)
Expert group cycle	Multiannual
Year cycle started	2019
Reporting year in cycle	3/3
Chair(s)	Anna H. Ólafsdóttir, Iceland
	Per Arneberg, Norway
Meeting venue(s) and dates	25-29 November 2019, Bergen, Norway (20 participants)
	23-27 November 2020, Online meeting (47 participants)
	22-26 November 2021, Reykjavík, Iceland

1 Terms of Reference

ToR	Description	Background	Science Plan Codes	Duration	Expected Deliverables
A	Perform integrated assessment of the pelagic ecosystem in the Norwegian Sea and develop a framework for identifying warning signals for management.	Addresses needs in the Science Plan for developing understanding of the ecosystem and its responses to human impact and other challenges. In addition, start developing a framework for ecosystem-based advice that can be used by WGWIDE, OSPAR and similar recipients.	6.5	years 1-3	WG report to SCICOM and ACOM January following each year
b	Utilize multispecies and ecosystem models to evaluate effects of single and multispecies harvest control rules on fishing yield and ecosystem state of the pelagic ecosystem in the Norwegian Sea.	Addresses needs in the Science Plan for developing ecosystem-based advice for sustainable use of marine ecosystems resources.	5.3	years 2-3	WG report to SCICOM and ACOM January following year 2 and 3
c	Initiate development of forecast products (1-5 years) for key indices of ocean climate in the Norwegian Sea.	Aims at providing better understanding of links between the physical environment and productivity of the pelagic ecosystem in support of integrated ecosystem assessment.	1.2	years 1-3	WG report to SCICOM and ACOM January following each year
d	Develop a foodweb assessment of the pelagic ecosystem in the Norwegian Sea, including hindcasts and conditional forecasts of the main species or trophic groups.	Aims at providing better understanding of energy flow in the foodweb of the pelagic ecosystem in support of integrated ecosystem assessment.	5.2	years 1-3	WG report to SCICOM and ACOM January following each year
e	Establish a dialogue between WGINOR and relevant pelagic fisheries stakeholders and managers in Norway, Faroe Island and Iceland.	Aims at steering the work of the group so that it addresses management needs.	6.4	years 1-3	WG report to SCICOM and ACOM January following each year
f	Update the ecosystem overview based on the ICES guidelines.	Summarizes key achievements in developing an understanding of the ecosystem and its responses to human impact and other challenges.	6.5	year 3	WG report to SCICOM and ACOM January following year 3

2 Progress on terms of reference

This section describes progress made on the terms of reference. No work was done on ToR E as this would have required a physical meeting with stakeholders from the Faroe Islands, which was not possible due to the covid 19 situation. Progress is therefore reported for ToRs A, B, C, D and F. As part of ToR A, a separate document with a summary of the state of the Norwegian Sea ecosystem has been prepared and is presented in Annex 3. As part of ToR B, a plan for working with exploring multispecies harvest control rules for pelagic fish has been developed and is presented in Annex 4.

Progress on ToRa

The summary document for the state of the Norwegian Sea ecosystem (Annex 3) was prepared as a part of an interim integrated ecosystem assessment (IEA). This document covers the themes ocean climate, primary production, zooplankton, pelagic fish, seabirds, and marine mammals. The core information about ecosystem state is found in Annex 3. Additional information is given in the subchapters below. Thus, the best way to read the interim IEA will for many readers be to first consult the summary in Annex 3 before going to the additional text in this chapter. In this chapter, there is also text on tuna, redfish, Atlantic salmon, and mesopelagic fish, all themes not included in Annex 3. In addition to the interim IEA, work under ToR A was done on classification of trends and a framework for identifying warning signals, and results from this is given at the end of this section.

Interim IEA

Oceanographic condition

No additional text to the summary in Annex 3.

Primary production

Monitoring phytoplankton programs using ocean color observed from space provide global, round the year information that needs to be reduced to produce time series in formats such as reported in key findings. Satellite sensed chlorophyll data were downloaded from NASA ocean color data reprocessed in 2018, as level 3, 8-day binned, 9x9 km resolution arrays and further binned into grid cells limited by 1° longitude and 0.5° latitude. Estimates of net primary production from the Vertically Generalized Production Model were downloaded from www.science.oregonstate.edu.

Figure 1 shows an example from a single grid cell and a single year. The annual averages presented in key findings are from 312 grid cells.

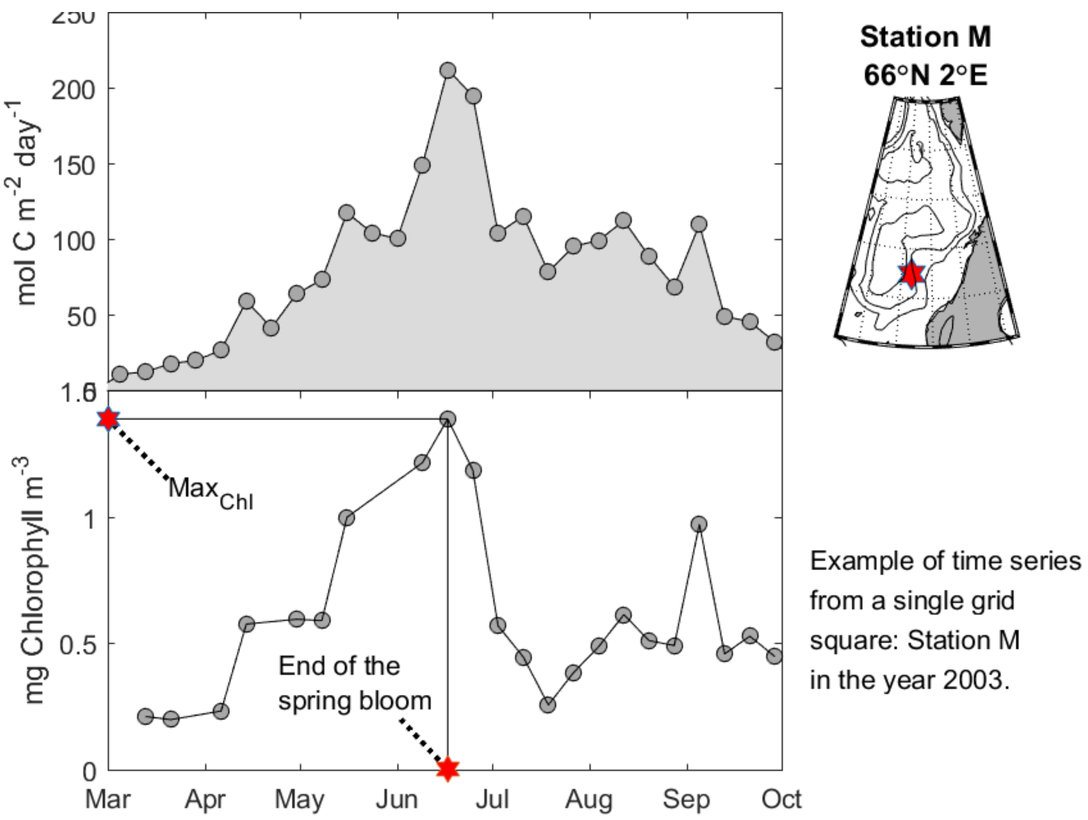


Figure 2.1. Time series from a single grid cell and a single year. Upper panel: NPP. Lower panel: Satellite sensed concentration of chlorophyll.

To produce annual primary production, the weekly data from the VGPM model were integrated through the year, indicated as the grey area in Figure 1. The weekly chlorophyll concentration was used to estimate the end of spring bloom, which is indicated by day with the maximum concentration of chlorophyll. The maximum chlorophyll is marked by red star on the y-axis in Figure 2.1, and the day number is indicated on the x-axis. Invariably, after this peak, the chlorophyll concentrations rapidly decrease, and lower concentrations prevails through summer. In the example, a spring bloom is evident, those are sporadically present.

Zooplankton

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 periods 1995-2015, 2016-2018, 2019 and 2020 (Figure 2.2). In 2020, sampling stations were evenly spread over the area, covering Atlantic- and Arctic waters, and the Arctic frontal zone. The highest zooplankton biomasses were not concentrated in a specific area but spread over several locations in the northern half of the sampling area. High biomasses were found in northwestern parts of the central Norwegian Sea, northeast of Iceland and Jan Mayen, and in an area around Lofoten/Vesterålen and north of that area. Lower biomasses were found in the entire southern part of the sampling area, especially in southwest, where Modified North Atlantic Water dominates. This distribution was different from the mean zooplankton distribution pattern during the period 1995-2015, where the zooplankton biomass was higher in the western part compared to the eastern part of the study area.

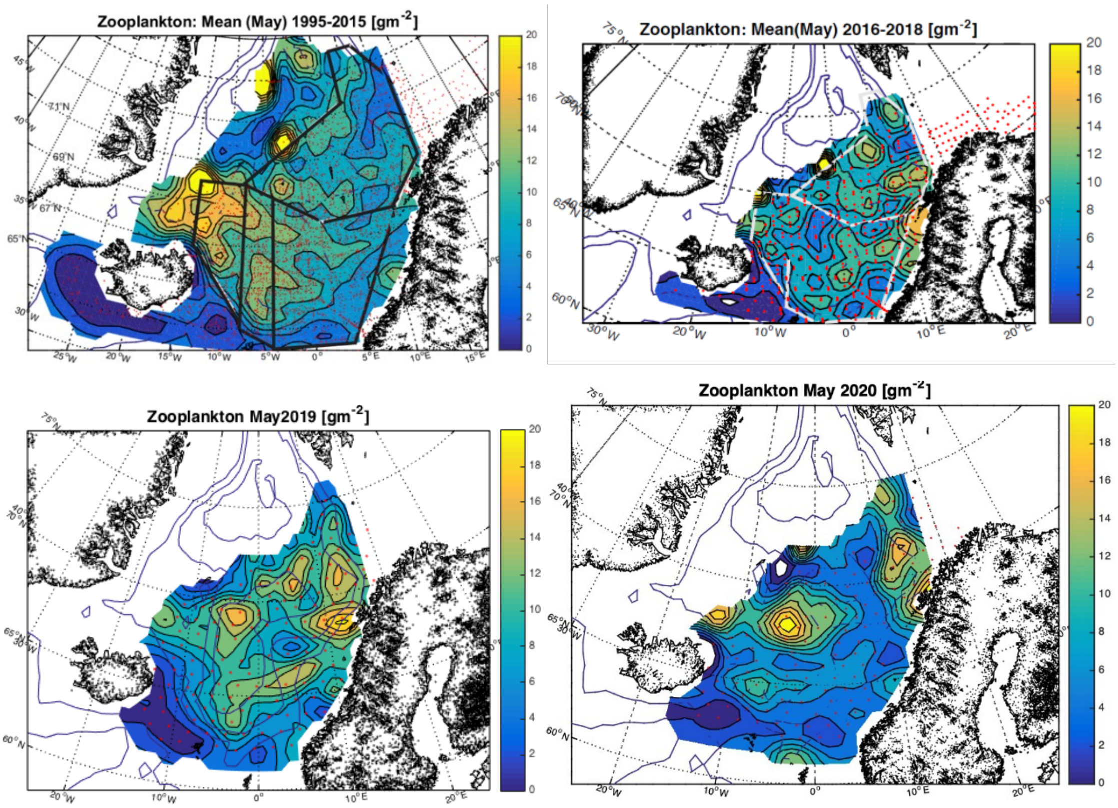


Figure 2.2. Distribution of zooplankton biomass (g dry weight m^{-2}) in the upper 200 m in May in the periods 1995-2015, 2016-2018, 2019, and 2020. Red dots are sampling stations. Bold black lines divide the Norwegian Sea with adjacent areas into different subareas.

The zooplankton biomass index for the Norwegian Sea and adjacent areas in May has been estimated since 1995. For the period 1995-2002 the plankton index for the Norwegian Sea was relatively high (mean 11.5 g), with fluctuations between years (Figure 2.3). From 2003-2006, the index decreased continuously and has been at lower levels since then, with a mean of 7.9 g for the period 2003-2020. There may however have been an increase during the last part of the low-biomass period. This general pattern applies more or less to all the different sub-areas within the sampled area. The zooplankton biomass at the Jan Mayen Arctic front was high until 2007 but has since then been at the same level as the Norwegian Sea. The zooplankton biomass East of Iceland was in general higher compared with the other sub-areas until 2015. In 2020, the zooplankton biomass index for the Norwegian Sea was 8.3 g dry weight m^{-2}, which is a decrease from last year. A similar decrease was observed in all sub-areas, except from East of Iceland where an increase was observed.

The reasons for the changes in zooplankton biomass are not obvious. It is worth noting that the period with lower zooplankton biomass coincides with higher-than-average heat content in the Norwegian Sea ((ICES, 2020g), present report) and reduced inflow of Arctic water into the southwestern Norwegian Sea (Kristiansen et al., 2019). Timing effects, such as match/mismatch with the phytoplankton bloom, can also affect the zooplankton abundance. The high biomass of pelagic fish feeding on zooplankton has been suggested to be one of the main causes for the reduction in zooplankton biomass. However, carnivorous zooplankton and not pelagic fish may be the main predators of zooplankton in the Norwegian Sea (Skjoldal et al., 2004), and we do not have good data on the development of the carnivorous zooplankton stocks. More ecological and environmental research to reveal causes for inter-annual variations and long-term trends in zooplankton abundance is recommended. Quantitative research on carnivorous zooplankton stocks (such as krill and amphipods) across the whole survey area, is an important step in that direction and needs a further effort by all participating countries.

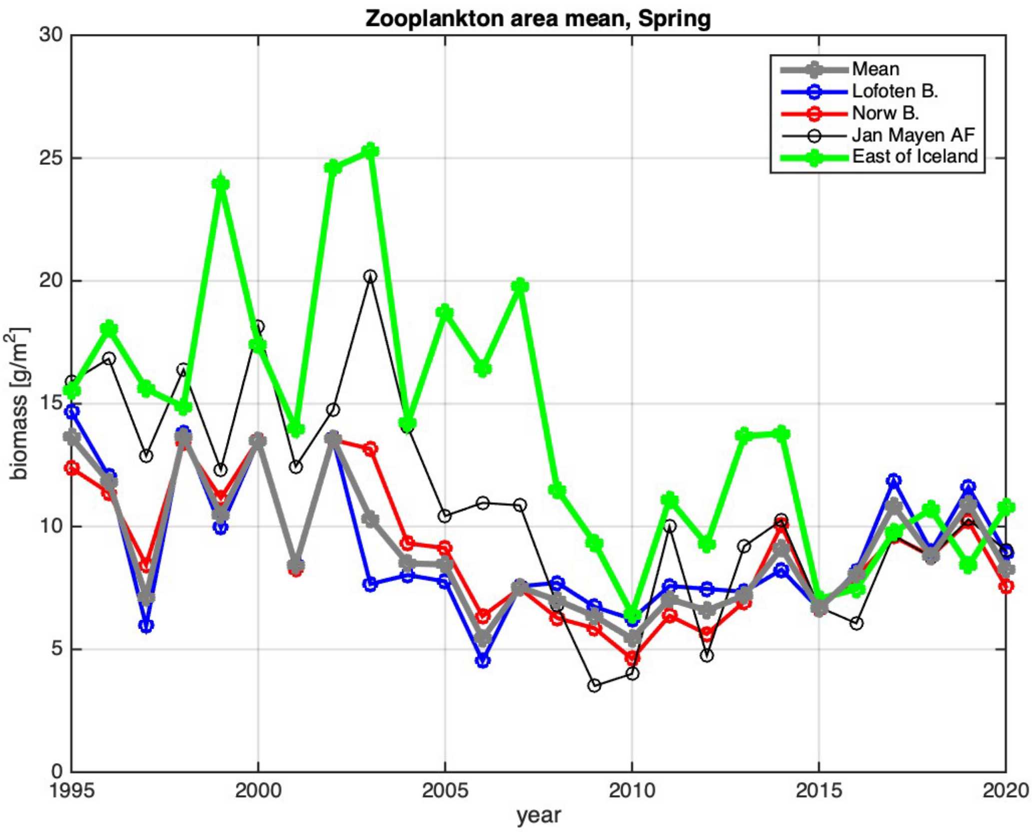
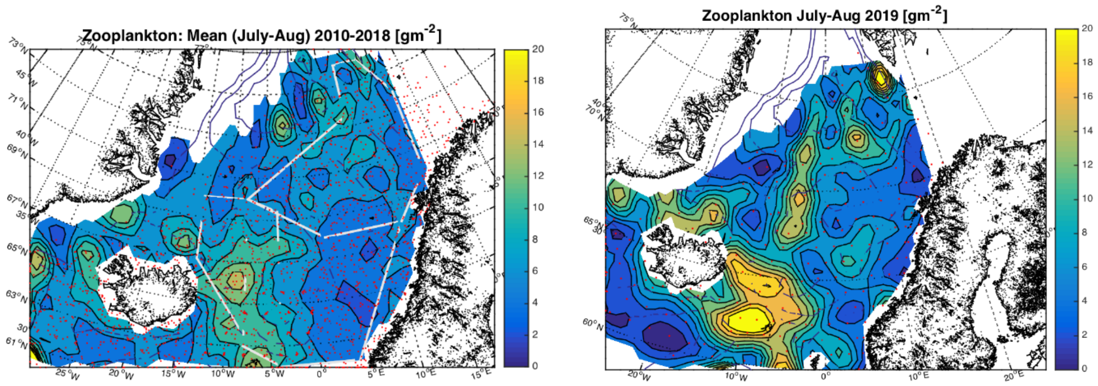


Figure 2.3. Indices of zooplankton biomass (g dry weight m^{-2}) sampled by WP2 in May in the Norwegian Sea and adjacent waters from 1995-2020 as derived from interpolation using objective analysis utilizing a Gaussian correlation function (see details on methods and areas in (ICES, 2016)). The sampling area included in the calculations is delimited to east of 14°W and west of 20°E. To examine regional difference in the biomass, the total area where divided into 4 subareas: 1-red) Southern Norwegian Sea including the Norwegian Sea Basin; 2-blue) The Northern Norwegian Sea including the Lofoten Basin; 3-black) Jan Mayen Arctic front, and 4-green) East of Iceland. The mean index of subarea 1 and 2 is given in grey.

July/August time series (IESSNS). Zooplankton biomass from regional coverages from 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, 2019 and 2020 (Figure 2.4). The zooplankton distribution in 2019 and 2020 was comparable to the averaged distribution for all previous years sampled, however with higher concentrations. In 2020, the highest concentrations were in southwestern Norwegian Sea, in the area between Iceland and Faroe Islands.



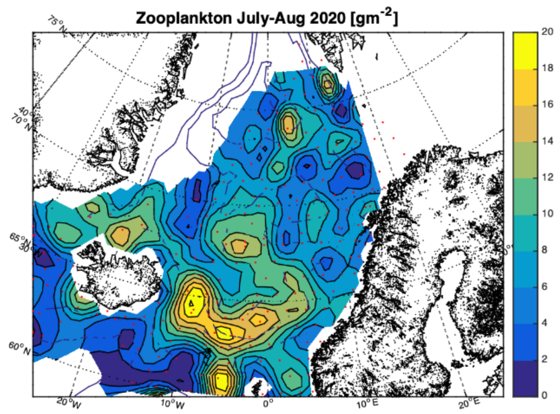


Figure 2.4. Distribution of zooplankton biomass (g dry weight m-2) in the upper 200 m in July/August in the time periods 2010-2018, 2019, and 2020.

Year-to-year variations of zooplankton biomass in July and August is shown in Figure 2.5. After a minimum level in 2011, the biomass may have increased the years after. Highest biomass has in previous years been found in the sub-areas Jan Mayen and east of Iceland. However, the last three years the area east of Iceland have been down to the same level as the Norwegian Sea, while high biomasses have continued in the Jan Mayen area. There seem in general to be an increasing zooplankton biomass trend, however the dataset is too short to draw robust conclusions.

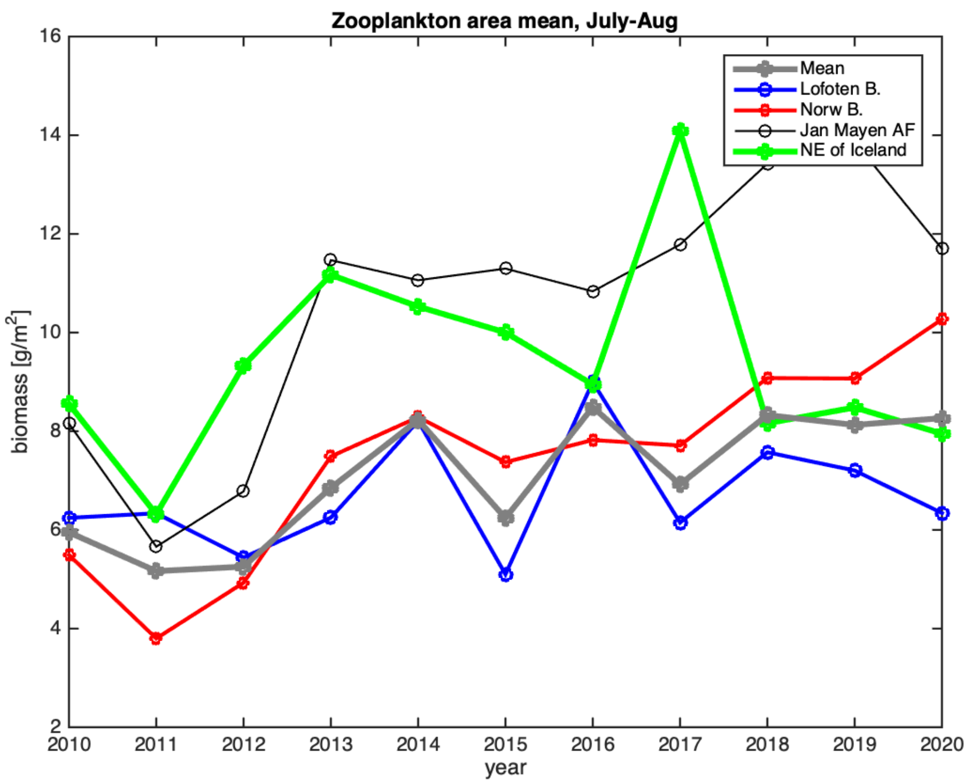


Figure 2.5. Indices of zooplankton biomass (g dry weight m-2) sampled by WP2 in July/August in the Norwegian Sea and adjacent waters from 2010-2020 as derived from interpolation using objective analysis utilizing a Gaussian correlation function (see details on methods and areas in ICES 2016). For description of sub-areas, see text Figure 3.

Pelagic fish

Three fish stocks dominate the pelagic ecosystem of the Norwegian Sea. They are Norwegian spring-spawning herring (NSSH, *Clupea harengus*), Atlantic mackerel (*Scomber scombrus*), and blue whiting (*Micromesistius poutassou*). The cumulated spawning-stock biomass (SSB) of these three species increased for the period 1988 to 2020 ranges from 7.2 to 15.5 million tonnes (Figure 2.6, (ICES, 2020h). Peak biomass was in 2017 and by 2020 it had declined by 28% to 11.2 million tonnes. Biomass of all three stocks has declined during the last three years.

Combined catch of the three stocks was 3.1 million tonnes in 2019, of which approximately half was blue whiting and quarter each for herring and mackerel. Current exploitation level, relative to biological reference points, show that fishing pressure on herring and blue whiting is above management plan targets and above maximum sustainable yield, but within limits for sustainable harvest. There is no international management plan for mackerel and mackerel exploitation is within limits for maximum sustainable yield. Stock status, for all three stocks, is good as SSB is above all biological reference points related to the risk of impaired reproductive capacity, However, herring SSB is very close to biological reference limits (ICES, 2020h).

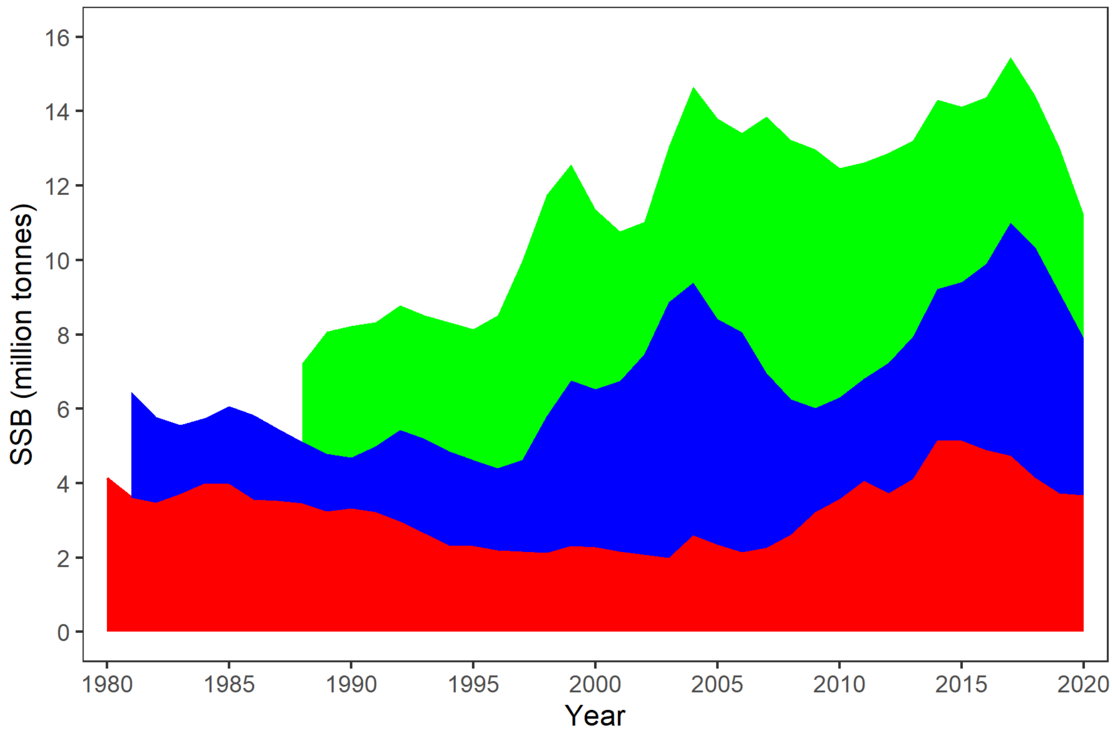


Figure 2.6. Estimated spawning-stock biomass for Norwegian spring-spawning herring (green), mackerel (red) and blue whiting (blue) from 1980 to 2020 (ICES, 2020h).

Summary of stock size, recruitment, somatic growth, and geographical distribution during the last three to four decades

Norwegian spring-spawning herring (NSSH)

Estimated NSSH SSB varied by a factor of 3.5 during the period from 1988 to 2020 (Figure 2.7; (ICES, 2020h)). SSB was lowest in the late 1980s, peaked at 7 million tonnes in 2007-2009 and has since gradually declined to 3.3 million tonnes in 2020. Average SSB, for period 1988-2020, is 4.7 million tonnes. Over a decade of mostly below average estimated recruitment (age 2) is a major factor causing gradual decline of SSB since 2010 (Figure 2.8). The last NSSH year class that was above average recruitment was in 2004. Since 2004, four year-classes have been average and nine have been below average. Furthermore, fishing above advised level accelerates stock decline during a period of low recruitment. Since

2013, commercial catches have been 10% to 64% higher than the ICES advised total allowable catch (ICES, 2020h). In the latest assessment, the recruitment of the 2016 year-class was estimated to be 2.7 billion, which is the largest year class since the 2004 year-class. The 2016 year-class is expected to have fully recruited at around age 7, at which age more precise estimates of year-class strength will be available.

The cause for an extended period of poor recruitment is poorly understood and surprising as SSB has been above average for the last approximately fifteen years. Factors that have been related to year class size at recruitment are spawning success of the spawning stock, influences of the Norwegian coast costal current on larvae survival, predation from mackerel and ecosystem dynamic in their main nursing area in the Barents Sea.

NSSH mean annual growth (measured as length-at-age 6) from 1982 onward fluctuates from 30.7 cm to 34.7 cm, the overall mean is 32.4 cm (Figure 2.9). Growth rate was higher in the 1980s and early 1990s, excluding a few years, compare to the last 25 years. In recent years, growth has been similar to the overall mean. Studies indicate that length-at-age is negatively related to stock size which suggests density-dependent effects on growth (Homrum et al., 2016; dos Santos Schmidt et al., 2020).

NSSH seasonal migration pattern is to spawn along the coast of Norway in February and March. After spawning they migrate towards feeding areas to feed during spring and summer, and aggregate at overwintering area(s) in fall (Holst et al., 2004). Since 1950, herring geographical distribution, specifically during summer feeding and overwintering, has changed several times, both suddenly and gradually (Dragesund et al., 1997; Huse et al., 2010; Utne et al., 2012).

During the 1980s, a period of small stock size, all three stages of the seasonal migration were located close to the Norwegian coast. As the stock increased in size during the early 1990s the summer feeding area expanded offshore into the Norwegian Sea (Dragesund et al., 1997). From 1995 to 2006, NSSH distribution during early summer (May) gradually expanded northward in the Norwegian Sea and westward entering exclusive economic zones of Faroe Islands and Iceland (Utne et al., 2012). In early summer 2005 and 2006, the feeding migration split into two major areas, one located on the north coast of Norway and the other part in the area north of Faroe Islands and east of Iceland (Utne et al., 2012). From 2007 onward, the main area has been north of the Faroe Islands and east of Iceland with some annual variation, and in some years the herring is located further eastward and closer to the west coast of Norway. In some years, another major NSSH aggregation is located close to the north coast of Norway. In 2019 and 2020, the early summer feeding distribution was split between two areas, older fish located north of Faroe Islands and east of Iceland, and aggregations of younger fish were close to the north coast (in 2019) and the central coast (in 2020) of Norway (ICES, 2020d). In general, the summer feeding migration moves east- and north-eastward as the feeding season progresses from May to July. During the feeding season, usually the oldest and largest individuals are located furthest westward and smaller individuals are closer to the Norwegian coast (ICES, 2020c).

In winter 2017/2018, NSSH overwintering location shifted northward along the coast of Norway, and older individuals have occupied oceanic areas. In the past, such changes coincided with large year classes entering the spawning stock, however the recent changes did not. Furthermore, during the last decade onset of the overwintering period has been delayed for unknown reasons.

The mechanism causing changes in NSSH migration patterns is not comprehensively understood but various factors have been suggested to influence observed changes: stock size (Dragesund et al., 1997), recruitment of large year classes to the stock (Huse et al., 2010), prey abundance, feeding competition with mackerel, oceanographic condition, and age composition of the stock.

Currently, three research surveys target distribution and density of NSSH on annual basis using acoustic method: the international ecosystem survey in the Nordic Seas (IESNS) conducted in May-early June from 1995 onward (ICES, 2020d);the international ecosystem summer survey in the Nordic Seas (IESSNS) conducted in late-June to early-August from 2007 onward, excluding 2008-2009 (ICES, 2020c);and the Norwegian acoustic survey on the NSSH spawning grounds in February-March which has been conducted from 1988 onward, excluding 2001-2004 and 2009-2014 (ICES, 2020h).

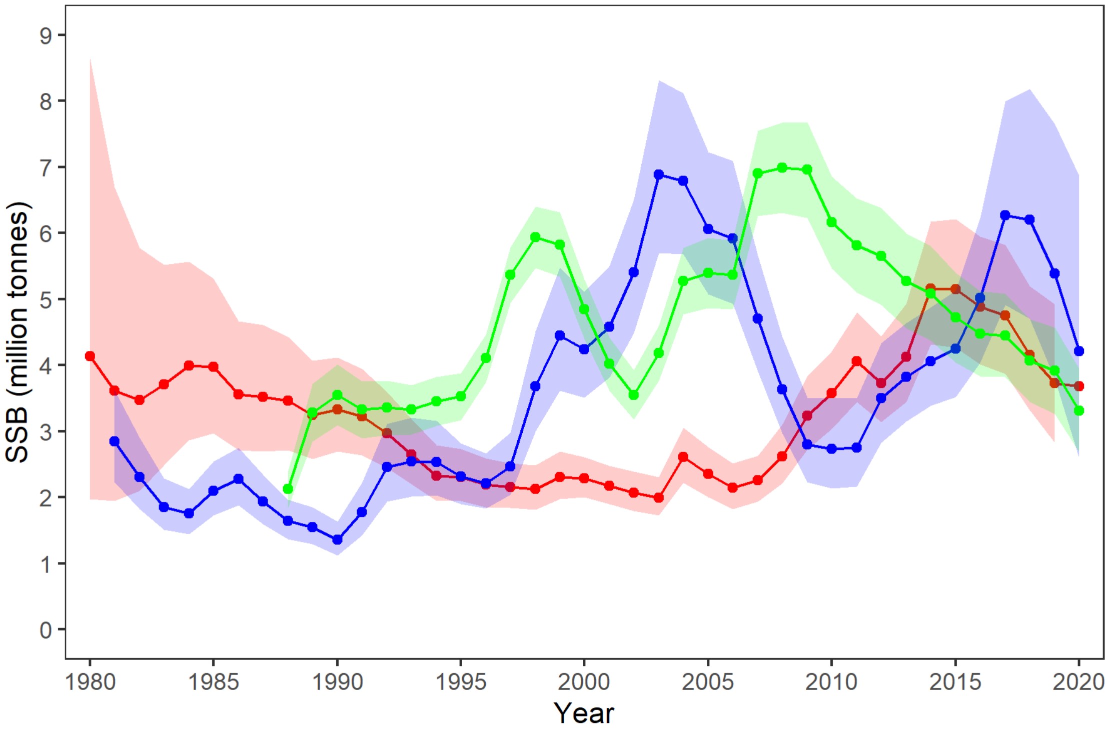


Figure 2.7. Estimated spawning-stock biomass (line) and 95% confidence intervals around the estimated biomass (shaded areas) for Norwegian spring-spawning herring (green), mackerel (red) and blue whiting (blue) from 1980 to 2020 (ICES, 2020h).

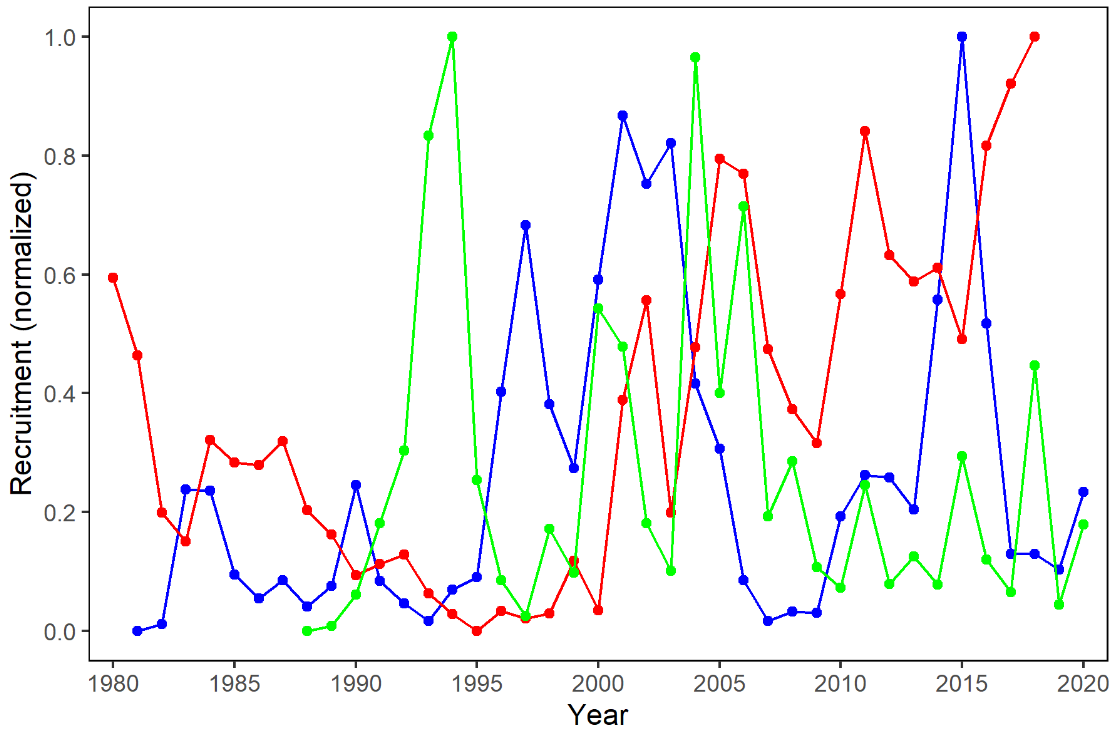


Figure 2.8. Estimated year-class strength (*i.e.* recruitment) of Norwegian spring-spawning herring (age 2, green line), mackerel (age 0, red line) and blue whiting (age 1, blue line) from 1980 to 2020 based on the most recent assessment compared to the average for the total period (ICES, 2020h). Recruitment values normalised to a common scale with the maximum value of one and the minimum value of zero.

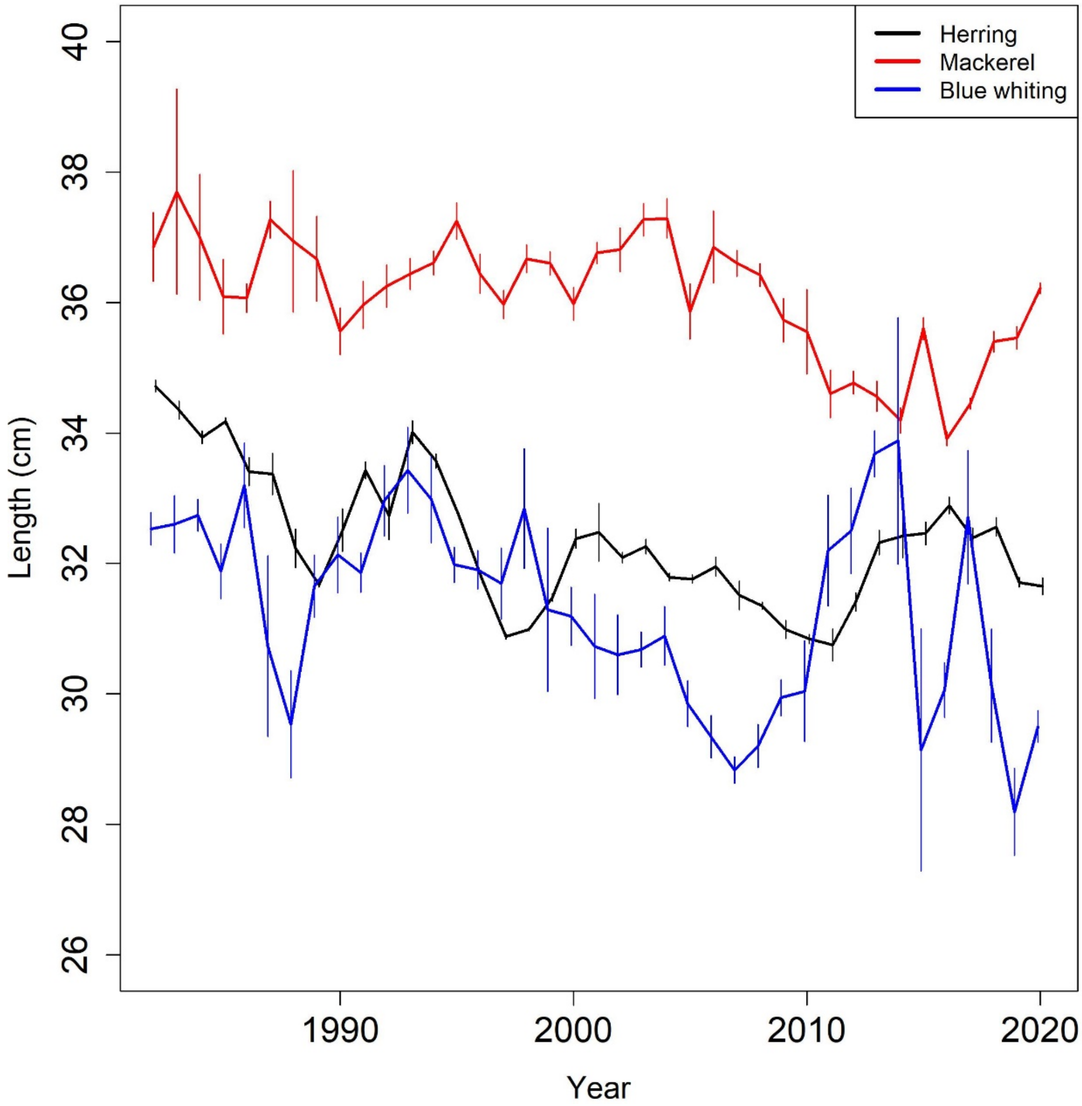


Figure 2.9. Mean total length with one standard deviation for 6-year old Norwegian spring-spawning herring (NSSH), mackerel and blue whiting in the Norwegian Sea from 1982 to 2020. Data are from the winter period (October-March for NSSH, October-April for mackerel, January-March for blue whiting) when the individual growth is assumed minimal. Data from IMR, Bergen, Norway.

Northeast Atlantic mackerel

Estimated mackerel SSB during the period from 1980 to 2020 has varied by a factor of 2.6, and ranges from 2.0 to 5.2 million tonnes with an average of 3.2 million tonnes (Figure 2.7; (ICES, 2020h)). SSB was above average in the 1980s, gradually declined during the 1990s and into the early 2000s with a minimum of 2 million tonnes in 2003. In the mid-2000s, SSB began increasing and peaked at 5.2 million tonnes in mid-2010s and has since declined to 3.7 million tonnes (ICES, 2020h).

The increase in SSB from 2007-2015 was facilitated by recruitment of many large year-classes. From 2001 onward, 16 of 20 year-classes are estimated above the long-term average compared to 2 of 21 year-classes above the average for the period from 1981 to 2000. However, despite good recruitment, the SSB has been declining since 2015, and in 2020 there was also a marked drop in the recruitment compared to the previous four years (Figure 2.8). Research suggest that prey availability during the 0-group feeding season influences year-class size at recruitment (Jansen, 2016), however the mechanism deciding year-class strength is not fully understood.

During the period 1998 to 2019, mackerel has been fished above advised levels in all years except one. The amount of annual catch above advised total allowable catch (TAC) ranges from 9% to 86% of TAC and the average is 34% (ICES, 2020e).

It is worth noting that the mackerel stock assessment has suffered difficulties and frequent revisions in recent years (ICES, 2019g). Since 2014, there have been three benchmarks, all resulting in either changes to the stock assessment model, the input data or model settings which have drastically changed perception of the stock, SSB and fishing mortality (ICES, 2014; ICES, 2017; ICES, 2019b). The main cause for unstable assessment results are conflicting signals between data sources and short input time series (ICES, 2019b). When additional year of data is added, weight of data sources changes in the assessment model resulting in a revised estimated SSB and mean F (ICES, 2019b). The last benchmark was in 2019, the changes done to the assessment resulted in the forecasted mackerel SSB, for 2019, to increase from 2.1 million tonnes to 4.3 million tonnes (ICES, 2018; ICES, 2019b). Subsequently, the fishing advice for mackerel in 2019 increased from 318 thousand tonnes to 770 thousand tonnes. To improve the fishing advice for mackerel, ICES initiated work on a mackerel research roadmap in collaboration with the fishing industry, managers, and scientists in spring 2019, and the aim is to improve the advice within 3-5 years (ICES, 2019g).

Even though the mackerel catches the last decade have been above the long-term average, mackerel has been fished sustainably since 2016 according to the most recent ICES advice which is from 2020 (ICES, 2020e).

Mackerel average annual growth (measured as length-at-age 6) from 1982 to 2019 fluctuates from 33.9 cm to 38.3 cm with an overall mean of 36.6 cm (Figure 2.9). Length-at-age was higher in the earlier part of the period compared to the last fifteen years. There was a declining trend from mid-2000s to mid-2010s, but since 2016 it has increased again, reaching the long-term average in 2020. Somatic growth rate of juvenile mackerel is negatively related to mackerel abundance (Jansen and Burns, 2015) and growth of mature mackerel is negatively related to mackerel and NSSH abundance (Olafsdottir et al., 2015). The observed increasing trend in growth during the last few years coincides with declining mackerel and herring SSB.

Mackerel is a widely distributed and highly migratory stock, their north-to-south distribution boundary range approximately from 78 °N to 36 °N in the North Atlantic (Utne et al., 2012; Brunel et al., 2017; ICES, 2019f; Olafsdottir et al., 2019). Their migration cycle is characterized by feeding in the northern part of their distribution, centred on the Norwegian Sea, during summer and fall and spawning in the southern part in January to July, southward from the Norwegian Sea (Utne et al., 2012; Brunel et al., 2017; Olafsdottir et al., 2019). From the 1990s to 2020, large changes have been observed specifically in mackerel summer feeding distribution and on a smaller scale in location of their spawning area.

Prior to mid-2000s, summer feeding distribution was limited to the Norwegian Sea (east of longitude 10°W and south of latitude 72°N), the North Sea, and the shelf west of Scotland (Utne et al., 2012). From mid-2000s to mid-2010s their feeding distribution range expanded westward, towards the coast of Greenland, by approximately 1650 km and northward, towards Svalbard, by approximately 400 km (Olafsdottir et al., 2019). Concurrently centre-of-gravity of the stock shifted northward and westward. Distribution range peaked in 2014 when the mackerel distribution range during July in Nordic Sea was measured as 2.5 million km^2 (Olafsdottir et al., 2019). From 2014 to 2020, distribution range in the westward expansion area (longitude > 10°W) has retracted from the east coast of Greenland (longitude 44°W) to the southeast coast of Iceland, approximately longitude 17°W (Olafsdottir et al., 2019; ICES, 2020c). Retraction of the westward area coincided with centre-of-gravity shifting towards the northeast and it was located east of Jan Mayen and in the northern part of the Norwegian Sea in July 2020 (ICES, 2020c).

Expansion in mackerel summer distribution range was facilitated by increasing stock size and constrained by availability of preferred temperature (9 – 13 °C) and mesozooplankton abundance (Olafsdottir et al., 2019). It is not understood why mackerel distribution in the westward area drastically retracted, from 2015 to 2020, compared to mackerel distribution in the Norwegian Sea. In 2020, temperature in the westward area was within the range preferred by mackerel and mesozooplankton abundance was similar compared to years when mackerel was abundant in the area (ICES, 2020c). Research is needed to understand which factors influence the migration route taken by mackerel after spawning, whether they migrate northward into the Norwegian Sea or westward towards Iceland and Greenland.

Mackerel spawning distribution is centred on the continental shelf edge from the Bay of Cadiz, Spain (approximately longitude 36°N) to the west coast of Norway (approximately latitude 64°N); it starts in the south in January and moves northward as winter progresses into summer (ICES, 2019e). Since 1998, peak spawning varies between years from February/March to June and location of the major spawning area has shifted along the shelf edge between Bay of Biscay, in the south, to the shelf edge west of Ireland, in the north (ICES, 2011; ICES, 2019e). Spawning location has been related to coordinates and bottom depth but not to the physical environment (Brunel et al., 2017).

Currently, two research surveys target distribution and density of mackerel. The international ecosystem summer survey in the Nordic Seas (IESSNS) uses standardized swept-area trawling in the surface mixed layer to measure mackerel density during the summer feeding season (ICES, 2019a). This survey is conducted during the period from late-June to early-August and has been executed annually since 2007, excluding 2008-2009. The ICES triennial mackerel and horse mackerel egg survey measures mackerel daily egg production during the spawning season and has been conducted during the period from January/February to July every third year since 1992 (southern and western stock component) and the last one was in 2019 (ICES, 2019e).

Blue whiting

Estimated blue whiting SSB during the period from 1981 to 2020 varies by a factor of 4, and ranges from 1.4 to 6.9 million tonnes with an average of 3.6 million tonnes (Figure 2.7; (ICES 2020a)). SSB was low prior to late-1990s and has since fluctuated between low and high levels with peak abundance in mid-2000s and late-2010s (ICES 2020a). Year-class size shows similar trend in size compared to SSB except changes occur a few years in advance of SSB changes (Figure 2.8). This is expected as year-class size at recruitment has major effects on SSB. It is worrying that year-class size at recruitment remains low for the fourth consecutive year which is reflected in the recent declining trend in SSB.

During the period from 1995 to 2020, blue whiting was fished both above and below advised levels. The fishing has been 16% to 55% above advised levels with an average of 30% (ICES, 2020b).

Blue whiting average annual growth (length-at-age 6) from 1982 to 2020 fluctuates from 28.2 cm to 33.9 cm with an overall mean of 31 cm (Figure 2.9) Growth has a declining trend since 2017 with a record low mean weight in 2019, see figure 2.9.

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 according to the fishery during the spawning time (ICES 2020a). No spawning stock survey was undertaken in 2020 due to the Covid-19 situation. Post-spawning migration has been into the southern Norwegian Sea on both sides of the Faroe Islands and along the continental slope off the Norwegian coast (ICES 2020a). No drastic change was observed in blue whiting distribution in the Norwegian Sea during spring and summer 2020 compared to previous years (ICES 2020a).

Currently, two research surveys target distribution and density of blue whiting on annual basis in the Norwegian Sea using acoustic methods: the international ecosystem survey in the Nordic Seas (IESNS) conducted in May-early June from 1995 onward (ICES 2020c); and the international ecosystem summer survey in the Nordic Seas (IESSNS) conducted in late-June to early-August from 2007 onward, targets blue whiting since 2016 (ICES, 2020c).

Atlantic salmon

Atlantic salmon live their first years in the river where they are born, and thereafter migrate to the sea where they spend 1-3 years. The pre-fishery abundance (PFA) of salmon both in the northern (Norway, Finland, northern Iceland, Sweden, Russia) and southern (Denmark, Ireland, UK, France, Spain, Germany) part of Europe has declined since the time-series started in 1983 (ICES, 2020f). The total (1 sea-winter and multi sea-winter) PFA for 2019 was the lowest in the time series. Salmon are affected by a wide range of factors in the rivers, coastal regions, and open oceans. Decreasing return rates for salmon can partly be explained by issues such as acid rain, salmon lice and parasites (Forseth et al., 2017). Nevertheless, part of the decline is due to lower survival at sea. The Norwegian Sea is an important feeding ground, especially for post-smolts during their first summer in the sea (Holm et al., 2000). Poorer feeding conditions for post-smolt has been forwarded as a hypothesis for the lower survival in the sea. There was a declining growth rate for post-smolt sampled in the Norwegian Sea in the period 2002 – 2009 (Jensen et al., 2012). Whether the low growth rates have continued in recent years is unknown. Warmer waters due to climate change is affecting plankton production, which is correlated to salmon catches (Beaugrand and Reid, 2012; Almodóvar et al., 2019). However, the direct mechanisms affecting salmon survival is unknown.

Redfish

The population of beaked redfish (*Sebastes mentella*) undergoes migrations between the continental slopes and the open Norwegian Sea in summer where it is primarily found in the mesopelagic layer. Beaked redfish is a long-lived species (>50y) with known important variations in recruitment and slow changes in stock biomass. Since 2016, estimated recruitments have been at high levels with (>400 million new age-2y individuals each year). The spawning-stock biomass has been relatively stable around 850 thousand tonnes for the last 15y while the total-stock biomass has gradually increased from 1 to 1.4 million tonnes during the same period (Figure 2.10). The bulk of the population biomass is constituted by fish of age 24-33y (born in 1986-1995) and 5-16y (born in 2003-2014). The total catches have increased since the early 2000. The first increase in 2006 coincided with the start of a new pelagic fishery in the international waters of the Norwegian Sea and the second increase in 2014 coincided with the opening for a pelagic and demersal fishery in Norwegian waters. The catches in 2019 (~46 thousand tonnes) are the highest since 1986.

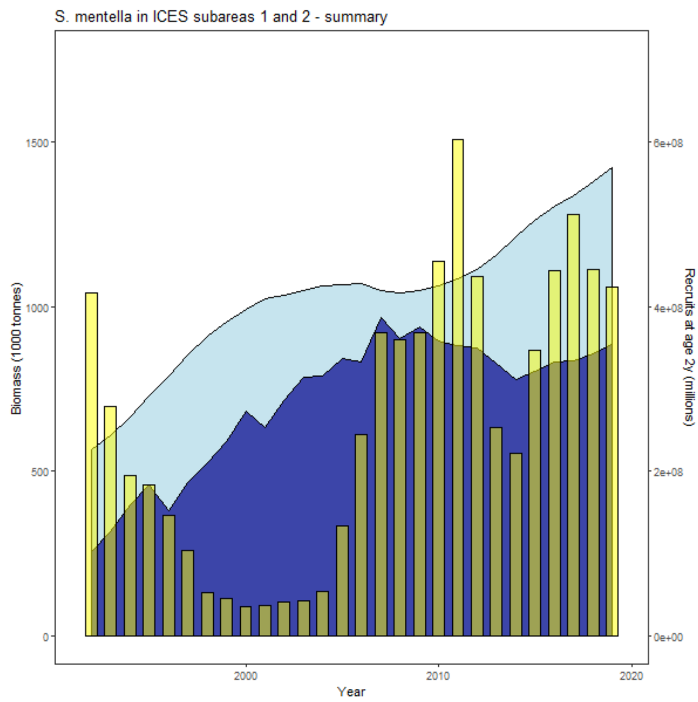


Figure 2.10. ***Sebastes mentella*** **in subareas 1 and 2. Results from the statistical catch-at-age model showing the evolu-tion of total biomass (in tonnes light blue left axis) spawning-stock-biomass (in tonnes dark blue left axis) and recruit-ment-at-age 2 (in num-bers yellow right axis) for the period 1992–2019 for *S. mentella* in subareas 1 and 2 (ICES, 2020a).**

Atlantic bluefin tuna

We have witnessed a successful comeback of Atlantic bluefin tuna (BFT) to Norwegian waters includ-ing the Norwegian Sea from around 2012 (Nøttestad et al., 2020a), with a significant increase in BFT observations during the last few years (Boge, 2019; Nøttestad et al., 2020a). BFT have reoccurred in increasing numbers in the Norwegian Sea and along the coast of Norway during the last years, and there have been a furthermore increased targeted fishing and different scientific studies conducted in 2020. The targeted commercial fishing in 2020 has been done by eight purse-seine vessels and four small longline vessels. The Norwegian quota for BFT was around 313 tons in 2020. It is predominantly small school sizes of BFT which have been taken by the purse-seine vessels during the last few years (Nøttestad et al., 2020b). There has also been conducted rod-and reel fishing on BFT mainly for scientific purposes along the coast of Norway in 2020 (Ferter et al., 2020). A substantial number of biological and genetic samples have been taken from altogether 359 individual fish from August - September 2020. A total number of 359 genetic samples, 359 spines and 163 pair of otoliths have been taken from large BFT for further analyses on e.g. age determination and origin of spawning site. The Institute of Marine Re-search (IMR) in Norway has also in 2020 received samples from BFT penetrating and trapping them-selves into Atlantic salmon farms along the coast of Norway. There has also been conducted successful satellite tagging of five individuals and nine spaghetti tags of BFT along the west coast of Norway waters in 2020. This is the first time that BFTs have been tagged with PSATs north of 61°N (Ferter et al., 2020), which will fill important knowledge gaps (Horton et al., 2020; Nøttestad et al., 2020a). IMR has also initiated acoustic studies of BFT in Norwegian waters in 2020 using multibeam sonars and multi-frequency echosounder together with visual observations.

Observations of bluefin tuna have been reported throughout the season from July to November. The lesser occurrence of juvenile mackerel as prey for BFT along the coast of Norway witnessed in both 2019 and 2020 compared to in 2018 (Bjørdal, 2019), may have influenced the feeding migration pattern and behavior of BFT entering and staying within the Norwegian Sea and along the Norwegian coast in 2020.

Mesopelagic fish

The deep scattering layer (DSL) is a near-permanent feature of the Norwegian Sea waters. This layer is located at depths where light intensity is very low and is composed of a wide variety of species including fish, crustaceans, cephalopods and gelatinous plankton. The actual depth of DSL varies with season and time-of the day. Although estimates of the biomass present in the mesopelagic layer are still highly uncertain, hydroacoustic registrations can provide qualitative information about the location and density of biomass in different regions and depths. The International Deep Pelagic Survey in the Norwegian Sea (ICES, 2019d) registers acoustic energy down to a maximum depth of 800m, over most of the Deep Norwegian Basin of the Norwegian Sea. During this survey, the acoustic energy in the epi- and meso-pelagic layers have been recorded following the method outlined in (Siegelman-Charbit and Planque, 2016). Using these registrations, an index of the ratio of meso- over epipelagic energy is produced. The time series of this ratio is provided in table 2.1. Since 2008, there appear to have been an increase in the ratio of acoustic energy between the mesopelagic and the epipelagic layer. This increase appears primarily due to a decrease in the energy recorded in the epipelagic layer while the energy recorded in the mesopelagic layer is variable but does not display any long-term trend. How much this reflects changes in the biomass or species composition is not known.

Table 2.1: Average acoustic energy (s_A) recorded in the epipelagic and mesopelagic layers (m^2/nmi^2) and the ratio between the two layers.

	Epipelagic	Mesopelagic	Meso/Epi
2008	116	133	1.2
2009	71	140	2
2013	NA	NA	NA
2016	53	184	3.5
2019*	(25)	(104)	4.2

** in 2019 the echosounder was not calibrated before the survey. The absolute energy estimates in each layer are therefore uncertain. The ratio between these two estimates is however robust to mis-calibration. These results were communicated by Hannes Höffle (Norway) in advance of their publication in the forthcoming WGIDEEPS report 2020.*

Seabirds

Introduction about Seabird indicators for the eastern Norwegian Sea

Mapping and monitoring of Norwegian seabirds is organized through SEAPOP (www.seapop.no/en) and the National monitoring programme for seabirds, an integrated part of SEAPOP. In the eastern part of the Norwegian Sea a total of 15 seabird species, representing 5 foraging habitat ecotypes (pelagic surface/diving and coastal surface/diving/benthic) are monitored at 5 key-sites. Annually, 117 times series, on average > 20 years long are updated and made available for management authorities and the public through SEAPOP's webpage and used for a wide variety of analyses to uncover the main drivers of population trends.

Five species of seabirds feeding in the pelagic (3) and coastal (2) parts, of the ecosystem, are selected as indicator species for the eastern part of the Norwegian Sea, i.e. along the central part of the Norwegian coast (hereafter eastern Norwegian Sea).

The pelagic species are represented by the black-legged kittiwake (*Rissa tridactyla*), Atlantic puffin (*Fratercula arctica*) and common guillemot (*Uria aalge*). The main reason for selecting these species is that they feed in different parts of the pelagic ecosystem. The black-legged kittiwake obtains its food within the upper half meter of the sea surface layer in the form of (in the Norwegian Sea) 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 m and may prey heavily on very small fish such as 0-group cod (Erikstad et al., 2013) but most often feeds its chick 10-15 cm long fish. In the eastern Norwegian Sea the chicks are fed mainly young saithe and haddock, to a lesser extent sandeel and herring (Barrett et al., In manuscript), all of which are brought back to the colony one by one. The Atlantic puffin typically feeds at depths down to 30 m and brings loads of smaller fish to the chick, in the eastern Norwegian Sea in particular first-year herring along with sandeel and gadids. Outside the breeding season, puffins also feed on crustaceans.

Representatives of the coastal species are the common eider (*Somateria mollissima*) and the European shag (*Phalacrocorax aristotelis*, hereafter shag), which were selected because they feed in different parts of the coastal ecosystem. The common eider mainly feed on benthic prey like crustaceans, molluscs and echinoderms, but can also utilize polychaetes and fish species. The shag is a fish specialist, typically feeding at depths down to 50 m. In Norwegian waters the diet typically consists of sandeels or gadids (e.g. (Barrett et al., 1990; Hillersøy and Lorentsen, 2012)).

Average generation time has been estimated at around 10 years for black-legged kittiwake, 14 years for Atlantic puffin, 15 years for common guillemot, 11 years for common eiders and 9 years for shags (Bird et al., 2020). Common eiders typically lay 3-5 eggs, shags 2-3, kittiwakes two (1–3), whereas the common guillemot and Atlantic puffin only lay a single egg. Except for the breeding season, the pelagic species spend their entire life at sea, whereas the coastal ones stay at the coast.

Population sizes

The total population sizes of seabirds breeding on the coasts of the Norwegian parts of the Norwegian Sea in 2013 were estimated based on the latest counts in all areas (Table 2.2, (Anker-Nilssen et al., 2015)), which for the mainland were also adjusted for trends in numbers at the monitored colonies (Fauchald et al., 2015). In total, the Norwegian Sea including Jan Mayen has about 1.3 million pairs of breeding seabirds. The pelagic feeding species are the most abundant. Atlantic puffin dominate in numbers (> 550,000 pairs; 44% of all seabirds), whereas the common guillemot and black-legged kittiwake populations counts only 3000 and 50,000 pairs, respectively. For the coastal breeding indicators, the common eider and European shag populations numbers 41,000 and 9000 pairs respectively. Updated estimates are planned to be produced in 2021.

Table 2.2 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), European numbers are from (Mitchell et al., 2004)).

Species	Mainland coast of Norway	Jan Mayen	Sum	Norway total (incl. Svalbard & Jan Mayen)	Europe total
Northern fulmar	< 1,000	> 170,000	177,500	± 1,000,000	3,000,000
European storm-petrel	> 1,000	0	> 1,000	< 10,000	690,000
Leach's storm-petrel	> 100	0	> 100	< 1,000	150,000
Northern gannet	3,600	0	3,600	5,700	300,000
Great cormorant	13,500	0	13,500	21,000	45,000
European shag	9,000	0	9,000	28,000	81,000
Common eider	41,000	< 100	41,000	104,000	2,000,000

King eider	0	0	0	500	500
Great skua	90	< 10	100	1,100	16,000
Arctic skua	< 1,000	< 10	< 1,000	3,000	17,500
Common tern	< 3,000	0	< 3,000	< 11,000	300,000
Arctic tern	20,000	< 1,000	21,000	< 40,000	750,000
Common gull	75,000	0	75,000	90,000	500,000
Lesser black-backed gull	6,500	< 10	6,500	28,000	180,000
Herring gull	42,000	< 10	42,000	72,000	850,000
Glaucous gull	0	> 200	> 200	4,000	21,500
Great black-backed gull	30,000	< 10	30,000	43,000	120,000
Black-legged kittiwake	44,000	< 10,000	> 50,000	340,000	2,500,000
Ivory gull	0	0	0	2,000	2,000
Common guillemot	2,600	< 1,000	> 3,000	150,000	2,900,000
Brünnich's guillemot	0	> 110,000	> 110,000	725,000	1,000,000
Razorbill	< 10,000	< 100	< 10,000	55,000	500,000
Little auk	0	< 100,000	< 100,000	± 1,000,000	> 1,000,000
Black guillemot	15,000	< 1000	> 15,000	55,000	200,000
Atlantic puffin	553,000	< 5 000	< 558,000	1,500,000	5,500,000
Total	870,000	400,000	1,270,000	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) and (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).

Population 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 (pelagic species) or mid-1980s (coastal species).

Pelagic seabird indicators

For the three pelagic species, time series of population size development in the eastern Norwegian coast (Figure 2.11) were derived from their estimated regional breeding numbers in 2013 (Fauchald et al., 2015) and annual monitoring of trends in selected breeding colonies. The main colonies (key-sites) monitored in this area are Runde (62.4°N), Sklinna (65.2°N), Røst (67.5°N) and Anda (69.1°N, only black-legged kittiwake and Atlantic puffin). Time series from the remote island of Jan Mayen (71.1°N)) in the north-western Norwegian Sea are not considered here. As there was no monitoring of common guillemots at Runde and Røst in 1984–1987, we assumed a constant rate of change over those years.

The breeding population of black-legged kittiwake in the eastern Norwegian Sea has declined by 78% since monitoring started in 1980. Its outlook is grim, with several large colonies already gone and many more risking extinction within a few decades (Sandvik et al., 2014).

The breeding population of Atlantic puffin in the eastern Norwegian Sea has declined by 75% since monitoring started in 1980.

The breeding population of common guillemot in the eastern Norwegian Sea has declined by as much as 99% in the same period. The remaining population breeds in shelter of predation and are currently relatively stable, but the species is at high risk of extinction as a breeding species along a large part of the Norwegian mainland coast.

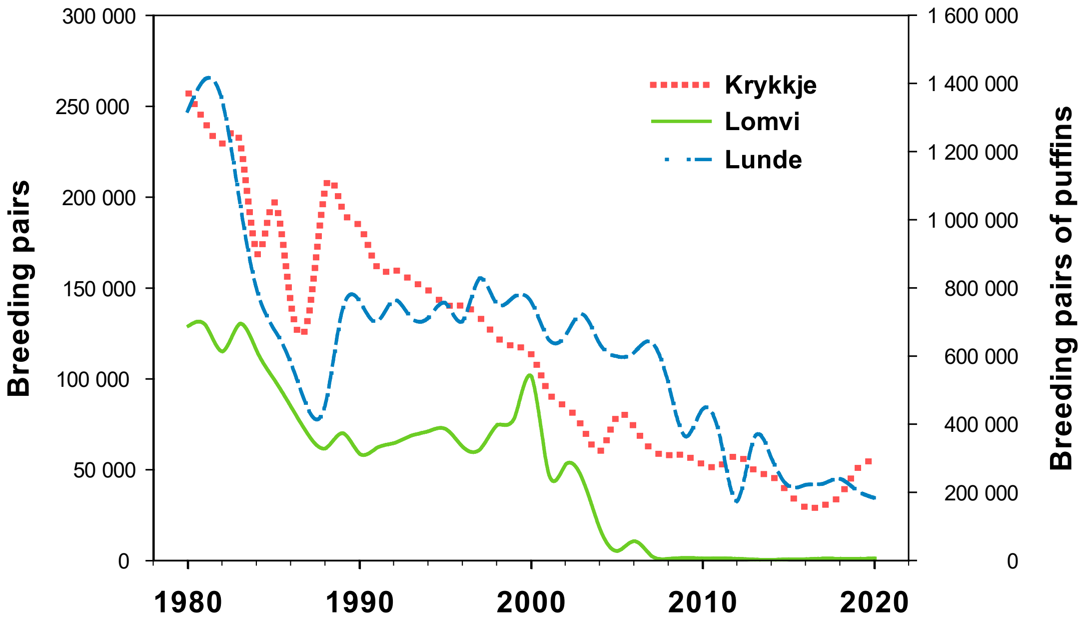


Figure 2.11 Population trends for black-legged kittiwake, common guillemot and Atlantic puffin breeding in the eastern Norwegian Sea in the period 1980–2020.

Coastal seabird indicators

For the two coastal species, trends in breeding populations in the eastern Norwegian are monitored in selected areas along the mainland coast. The main are Trondheimsfjorden (63.4°N, common eider), Sklinna (65.2°N common eider and shag), Ranfjorden (66.2°N, common eider), and Røst (67.5°N common eider and shag).

The breeding population of the common eider in the eastern Norwegian Sea has declined by c. 80% since the first counts were done in the mid-80'ies (Figure 2.12).

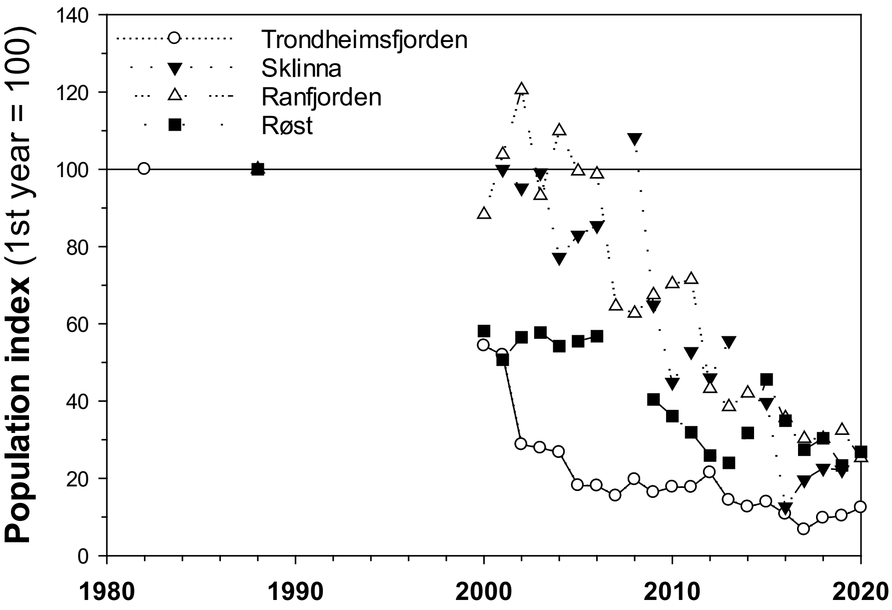


Figure 2.12. Population trends for breeding common eiders in selected areas along the coast of the eastern Norwegian Sea. The reference line (index value = 100) represents the population size at the first count.

In both colonies monitored the populations of European Shag increased from the mid-1980s to c. 2005 but have decreased markedly thereafter (Figure 2.13).

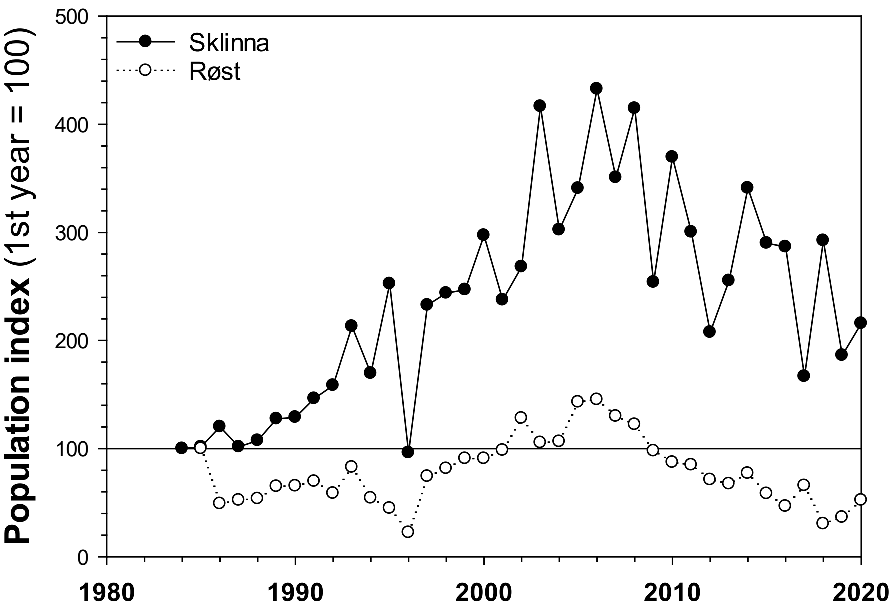


Figure 2.13. Population trends for European shag in two breeding colonies in the eastern Norwegian Sea. The reference line (index value = 100) represents the population size at the first count.

Discussion

The causes for the negative trends registered especially for the pelagic seabirds breeding in the eastern Norwegian Sea are not fully understood, but changes in food availability and climate play a major role. This has 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 (SEATRACK, unpublished data). At the SEAPOP key-sites on the Norwegian coast (i.e. Runde, Sklinna, Helgeland, Røst and Anda), numbers of most pelagic seabird 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., 2020). 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). A key factor in this context is the long-term lack of 0-group herring of the Norwegian spring-spawning stock, perhaps the most important food source for pelagic seabirds breeding in the eastern 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 at this part of the Norwegian coast. 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) which again triggers 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 Northeast Atlantic. In addition, the dynamics of the SPG has proven important for the survival of pelagic seabirds that spend the winter in the Central or Northwest Atlantic (e.g. (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 allows 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, breeding common guillemots and razorbills are able to forage efficiently in shallow waters (< 20 m) where they can access and utilize other prey such as sandeels and 0-group saithe. Common guillemots that breed in shelter are doing better than those breeding on exposed ledges. This is probably 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).

Changes in food availability and climate is assumed to play a role in regulating population size also for the coastal species. In addition, eutrophication of coastal waters might be important, especially for the common eider. This was shown in a study in Danish waters where the run-off of fertilizers to coastal waters increased during the 20th century, with parallel increases in blue mussel stocks and the numbers of breeding common eiders (Laursen and Møller, 2014). Concurrently, when the run-off of fertilizers was reduced from c. year 2000, the numbers of blue mussels and common eiders dropped.

Sea temperatures are also important. (Waldeck and Larsson, 2013) demonstrated that a 3.6 °C increase of the average sea temperature in winter decreased blue mussels dry flesh mass by 11%. Common eiders have to crush the shells in their gizzard. Hence, digestion of the mussels can, at some stage, be a limiting factor where the birds cannot compensate for lower flesh mass by eating more mussels. Since breeding success in common eider females are dependent on pre-breeding food availability, low nutrient levels in blue mussels is expected to reduce breeding success and ultimately, population size.

Common eiders are exposed to predators such as American mink, corvids and white-tailed eagles that takes both eggs and adult birds. Large gulls may also prey heavily on small chicks.

The rich kelp forest along this coastline is also the nursery ground for young saithe, which has proved to be an important food source for European shag (Hillersøy and Lorentsen, 2012). Shag timing of breeding, population size, and breeding success have been found to be closely correlated with abundance of 0- and 1-year old saithe (Bustnes et al., 2013; Lorentsen et al., 2015; Lorentsen et al., 2018).

Seabirds as indicators for fisheries management

In fisheries management, assessments of year-class strengths and recruitment to commercial stocks is essential. Young age classes of saithe stay in the kelp forests and therefore cannot be assessed by ship-based surveys before they join the adult population at the age of 3 years. However, shags feed on these younger age-classes and (Lorentsen et al., 2018) have recently demonstrated that the sizes and numbers of saithe otoliths in shag regurgitates can be used to assess saithe recruitment to the adult population 2-3 years before it can be assessed by ship-surveys. These findings may help managing fisheries on young (3-4-year old) age classes of saithe.

Concluding remarks

The main reasons for the substantial declines in seabird breeding populations in the eastern Norwegian Sea are not obvious and possibly not the same for the species focused in this report. Research affiliated to the SEAPOP programme is constantly exploring this in further detail and highlighted as news issues at the SEAPOP website as soon as it is published (www.seapop.no/en). The largest changes in seabird numbers in the eastern Norwegian Sea are most likely been mediated through substantial changes in prey abundance and availability with dire consequences for reproductive success and recruitment. Still, an increasing number of studies document effects of other natural and man-induced changes that may also contribute to the variation in seabird breeding performance. This includes factors such as competition with fisheries and increased predation from white-tailed eagles, as well as contaminants and human disturbance. The magnitude of seabird bycatch in some of Norway's most important fisheries has also been quantified in a series of recent studies, to a large extent based on data from the IMR reference fleet.

To strengthen the ecosystem-based management of living resources in the Norwegian Sea, time series of seabird breeding performance, diets and survival rates, should be explored further with the aim to develop useful indicators of important changes, including early recruitment indices for both pelagic and coastal fish stocks.

Marine mammals

No additional text to the summary in Annex 3

Ecosystem trend analyses

Results from two types of trends analyses are reported in this section, one estimating trends and classifying them into similar trend classes (TREC (Solvang and Planque, 2020)) and another one detecting flagged observations, whose recent data deviate from the estimated trend. These analyses will be used by the group to develop the IEA approach further in the years to come, and will also be done as a part of the project "Sustainable multispecies harvest from the Norwegian Sea and adjacent ecosystems". The results from the classification of trends may be used to compare and present trends for a given number of the most recent years, while the flagged observation analyses may be used to identify variables that can be subject for more thorough assessments. The time series analysed have been assembled by WGINOR through the years the group has worked and covers key aspects of the physical environment and biological components of the Norwegian Sea ecosystem. The time series are presented in Figure 2.14. The abbreviation used in figures and tables in this section are summarized in Table 2.3.

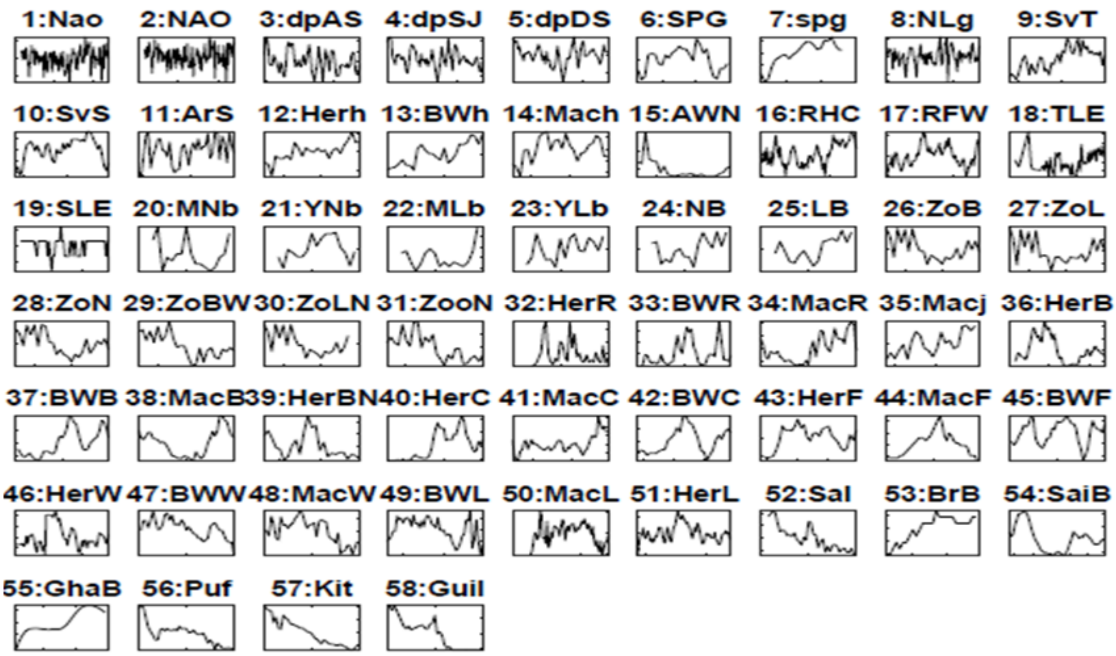


Figure 2.14 Time series data in WGINOR. The x- and y- axes indicate the observed year and the values defined in each data.

Table 2.3. The abbreviation used in the title of the figures and tables in this section.

Type	Data name	Abbrev-iation	Type	Data name	Abbrev-iation
Climate	Nao_djfm	1: Nao	Secondary	Zoopankton B (mean in the two Basins)	30: ZoLN
	NAO_djfm	2: NAO		Zooplankton Northeast of Iceland	31: ZooN
	dp : Agmasalik-Stykkis	3: dpAS	Pelagic fish	Herring R – age2	32: HerR
	dp: Scoresbysund-Jan Mayen	4: dpSJ		Blue whiting R - age 1	33: BWR
	dp: Danmarksh-Svalbard	5: dpDS		Mackerel R - age 0	34: MacR
	SPG_index	6: SPG		Mackerel juvenile index	35: Macj

	spg_index	7: spg		Herring B	36: HerB
	Norw-Lof gyre index	8: NLg		Blue whiting B	37: BWB
	Svinoy-coreT	9: SvT		Mackerel B	38: MacB
	Svinoy-coreS	10: SvS		Herring B from Norwegian Sea survey	39: HerBN
	Areal for S>35 (km2)	11: ArS		Herring C	40: HerC
	Herring habitat	12: Herh		Mackerel C	41: MacC
	Blue Whiting Habitat	13: BWh		Blue whiting C	42: BWC
	Mackrel habitat	14: Mach		Herring F	43: HerF
	Arctic Water in NS	15: AWN		Mackerel F	44: MacF
	Relative Heat Content	16: RHC		Blue whiting F	45: BWF
	Relative Fresh Water content	17: RFW		Herring W6	46: HerW
	Temp.LanganesEast7	18: TLE		Blue whiting W6	47: BWW
	Salinity-Langanes-East7	19: SLE		Mackerel W6	48: MacW
Primary production	Maxchl Norwegian basin	20: Mnb		Blue whiting L6	49: BWL
	YDmaxChl Norwegian basin	21: YNb		Mackerel L6	50: MacL
	Maxchl Lofoten basin	22: MLb		Herring L6	51: HerL
	YDmaxChl Lofoten basin	23: YLb	Demersal fish and salmon	Salmon - northern NEAC	52: Sal
	Norwegian Basin	24: NB		Beaked redfish B	53: BrB
	Lofoten Basin	25: LB		Saithe B	54: SaiB
production	Zooplankton B	26: ZoB		Greenland halibut B	55: GhaB
	Zooplankton B, Lofoten basin	27: ZoL	Seabirds	Puffin stock size	56: Puf
	Zooplankton B, Norwegian basin	28: ZoN		Kittywake stock size	57: Kit
	Zooplankton B 4-8W	29: ZoBW		Guillemoth stock size	58: Guil

Trend estimation and classification analyses (TREC)

Common trends refer to trends that are similar across ecosystem components. Identifying common trends can be useful as a diagnostic tool to reveal past changes and to explore the relationship between biological communities and environmental conditions. In the present investigation, trend estimation and classification analyses (TREC) are applied to WGINOR time series data (Solvang and Planque, 2020). The analysis by TREC requires the same data length for all for all variables. These data are prepared as consistent annual time series. The observed time points for each data were not consistent (i.e. not of the same length Figure2.15).

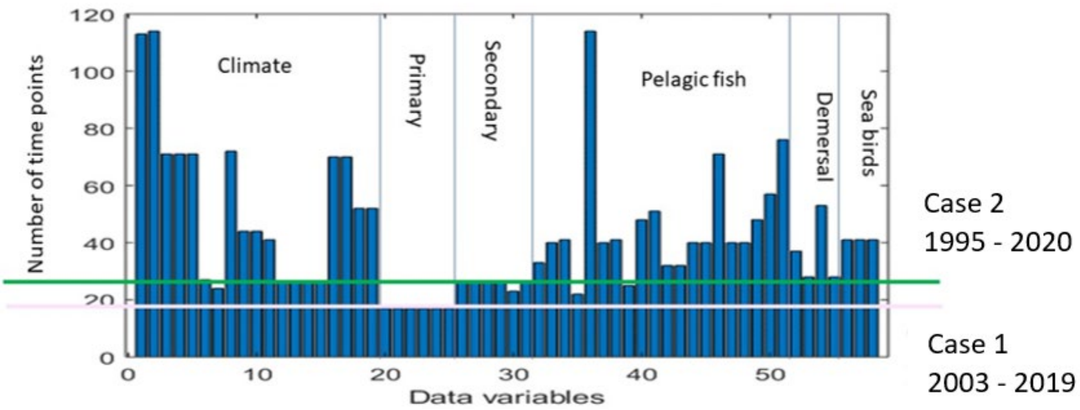


Figure 2.15 Number of time points for each time series data. Numbering in the x-axis corresponds to the number presented in abbreviations in Table 2.3.

Therefore, the following two datasets including comparative consistent time points (data length) are considered for the analysis:

Case 1: climate, primary production, secondary production, pelagic fish, demersal fish, and seabirds observed over the period 2003-2019, and

Case 2: climate, secondary production, pelagic fish, demersal fish, and seabirds observed over the period 1995-2020.

The analysing procedure in TREC is summarized in a flow chart of figure 2.16.

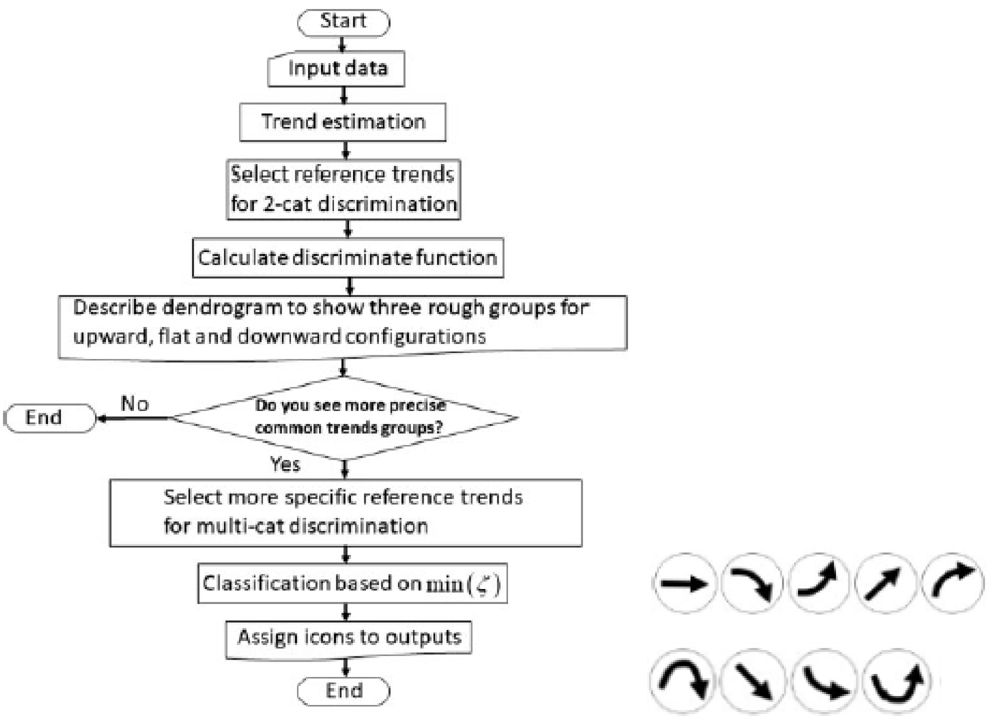


Figure 2.16. Flowchart for the analysing procedure by TREC and the pre-defined icons that are assigned to the represented trend patterns.

The estimated trends in cases 1 and 2 are shown in figure 2.17a and b, respectively. The simple classification categories the trends in the time series as either upward, flat, or downward by two category discriminates. The detailed results are shown in Table 2.4.

Table.2.4. The simple classification categories the trends in the time series as either upward, flat, or downward by two-categorical discriminates.

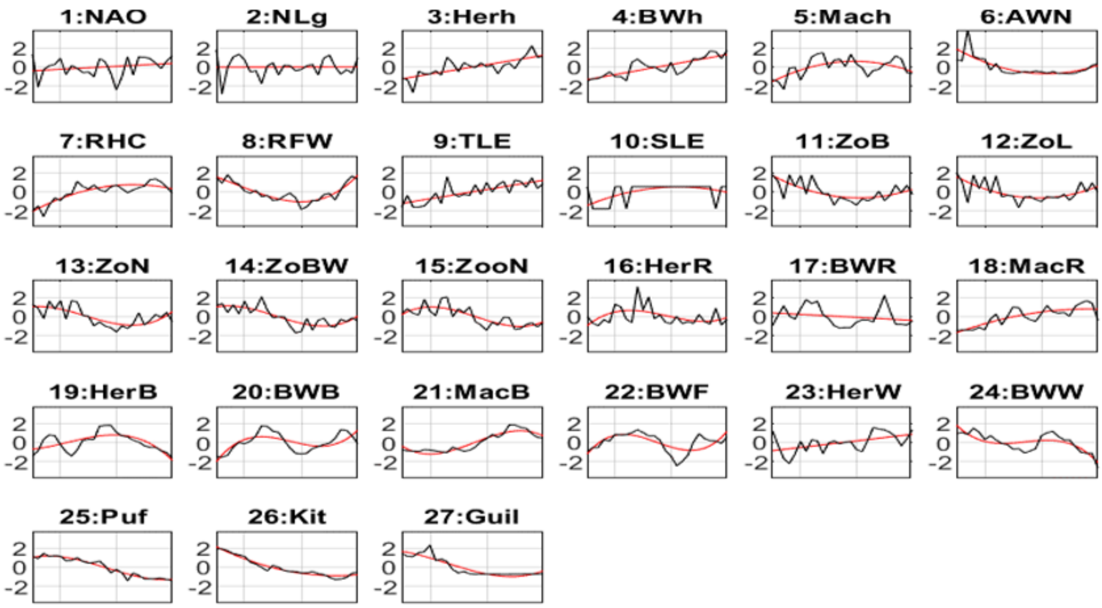
Case 1

Common trend configuration	Climate	Primary	Secondary	Pelagic fish	Demersal fish	Sea birds
Upwards	1:Nao, 2: NAO, 3:dpAS, 7:NLg, 10: Herh,11:BWh, 13:AWN, 14:RHC, 15:RFW,16:TLE,	19:Ynb, 20:MLb, 22:NB, 21:Ylb, 23: LB	24:ZooB, 25:ZooL	31: MacR, 32:Macj, 35: MacB, 38: MacC, 43: HerW, 48:HerL	52:GhaB	
Flat	5: dpDS		26: ZooN	30: BWR, 44:BWW, 46:BWL	50: BrB	
Downwards	4:dpSJ, 8:SvT, 12:Mach, 17:SLE, 6:SPG, 9:SvS	18:MNb,	27:ZooBW, 28:ZooN	29:HerR, 33:HerB, 34:BWB, 36: HerBN, 37:HerC, 39:BWC, 40: HerF, 41: MacF, 42: BWF, 45:MacW 47:MacL,	49:Sal, 51:SaiB	53: Puf, 54: Kit, 55: Guil

Case 2

Common trend configuration	Climate	Secondary	Pelagic fish	Sea birds
Upwards	1:NAO, 3: Herh, 4:BWh, 5:Mach, 7: RHC, 9: TLE, 10:SLE	24:ZooB, 25:ZooL	20:BWB, 23:HerW, 18:MacR, 21:MacB	
Flat	2:NLg, 8:RFW	12:ZooL, 14: ZooBW	16:HerR, 17:BWR, 19:HerB, 22:BWF	
Downwards	6: AWN	11:ZooB, 13:ZooN, 14:ZooBW, 15:ZooN	24:BWW	25: Puf, 26: Kit, 27: Guil

A, case 1,



B, case 2

Figure 2.17. The estimated trends (red solid line) and the standardized time series data (black solid line) for A: case 1 and B: case 2 (see text). The x- and y- axes indicate year and standardized values for the amplitude of the data.

Next, further classification by multiple categorical discriminates is performed. The represented trend patterns in each classified group are assigned by the predefined icons (see in Figure 2.17). In the case of the icon cannot be assigned, the trend configuration is presented. Summary results are presented in Table 2.5. These outputs will in the further work by the group be discussed about the time horizon to use in the TREC.

Table 2.5. Detailed results from multi-categorical classification of trends in the WGNOR dataseries, for case 1 and 2, respectively (see text).

Case 1

1:Nao		8:SvT		15:RFW		22:NB		29:HerR		36:HerBN		43:HerW		50:BrB	
2:NAO		9:SvS		16:TLE		23:LB		30:BWR		37:HerC		44:BWW		51:SaiB	
3:dpAS		10:Herh		17:SLE		24:ZoB		31:MacR		38:MacC		45:MacW		52:GhaB	
4:dpSJ		11:BWh		18:MNb		25:ZoL		32:Macj		39:BWC		46:BWL		53:Puf	
5:dpDS		12:Mach		19:Ymb		26:ZoN		33:HerB		40:HerF		47:MacL		54:Kit	
6:SPG		13:AWN		20:MLb		27:ZoBW		34:BWB		41:MacF		48:HerL		55:Guil	
7:NLg		14:RHC		21:YLb		28:ZooN		35:MacR		42:BWF		49:Sal			

Case 2

1:NAO		8:RFW		15:ZooN		22:BWF	
2:NLg		9:TLE		16:HerR		23:HerW	
3:Herh		10:SLE		17:BWR		24:BWW	
4:BWh		11:ZoB		18:MacR		25:Puf	
5:Mach		12:ZoL		19:HerB		26:Kit	
6:AWN		13:ZoN		20:BWB		27:Guil	
7:RHC		14:ZoBW		21:MacB			

Flagged observation detection analysis

To investigate whether the most recent observation follow or deviate from the recent trend prediction for the time series data in a specific period are calculated. The outline for flagged observations detection analysis is illustrated in figure.2.18.

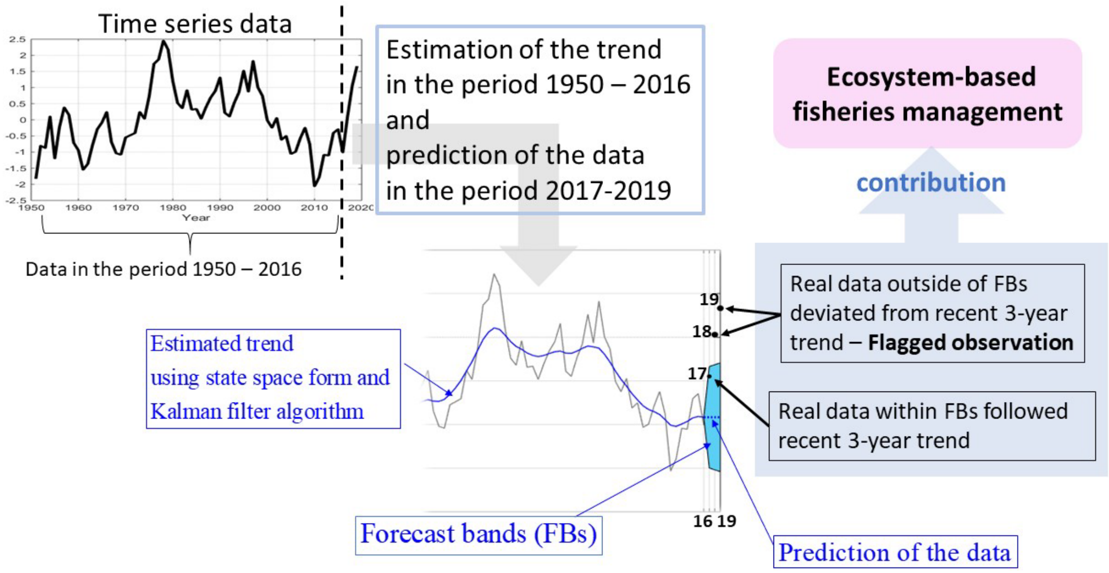
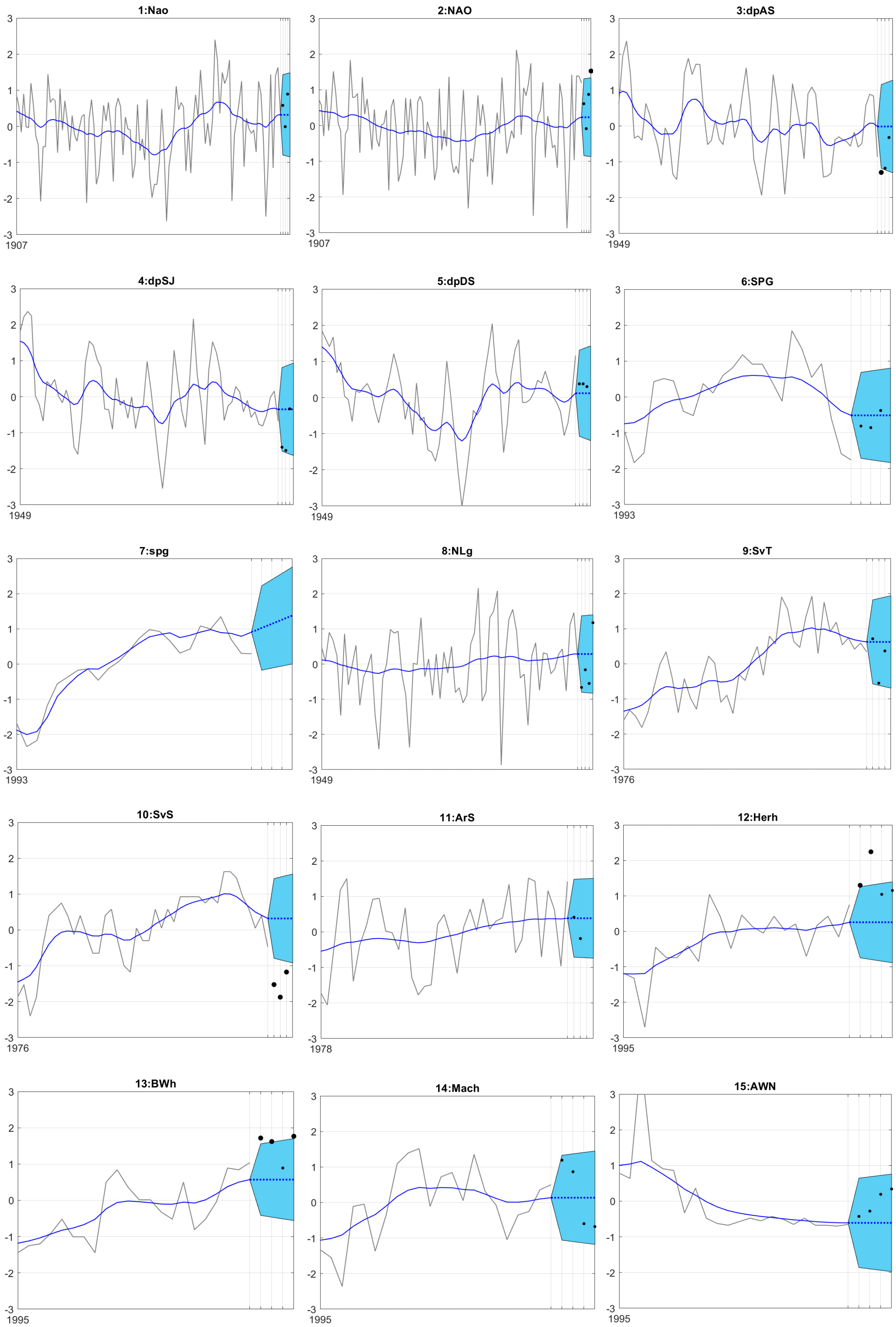


Figure 2.18. Outline of the analysis by flagged observation detection.

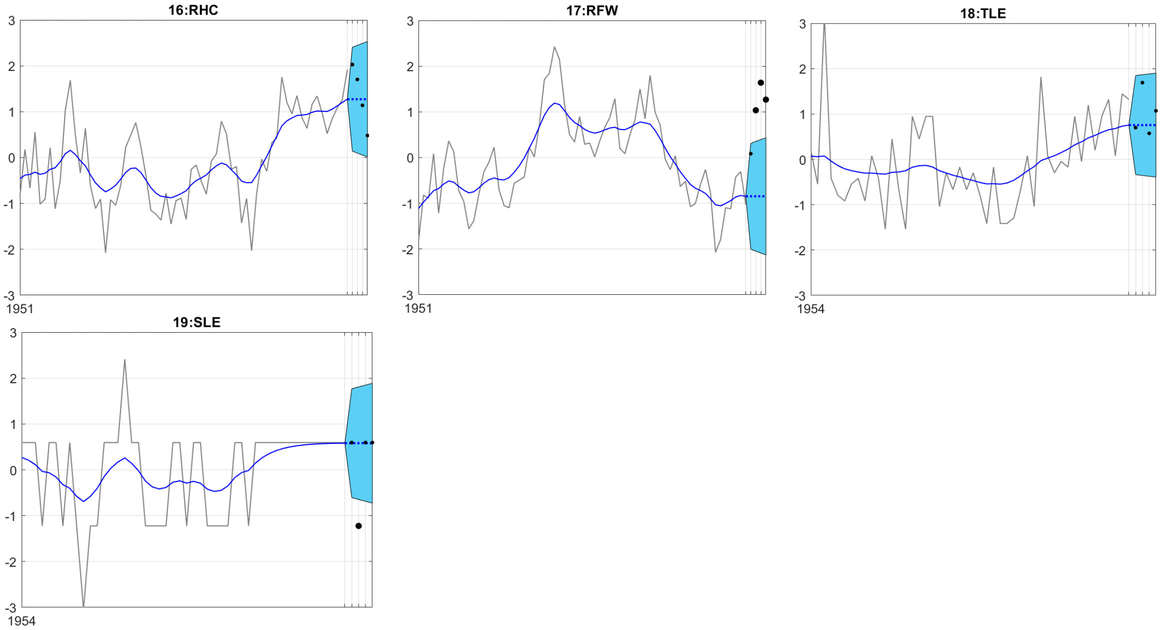
We performed the analysis using the data recorded until 2016 and make the predictions for the year within the period 2017-2020. In this analysis, it is not necessary for the data to cover the exact same years period, as is seen in the case applying TREC. Figure 2.19 presents the outputs of this analysis. The grey lines indicate the observations used for making the predictions and the black points indicate the observations that were plotted for comparison with the prediction. The blue lines present the smoothed trend estimates obtained by Kalman filter and smoother algorithm and the forecast band (FB) coloured by light blue presents the upper and lower limits. The observations are shown with smaller or larger black points depending on whether they are located inside or outside, respectively, the limits of FBs. Looking for years outside the limits of FBs is flagged observation detection.

The years presenting the flagged observation in a data are summarized in Table 2.6. As the further investigation to these outputs, qualitatively assessing whether these observations really represent possible flagged observation would be conducted and, if so, the implications would be considered. The flagged observations must be useful for the investigation whether it is caused by any biological/physical meaning or artefact of data correction.

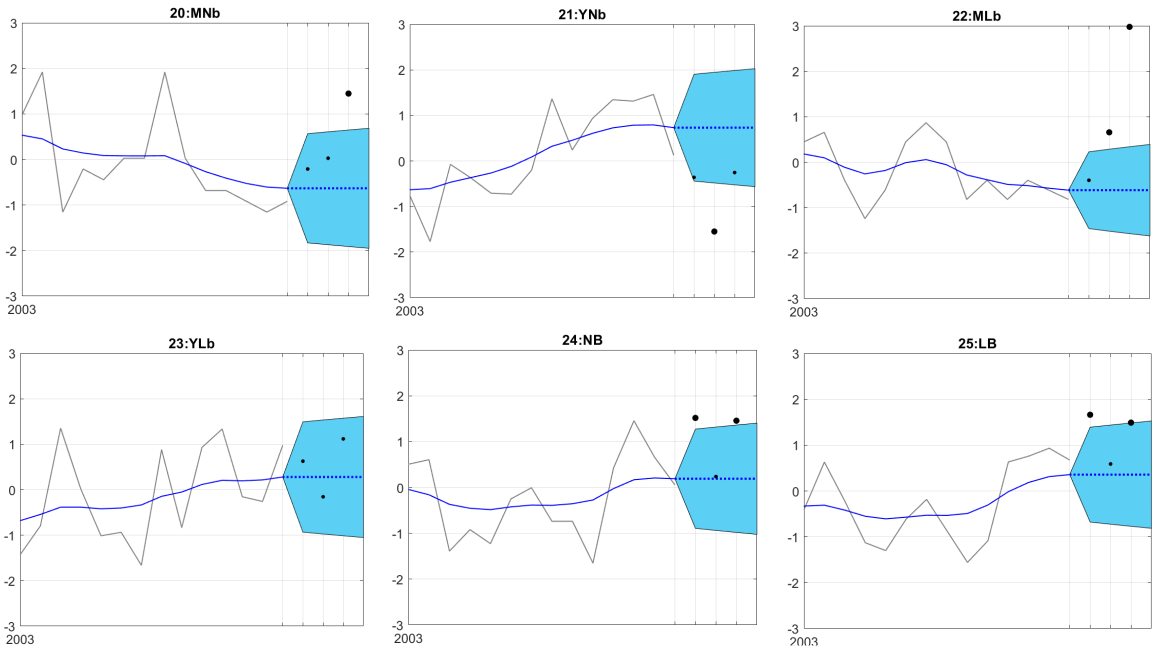
A note should be given to the shape of the predictions in Figure 2.19, which show mostly horizontal straight lines. This is because the model selection criterion, named AIC (Akaike, 1974) selected the first differential order stochastic trend model and the variances detecting the transition becomes small, meaning that the estimated trend indicates little flexibility. If a trend could be fitted with a higher differential order, more flexibility can be gained in the shape of the trend predicted for the most recent years. Figure 2.20 presents a plot for delta AIC, which is the difference of AIC between the first order difference stochastic trend model and the second order difference stochastic trend model. Negative delta AIC indicates that the first order difference stochastic trend model fits better to the observation than the second order difference stochastic trend model. In the case, the estimated trend presents a horizontal straight line as seen in 2: NAO or 12: Herh. Positive delta AIC indicates that the second order difference trend model fits better to the observation than the first order trend model and the estimated trend follows the tendency as the former years as seen in 53: BrB and 58: Guil. The procedure to detect flagged observations objectively performs an automatic trend model selection by AIC; however, the specific trend model might be fixed depending on the aim of study if the difference between AICs for possible models is not so large and the overfitting problem can be avoided.



Climate in Figure2.19 *continued.*

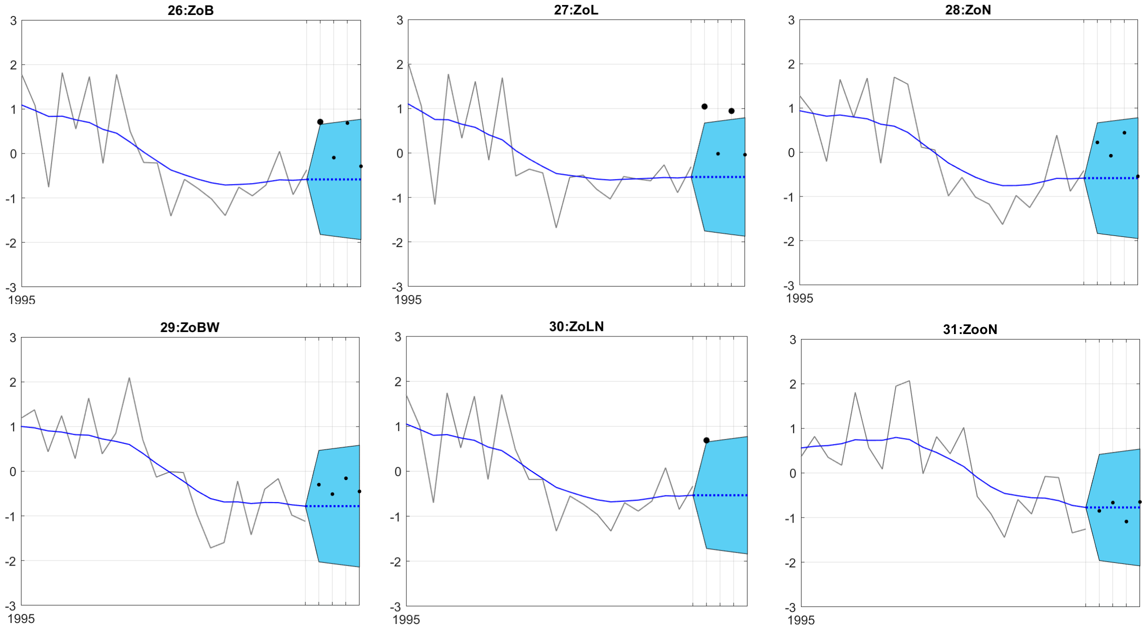


Climate

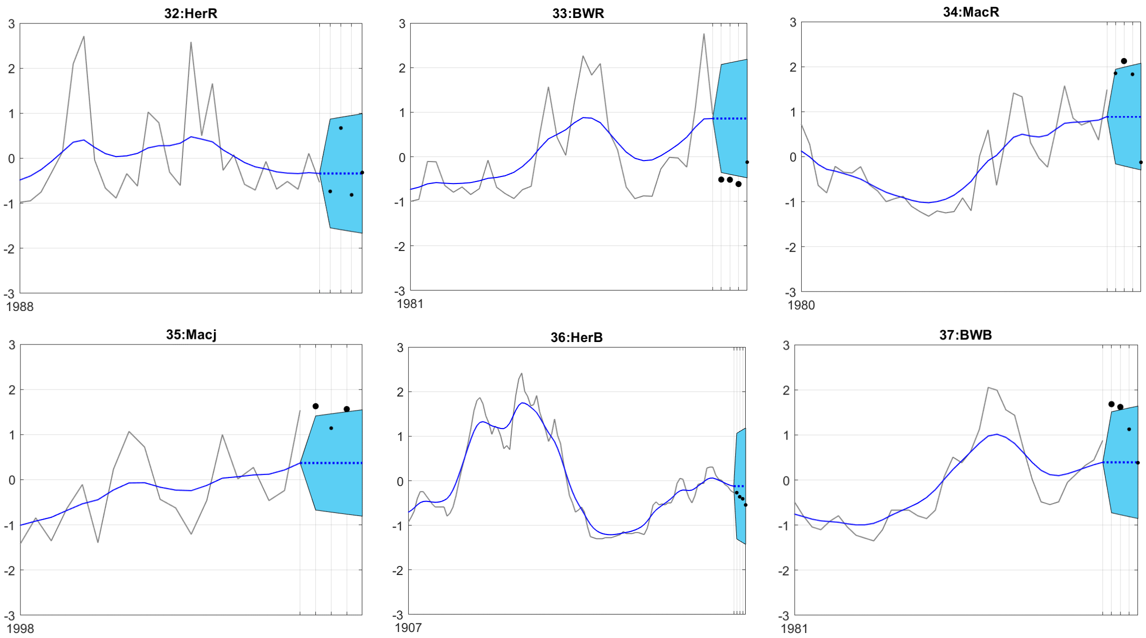


Primary production

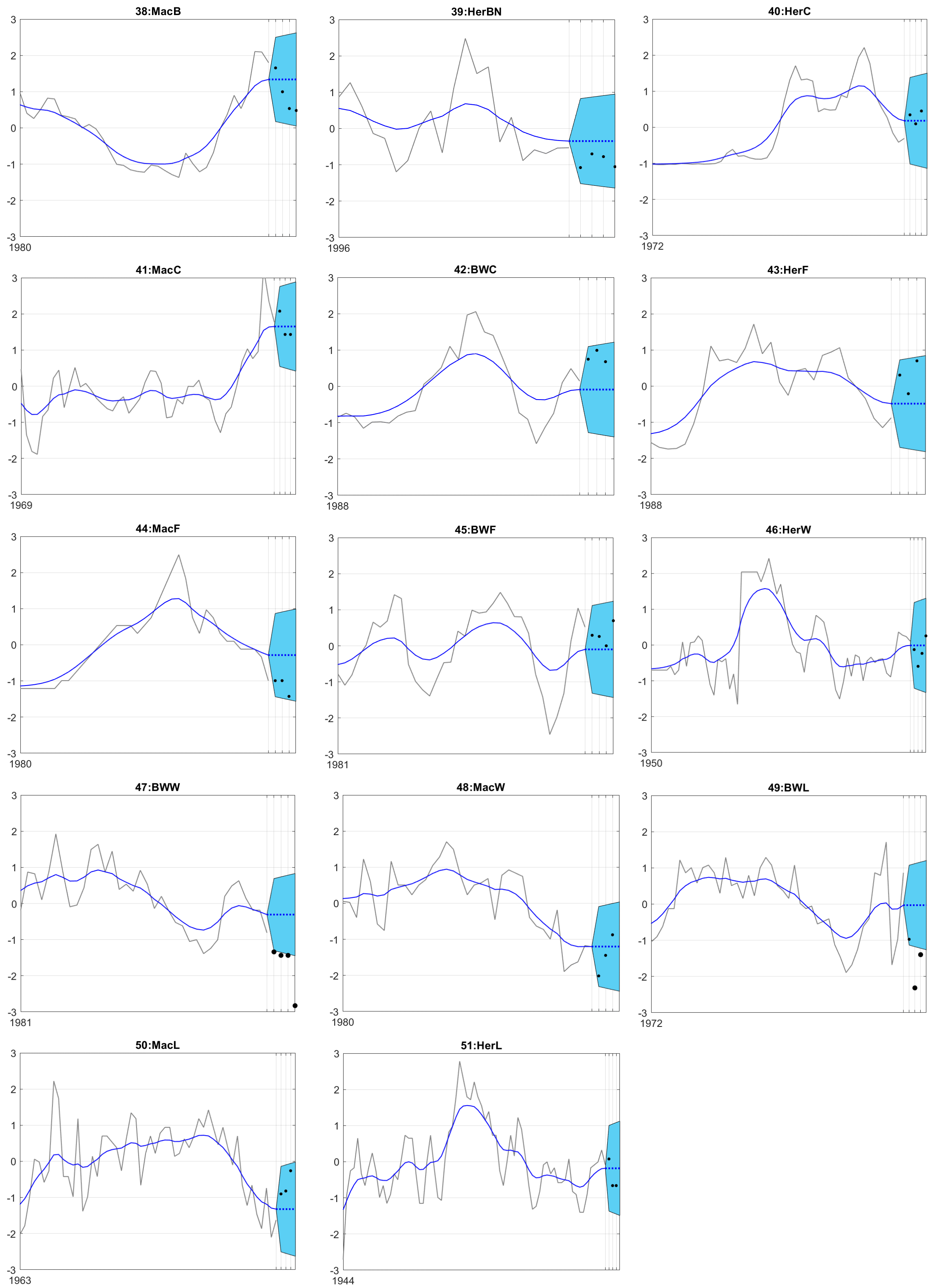
Figure2.19 *continued*



Secondary production

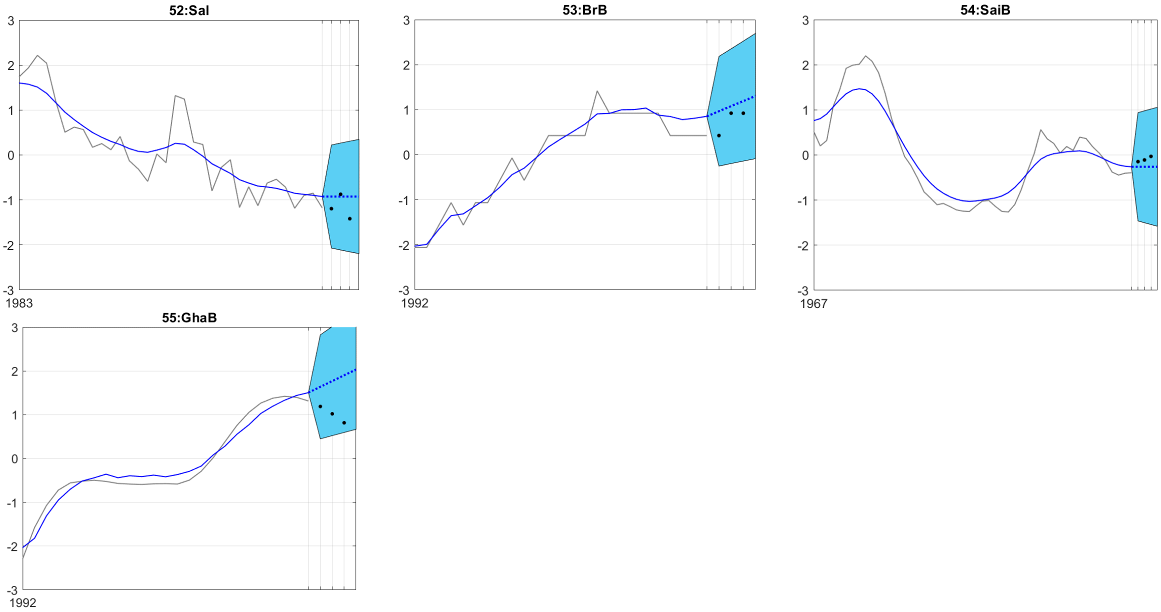


Pelagic fish in Figure2.19 ***Continued.***

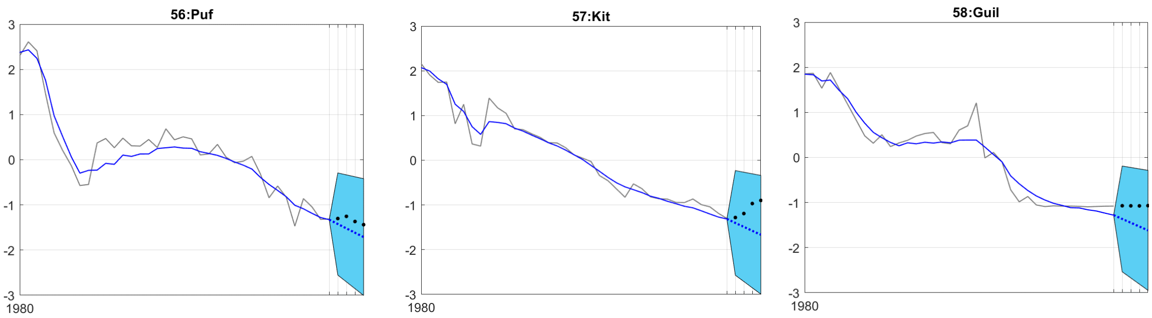


Pelagic fish

Figure 2.19 ***continued.***



Demersal fish and salmon



Seabirds

Figure 2.19. The estimated trend (blue line), 4-years-ahead prediction for 2017-2020 (dotted blue line) with forecast bands (FB, light blue), and the observation (grey line and black dots). The observations are shown with smaller or larger black points depending on whether they are located inside or outside the limits of FBs. If outside the limits of FBs, the observations are considered as flagged observations.

Table 2.6. Years found to be over the upper limit (red-coloured letters) or below the lower limit (blue-coloured letters) of the FBs of the prediction values for each dataset. The detected flagged observations will be investigated more carefully to assess whether they are caused by any biological/physical meaning or artefact of data correction.

Climate	Primary product	Secondary product	Pelagic fish
2: NAO 20	20: Maxchl Norwegian basin 19	26: Zooplankton B 17	33: Blue Whiting Recruitment 17, 18, 19
3: dp: Agmasalik-Stykkis 17	21: YDmaxChl Norwegian basin 18	27: Zooplankton B, Lofoten basin 17, 19	34: Mackerel Recruitment 18
10: Svinoy-coreS 17, 18, 19	22: Maxchl Lofoten basin 18, 19	30: Zooplankton B (mean in Lofoten and Norwegian basin) 17	35: Mackerel juvenile index 17, 19
12: Herring habitat 17, 18	24: Norwegian Basin 17, 19		37: Blue Whiting B 17, 18
13: Blue Whiting habitat 17, 18, 19	25: Lofoten Basin 17, 19		47: Blue Whiting Weight at age 6 17, 18, 19, 20
17: Relative Heat Content 18, 19, 20			49: Blue Whiting Length at age 6 18, 19
19: Salinity-Langanes-East7 18			

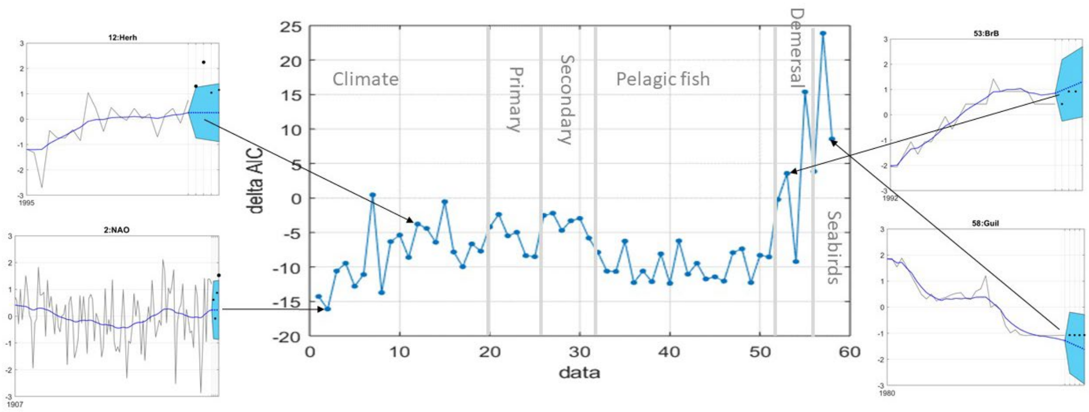


Figure 2.20. Plots for the difference of AIC between the first order difference trend model and the second order difference trend model. Negative delta AIC indicates that the first order difference trend model fits better to the observation. This is shown for two examples to the left, where the estimated trend presents a horizontal straight line for 2: NAO and 12: Herh. Positive delta AIC indicates the second order difference trend model fits better to the observation and the estimated trend follows the tendency as the former years as seen to the right in 53: BrB and 58: Guil.

Progress on ToRb

Progress on this ToR has followed two lines. One is within the project "Sustainable multispecies harvest from the Norwegian Sea and adjacent ecosystems" where a plan has been made for how to develop and test ecosystem-based management strategies for the Norwegian Sea. This will be followed up in the years to come with participation from many of the WGINO members. The other line is a study that has been done in cooperation with colleagues in the US and where harvest control rules have been tested for Norwegian and US system using end-to-end ecosystem models.

Testing preliminary ecosystem-based management strategies for the Norwegian Sea using an ecosystem MSE framework

Currently, most fishery resources are managed according to HCR based in biological reference points that respond to precautionary and maximum sustainable yield criteria. However, in most cases, when the reference points are calculated and the HCRs are designed, no environmental conditions affecting the productivity of the stocks are considered. Previous studies in the Norwegian sea ecosystem have shown potentially important predatory and competency interactions between the main commercial pelagic stocks (NEA mackerel, blue whiting and NSS herring), but also predation interactions with *Calanus finmarchicus* that might affect the productivity of this stocks overtime via top–down and bottom–up effects.

Within project "Sustainable multispecies harvest from the Norwegian Sea and adjacent ecosystems", an ecosystem MSE framework will be developed, with the aim of designing and testing ecosystem-based HCRs and joint management strategies for the main commercial stocks in the Norwegian sea, accounting for ecological interactions and the impact of oceanographic conditions. The ICES guidelines on MSE simulations will be followed as closely as possible when designing the MSE framework, as well as when designing and testing the ecosystem-based HCRs. The ENAC simulation model, developed as a continuation of the simulation model by Skagen et al. (2013), will be used as a base model to create a new MSE framework. As part of the work that will be developed in this project, there will be a general review of the structure of the framework, and an in depth review of the biology and ecology underlying the operating model, as well as the observation model, management procedure and implementation model. Given the existing uncertainty on the ecological interactions, as well as the complexity of the ecological-fisheries system under study, a conservative approach will be aimed, with a trade-off between model complexity and uncertainty.

The plan for the work described here is given in Annex 4.

Ecosystem-Based Harvest Control Rules for Norwegian and US Ecosystems

We applied two complex end-to-end ecosystem models (for the Norwegian and Barents Sea and for the California Current Ecosystems) to test six different harvest control rules (HCRs). Four of these HCRs explicitly address predator–prey relationships, and the forage needs of predators and fisheries. Specifically, within Atlantis ecosystem models we focus on how forage (zooplankton) availability affects the performance of harvest rules for target fish, and how these harvest rules for fish can account for environmentally driven fluctuations in zooplankton. Our investigation led to three main results. First, consistent with studies based on single-species operating models, we found that compared to constant F = F_{MSY} policies, threshold rules led to higher target stock biomass for Pacific hake (*Merluccius productus*) in the California Current and mackerel (*Scomber scombrus*) in the Nordic and Barents Seas. Secondly, the multispecies operating models and the harvest control rules that linked fishing mortality rates to prey biomass (zooplankton) led to increased catch variability; this stemmed directly from the harvest rule that frequently adjusted Pacific hake or mackerel fishing rates in response to zooplankton, which are quite variable in these two ecosystems. Thirdly, tests suggested that threshold rules that increased fishing when productivity (zooplankton) declined had the potential for strong ecosystem effects on other species. These effects were most apparent in the Nordic and Barents Seas simulations. The tests of harvest control rules here do not include uncertainty in monitoring of fish and zooplankton, nor do they include uncertainty in stock assessment and implementation; these would be required for full MSE. Additionally, we intentionally chose target fish with strong mechanistic links to particular zooplankton groups, with the simplifying assumption that zooplankton biomass followed a forced time series. For further reading, see: https://www.frontiersin.org/articles/10.3389/fmars.2020.00652/full.

Progress on ToRc

Background

The ocean climate and variability of the Norwegian Sea is determined by the properties and relative fraction of the Atlantic or Arctic source waters (Helland-Hansen and Nansen, 1909). Changing hydrographic condition have a direct effect on both the metabolic rate as well as the habitat area for different biological species and are thus closely related to ecosystem changes (e.g. (Skjoldal, 2004)). Further ecosystem relevance is due to the fact that these source waters also differs in their composition of nutrients (Rey, 2012) and zooplankton (Wiborg, 1954). Due to the large inertia of the ocean there is a potential for prediction of the Norwegian Sea ocean climate by combining the present observational state upstream in the North Atlantic with knowledge of how anomalies propagate in relation to the general ocean circulation.

Aspects of Norwegian Sea climate prediction

A framework for prediction of the Norwegian Sea physical variability of ecosystem relevance involve two steps;

i) to identify observed anomalies upstream in the North Atlantic Current, Subpolar gyre etc and combine these with time-lag relations associated with different pathways to develop a climate probability for the Norwegian Sea on 1-5-year time-scale. Data to include here would be available hydrography, ocean state products, satellite sea surface height and sea surface temperature data, and atmospheric reanalysis.

ii) to further develop the understanding how changes in the biophysical changes in the Norwegian Sea will affect the ecosystem. This will involve both changes in T,S (including stratification), integrated quantities as heat- and freshwater content, upstream circulation changes effect on nutrients and associated effect on primary production as well as advection of zooplankton in the Norwegian Sea.

Work plan/Time line

Work on this will be done through the project “Sustainable multispecies harvest from the Norwegian Sea and adjacent ecosystems” after the following plan:

Nov-Dec 2020: Finalize a first version of paper titled “The main variability ocean climate and zooplankton abundance in the Norwegian Sea over the last 25 years” related to point ii).

Jan-Dec 2021: Develop a first observational based prediction framework for the Norwegian Sea for 1-5 year time-scale.

Jan-Dec 2021: Revise paper (ii) and extend work on biophysical relations.

2022: Write a paper on the concept of prediction.

Progress on ToRd

Foodweb assessment.

During 2020, the foodweb assessment work has focused on "Chance and necessity" (CaN) modelling. The concepts of CaN modelling are presented in (Planque and Mullon, 2020). Chance expresses the indeterminacy of many ecological processes. Necessity expresses the constraints within which ecological systems can operate. CaN modelling is a way to reconcile indeterminacy and constraints. Its aim is to reconstruct past and project future plausible ecosystem (e.g. foodweb) trajectories.

The work in 2020 has contributed to the development of an operational participatory foodweb modelling framework through 1) the development of a R-library (RCaN) to easily implement CaN modelling, 2) the conception of a standardized Excel template to document all the information needed to run a CaN model, 3) the development of 'RCaN model constructor', a graphical user interface written in Java to support participatory model building and 4) the preparation of educational slides to communicate about RCaN and educate interested scientists in this modelling approach. The library and associated article are in preparation and are expected to be submitted in early 2021 (Drouineau et al., In prep). A workshop is scheduled in December 2020 to initiate the construction of prototype foodweb models for WGINOR.

Progress on ToRe

According to the ToR (updated in 2018), the WGINOR group shall meet with stakeholders from the host country in order for stakeholders to be updated on WGINOR's work and to give input on issues that the WGINOR may address.

The Faroes were the planned meeting hosts for the 2020 meeting, and thus, according to the ToR, Faroese stakeholders should have been invited to the meeting for the first time. However, the meeting was held online, and it was considered that it would be difficult to hold a beneficial and fruitful session with stakeholders in such an environment for the first time. In addition, the stakeholders do not know the majority of the people in the group, which further complicates conveying the key-messages in an online environment. Probably this is best achieved in a physical meeting, hopefully in 2021. Therefore, this part of the ToR has been postponed to 2021.

Progress on ToRf

ICES Ecosystem Overview revision

The Norwegian Sea ecosystem overview (EO) is in need of a major revision. The revision began at the WGINOR 2019 meeting by selecting the major pressures during an in person plenary discussion (see (ICES, 2020g) for a list of attendant to this meeting). The meeting attendants did not assess sector-pressure-component pressure pathways. Some revisions were done of EO text by WGINOR members by correspondence. The revised EO was rejected by the ADGECO at a meeting November 28, 2020, due to lack of evaluation of sector-pressure-component pressure pathways.

At the 2020 WGINOR meeting, work continued revising the EO. In a plenary discussion it was decided to keep the four main pressures, decided at the WGINOR meeting 2019, which are: selective extraction of species, underwater noise, introduction of contamination compounds, and abrasion (see Annex 2 for a list participants to the meeting). The meeting attendants felt incompetent to either qualitatively or quantitatively evaluate sector-pressure-component pressure pathways due to lack of methods to do so.

The meeting conclusion was to have a workshop where a simplified version of the Options for Delivering Ecosystem-based Marine Management (ODEMM) methodology (Pedreschi et al., 2019) would be used to evaluate pathways, as outlined in the 2019 WGEAWESS report (ICES, 2019c).

The workshop was hosted online February 1st, 2021. It was attended by the two WGINOR chairs and 21 other WGINOR members and was chaired by Mette Skern-Mauritzen (see Annex 5 for a list). The chair calculated sum of impact risks from the ODEMM assessment which was used to guide a subjective scoring in the ICES EO tables. For pressures contaminants, noise, and abrasion, sum of impact risks was judge inflated compared to scientific knowledge of pressure impact on ecosystem. Pressure's impacts were inflated by high number of pressure pathways.

WGINOR had three online meetings in March 2021 to downgrade inflated sum of impart risk for pressures contaminants, noise, and abrasion. The first meeting was an online March 15th, 2021, attended by the WGINOR chairs and the WGINOR members Gro van der Meeren and Mette Skern-Mauritzen. Goal of meeting was to discuss how to use scientific knowledge to downgrade sum of impact risk for pressures noise and contaminants.

The second meeting was online March 22nd, 2021, to qualitatively adapt pressure-sector impact risk and pressure-ecosystem component impact risk for the three pressures. The meeting was attended by the WGINOR chairs and the WGINOR members Sigurvin Bjarnason, Petur Steingrund, Benjamin Planque, Gro van der Meeren, Hiroko Kato Solvang, Øystein Skagseth and Mimi Lam plus Inigo Martinez from the ICES secretariat. At the meeting, pressure-sector impact risks were qualitatively adapted by discussion. Unfortunately, there was no time to qualitatively adapt pressure-ecosystem component impact risk at the meeting. The WGINOR chairs met online March 23rd to discuss and qualitatively adapt pressure-ecosystem component impact risk.

Report on results from the February 1st workshop is in Annex 5. Meeting, March 15th 2021, conclusions for downgrading impact risk of noise and contaminants are listed in table 15 in Annex 5. Qualitatively changes to pressure-sector impact risk, done at the meeting March 22nd, are listed in Table 13 in Annex 5. Qualitatively changes to pressure-ecosystem component impact risk, done at the meeting March 23, are listed in Table 14 in Annex 5.

Once the sector-pressure-component pressure pathways had been accessed the EO text was revised accordingly by WGINOR members, by correspondence. The revised EO was submitted to ICES by March 26th, 2021. The revisions will be evaluated at an ADGECO meeting on May 6th, 2021.

3 Science highlights

Here are described science highlights that were not submitted through the e-evaluation from the meeting (WGINOR E-evaluation 2020).

3.1 Sustainable multispecies harvest from the Norwegian Sea and adjacent ecosystems (SIS HARVEST WGINOR): Overview and update 2020

Erik Askov Mousing (Institute of Marine Research, Norway)

Abstract: SIS HARVEST WGINOR is an IMR project funded by The Norwegian Research Counsel and The Norwegian Ministry of Trade, Industry and Fisheries. The overall aim of the project is the achieve an update of the knowledge base required to implement ecosystem-based fisheries management and harvest of living marine resources in a climate change perspective. The project is structured into 3 main work packages (WPs), investigating specific questions related to 1) Zooplankton dynamics, 2) Pelagic fish distribution and 3) Trophic interactions and management support product. In this talk, a short overview and background of the project, as well as an update of the progress in 2020, is presented. Progress has been made in all WPs, where the work has focused on time series analysis, early warning signals and mackerel dynamics. A major output in 2020 was the drafting of a Management Strategy Evaluation (MSE) framework for testing ecosystem-based management strategies in the Norwegian Sea, focusing on the interactions between mackerel, herring, zooplankton and the physical environment. Development and implementation of the MSE will be a major focus for the rest of the project period with output of the WPs being adjusted to support this.

3.2 Workshop on the dynamics of mackerel distribution 22-23.Sep - Future plans

Aril Slotte (Institute of Marine Research, Norway)

The sessions and contents of the workshop on dynamics of mackerel distribution arranged by IMR and SIS Harvesting project was presented, including the future collaboration plans to increase our understanding of the mackerel migration dynamics in time and space. The workshop itself were arranged over two days Teams meetings with 16 scientific presentations followed by discussions over 6 different sessions: 1.Spawning dynamics in time and space, 2.Potential role of bioenergetics, 3.Studying migration using models and tag data, 4.Age-year class effects and social learning, 5.Dynamics in summer-autumn-winter distribution in the North Sea area, 6. Does NEA mackerel consist of components or not? The outcome of the workshop were plans for 6 different collaborations with the following leaders and subjects: 1. Paul Fernandes fernandespg@abdn.ac.uk, Autumn-winter distribution, abundance and behavior using acoustics. 2. Mattias Kloppmann matthias.kloppmann@thuenen.de, Evaluating the data and methodology for going from egg survey estimates to SSB index for use in stock assessment – and other relevant issues for the egg survey itself as data to describe spawning dynamics in time and space. Anna Olafsdottir anna.olafsdottir@hafogvatn.is and Aril Slotte aril.slotte@hi.no, Digging into age-year class structure from catch data and various surveys to study spatio-temporal effects on both spawning, feeding and wintering migration. Teunis Jansen tej@aqua.dtu.dk, Sorting out the scientific evidence against continuing with component description in the stock assessment and management. Aril Slotte aril.slotte@hi.no, Using tag data to analyse migrations. Erik Mousing erik.askov.mousing@hi.no, Modelling the mackerel migration.

3.3 The Norwegian Sea Gyre – and more

Hjálmar Hátún (Faroe Marine Research Institute, Faroe Islands)

This presentation was an amalgamation of three papers – two recently published works on the Iceland-Faroe Slope Jet (IFSJ) and the Faroe-Shetland Channel Jet (FSCJ), respectively, and a work (in preparation) on the Norwegian Sea Gyre (NSG). The bulk of the volume transport of the IFSJ, is relatively uniform in hydrographic properties, very similar to the North Icelandic Jet flowing westward along the slope north of Iceland toward Denmark Strait. The IFSJ can account for approximately half of the total overflow transport through the Faroe Bank Channel (FBC), thus constituting a significant component of the overturning circulation in the Nordic Seas.
We further establish that, contrary to previous thinking, overflow type waters from north of the Faroes does not encircle and stay connected to the Faroe slope, throughout its journey towards the FBC. These dense waters become entrained into the southward flowing FSCJ, along the Norwegian and Shetland slopes, which carries dense waters the final stretch towards the FBC. Anticyclonic windforcing in the Nordic Seas via its regulation of the basin circulation plays a key role in activating this unrecognized overflow path from the Norwegian slope – at which times the overflow is anomalously strong. The finally presented unpublished work illustrates how the NSG regulates these deep jets and depths of the main interface between overflow waters and the overlying warmer Atlantic waters. This link between the NSG, overflow, interface and the Atlantic inflows provides basis for a better understanding of the Norwegian Sea oceanography, and its impact on the biogeography in this region.

3.4 Analysis of age-disaggregated herring distribution in the Norwegian Sea in May in the period 1996-2020

Sólvá Káradóttir Eliasen,[1] Eydna í Homrum[1], Jan Arge Jacobsen[1], Gudmundur J. Óskarsson[2], Are Salthaug[3], Erling Kåre Stenevik[3].
[1] Faroe Marine Research Institute, Faroe Islands. [2] Institute of Marine Research, Norway.
[3] Marine and Freshwater Research Institute, Iceland.

The commercially important Norwegian spring spawning herring feeds in the Norwegian Sea during the summer. In this work, data from the International Ecosystem Surveys in the Nordic Seas (IESNS), which has been carried out annually in May since 1996, have been used to analyse the spatial distribution of herring with regards to individual year classes in the period 1996-2020. The stock has been disaggregated into age groups and year classes and information about where the different age groups/year classes feed in May has been derived.

During this period, the youngest year classes were generally found closer to the Norwegian shelf compared to older year classes, which displayed larger variations in where they were displayed in May. The first few years in the survey period, the oldest year classes were found in the central and western Norwegian Sea – with varying size of the distribution area, depending on the size of each year class. The younger part of the adult stock seems to be more confined to the eastern and north-eastern part of the Norwegian Sea. However, for a few years (1999-2004) the whole stock migrated north-west after spawning leaving the regions in the southern Norwegian Sea void of herring. Since 2005 the oldest herring has again congregated in the south-western areas east of Iceland to feed in May.

There is a significant positive relationship both between stock size and distribution area and between stock size and density. Moreover, it is likely that relatively strong year classes (1991-2 and 1998-9) were important during the change in the migration pattern in 1999 and 2005 respectively.

3.5 Links between Modified East Icelandic Water, *Calanus* spp. and Norwegian Spring Spawning Herring

Inga Kristiansen (Faroe Marine Research Institute, Faroe Islands)

Interannual variability in zooplankton and Norwegian Spring Spawning Herring (NSSH) distribution is investigated in context of the highly changeable distribution of Modified East Icelandic Water (MEIW) in the Nordic Seas. The copepods *Calanus hyperboreus* and *C. finmarchicus* are two dominant zooplankton species in terms of biomass and are key species in the diet of herring, particularly within the western region. Pronounced changes are observed in the distribution pattern of herring in May since 1996. We attribute this changing pattern to the variable volume of MEIW and *Calanus* spp. from the western region. We show that prior to 2003, which is a period of increased influence of MEIW from the western region, increased zooplankton biomass prevailed throughout the Norwegian Sea, resulting in a shorter migratory route of the herring stock in May. A sudden reduction in the volume of MEIW occurred around 2003, which coincided with reduced zooplankton concentrations. Shortly after, the herring extended their migratory route to the southwestern Norwegian Sea in May, in search for adequate food availability.

3.6 Spatio-temporal distribution of NEA mackerel catches from 1998-2017

Nikos Nikolioudakis[1], Fabian Zimmermann[1], Kotaro Ono[1], Eydna í Homrum[2], Guðmundur J. Óskarsson[3] et al.
[1] Institute of Marine Research, Norway. [2] Faroe Marine Research Institute, Faroe Islands.
[3] Marine and Freshwater Research Institute, Iceland.

Within the framework of the IMR project «SIS høsting» («Strategic Initiative for Harvesting») work is envisioned to combine survey and commercial catch data of small pelagics, namely mackerel, herring and blue whiting with the aim to study the spatio-temporal distribution of these economically and ecologically important species. Additionally, possible relations with oceanographic process will be explored. A presentation regarding data availability and challenges was provided, complemented by a demonstration of the potential analytical framework to be used. The challenges in the datasets were also highlighted. Finally, a novel analytical framework that is based on the R package VAST was presented as a potential tool to address variations in spatio-temporal data and create ecosystem indices.

3.7 An appraisal of the drivers of Norwegian spring-spawning herring (Clupea harengus) recruitment

Benjamin Planque (Institute of Marine Research, Norway).

Norwegian spring-spawning herring (NSSH, Clupea harengus) is a key species in the foodweb and for fisheries in the north-east Atlantic. NSSH has been the focus of many ecological and fisheries studies over decades and several hypotheses have been put forward to explain variations in its recruitment. We conducted an extensive literature review of the processes that have been hypothesized to control recruitment at age-2 years. From this review, we constructed a conceptual model to represent how these processes are inter-connected. We then evaluated several of these hypothesized processes using quantile regression modelling and the most recent available dataseries as input. Most of the hypotheses were not supported by our analyses. Only two hypotheses were supported: the top–down control of herring larval stage by Atlantic mackerel (Scomber scombrus) and the positive effect of temperature on recruitment. For the latter the interpretation of the results is nevertheless ambiguous when the latest years

(1998-2018) of observations are included, as the correlation then changes from positive to negative. Furthermore, when retesting the hypotheses on age-2 years estimates, we observe a benefitting effect of a consistent strong forcing of the Norwegian Coastal Current and a possible positive effect of the NSSH spawning stock on recruitment. How much these hypotheses can be used to make predictions about future recruitment of herring remains to be tested but based on our results, the relatively short time series available and the dispersion of the observations around the regression models, we can anticipate that such predictions would have limited use for the purpose of fisheries assessment and management. The full article is available at https://onlinelibrary.wiley.com/doi/full/10.1111/fog.12510.

3.8 Managing Ethical Norwegian Seascape Activities (MENSA)

Mimi Lam (University of Bergen, Norway).

Management of marine resources, globally and in Norway, strives to achieve sustainable development by balancing resource extraction, biodiversity conservation, and societal acceptability. However, these three philosophical paradigms tend to stand as monolithic pillars in their approaches to sustainability, namely: rationalization, conservation, and community. Consequently, such un-integrated approaches tend to lead to management objectives and policy goals in conflict. These conflicts are often rooted in competing economic, ecological, and social values. MENSA’s overarching aim is to develop an integrated ethical approach to the sustainable management of Norwegian seascape activities: this will be done by making explicit values and valuation of the sea and negotiating the ensuing trade-offs with the input of diverse marine stakeholders in Norway, including scientific experts, government representatives, industry members, non-governmental organizations, and most importantly, its citizens.

MENSA’s objectives are threefold:

1. To contribute to a theoretical understanding of marine resource values and valuation in seascapes, informed by niche construction theory and sense of place empirical research.

2. To elicit societal values of the seas and coasts and activities associated with marine resources in Norway using the seascape concept and imagery in a novel methodology.

3. To evaluate value trade-offs and negotiate resource conflicts with Norwegian stakeholders by integrating ecological and oceanographic modelling of scenarios with elicited value priorities in an ethical framework for management strategy evaluation.

The knowledge gained in MENSA can contribute to ethical governance that can resolve disputes related to competing uses or protection of coastal and marine resources. This integrated ethical approach can serve as a proof-of-concept model at the national level for how to reconcile value trade-offs toward sustainable development. Such trade-offs must be reconciled to achieve the 17 United Nations Sustainable Development Goals (SDGs): MENSA focuses on SDG 14 (Life Below Water), SDG 15 (Life on Land), and SDG 16 (Peace, Justice, and Strong Institutions).

3.9 Estimated top–down effects of mackerel and herring predation on *Calanus* using models EwE and Norwecom

Kjell Rong Utne (Institute of Marine Research, Norway).

No abstract is available for presentation.

4 Reference list

Akaike, H. 1974. A new look at the statistical model identification. IEEE Transactions on Automatic Control, 19: 716-723.

Almodóvar, A., Ayllon, D., Nicola, G. G., Johnsson, B., and Elvira B 2019. Climate-driven biophysical changes in feeding and breeding environments explain the decline of southernmost European Atlantic salmon populations. Canadian Journal of Fisheries and Aquatic Sciences. , 76: 1581-1595.

Anker-Nilssen, T., and Aarvak, T. 2009a. Effects of White-tailed Eagles on the reproductive performance of Black-legged Kittiwakes; indications from a 26-year study in North Norway. In: Stienen, E., Ratcliffe, N., Seys, J., Tack, J. & Dobbelaere, I. (eds.). Seabird Group 10th International Conference Belgium, 27–30 March 2009. VLIZ Special Publication 42. Flanders Marine Institute, Oostende, Belgium.

Anker-Nilssen, T., and Aarvak, T. 2009b. Satellite telemetry reveals post-breeding movements of Atlantic puffins Fratercula arctica from Røst, North Norway. . Polar Biology, 32: 1657-1664.

Anker-Nilssen, T., Barrett, R., Christensen-Dalsgaard, S., Dehnhard, N., Descamps, S., Systad, G. H. R., Moe, B., et al. 2020. Key-site monitoring in Norway 2019, including Svalbard and Jan Mayen. SEAPOP Short Report 1-2020, 16 pp.

Anker-Nilssen, T., Barrett, R. T., Lorentsen, S.-H., Strøm, H., Bustnes, J. O., Christensen-Dalsgaard, S., Descamps, S., et al. 2015. SEAPOP – De ti første årene. SEAPOP Nøkkeldokument 2005-2014. Norwegian Institute for Nature research, Norwegian Polar Institute, and Tromsø University Museum, Trondheim/Tromsø. 58 pp.

Anker-Nilssen, T., and Lorentsen, S.-H. 2004. Seabirds in the Norwegian Sea. *In* The Norwegian Sea Ecosystem, pp. 435–446. Ed. by H. R. Skjoldal, R. Sætre, A. Færnö, O. A. Misund, and I. Røttingen. Tapir Academic Press, Trondheim.

Barrett, R. T., Erikstad, K. E., Anker-Nilssen, T., Lorentsen, S.-H., Reiertsen, T. K., Strøm, H., Systad, G. H., et al. In manuscript. Common guillemot Uria aalge chick diet reflects local fish availability.

Barrett, R. T., Lorentsen, S.-H., and Anker-Nilssen, T. 2006. The status of seabirds breeding in mainland Norway. . Atlantic Seabirds, 8: 97-126.

Barrett, R. T., Røv, N., Loen, J., and Montevecchi, W. A. 1990. Diets of shag Phalacrocorax aristotelis and cormorants P. carbo in Norway and possible implications for gadoid stock recruitment. Marine Ecology Progress Series, 66: 205-218.

Beaugrand, G., and Reid, P. C. 2012. Relationships between North Atlantic salmon, plankton, and hydroclimatic change in the Northeast Atlantic. Ices Journal of Marine Science, 69: 1549-1562.

Bird, J. P., Martin, R., Akçakaya, H. R., Gilroy, J., Burfield, I. J., Garnett, S. T., Symes, A., et al. 2020. Generation lengths of the world's birds and their implications for extinction risk. Conservation Biology, 34: 1252-1261.

Bjørdal, V. R. 2019. Juvenile mackerel (Scomber scombrus) along the Norwegian coast: distribution, condition and feeding ecology. Master thesis in Fisheries Biology and Management, Department of Biological Sciences, University of Bergen, Norway. . 73 pp.

Boge, E. 2019. The return of the Atlantic bluefin tuna to Norwegian waters. , Master thesis in Fisheries Biology and Management, Department of Biological Sciences, University of Bergen, Nor-way. 84 p. .

Brunel, T., Damme, C., Samson, M., and Dickey-Collas, M. 2017. Quantifying the influence of geography and environment on the northeast Atlantic mackerel spawning distribution. Fisheries Oceanography, 27.

Bustnes, J. O., Anker-Nilssen, T., Erikstad, K. E., Lorentsen, S. H., and Systad, G. H. 2013. Changes in the Norwegian breeding population of European shag correlate with forage fish and climate. Marine Ecology Progress Series, 489: 235-244.

Cury, P. M., Boyd, I. L., Bonhommeau, S., Anker-Nilssen, T., Crawford, R. J. M., Furness, R. W., Mills, J. A., et al. 2011. Global Seabird Response to Forage Fish Depletion—One-Third for the Birds. Science, 334: 1703-1706.

dos Santos Schmidt, T. C., Devine, J. A., Slotte, A., Claireaux, M., Johannessen, A., Enberg, K., Óskarsson, G. J., et al. 2020. Environmental stressors may cause unpredicted, notably lagged life-history responses in adults of the planktivorous Atlantic herring. Progress in Oceanography, 181: 102257.

Dragesund, O., Johannessen, A., and Ulltang, Ø. 1997. Variation in migration and abundance of Norwegian spring spawning herring (Clupea harengus L.). Sarsia, 82: 97-105.

Drouineau, H., Mullon, C., and Planque., P. In prep. RCaN: a software for chance and necessity modelling.

Erikstad, K. E., Reiertsen, T. K., Barrett, R. T., Vikebø, F., and Sandvik, H. 2013. Seabird–fish interactions: the fall and rise of a common guillemot Uria aalge population. MEPS 475: 267-276.

Fauchald, P., Anker-Nilssen, T., Barrett, R. T., Bustnes, J. O., Bårdsen, B. J., Christensen-Dalsgaard, S., Descamps, S., et al. 2015. The status and trends of seabirds breeding in Norway and Svalbard. Norwegian Institute for Nature research, NINA Report 1151. 84 pp.

Fayet, A. L., Freeman, R., Anker-Nilssen, T., Diamond, A., Erikstad, K. E., Fifield, D., Fitzsimmons, M. G., et al. 2017. Ocean-wide Drivers of Migration Strategies and Their Influence on Population Breeding Performance in a Declining Seabird. Curr Biol, 27: 3871-3878.e3873.

Ferter, K., Bjelland, O., Hinriksson, J., and Nøttestad, L. 2020. Tagging of Atlantic bluefin tuna (Thunnus thynnus) with pop-up satellite archival tags (PSAT) in Norway during 2020. Final project report prepared for the International Commission for the Conservation of Atlantic Tunas (ICCAT) / Grand Bluefin Year Programme (GBYP) 2020 – Phase 10. 10 p.

Fluhr, J., Strom, H., Pradel, R., Duriez, O., Beaugrand, G., and Descamps, S. 2017. Weakening of the subpolar gyre as a key driver of North Atlantic seabird demography: a case study with Brunnich's guillemots in Svalbard. Marine Ecology Progress Series, 563: 1-11.

Forseth, T., Barlaup, B. T., Finstad, B., Fiske, P., Gjoaester, H., Falkegard, M., Hindar, A., et al. 2017. The major threats to Atlantic salmon in Norway. Ices Journal of Marine Science, 74: 1496-1513.

Frederiksen, M., Anker-Nilssen, T., Beaugrand, G., and Wanless, S. 2013. Climate, copepods and seabirds in the boreal Northeast Atlantic - current state and future outlook. Global Change Biology, 19: 364-372.

Hatun, H., Azetsu-Scott, K., Somavilla, R., Rey, F., Johnson, C., Mathis, M., Mikolajewicz, U., et al. 2017. The subpolar gyre regulates silicate concentrations in the North Atlantic. Scientific Reports, 7.

Hatun, H., Lohmann, K., Matei, D., Jungclaus, J. H., Pacariz, S., Bersch, M., Gislason, A., et al. 2016. An inflated subpolar gyre blows life toward the northeastern Atlantic. Progress in Oceanography, 147: 49-66.

Helland-Hansen, B., and Nansen, F. 1909. The Norwegian Sea. Its physical oceanography based upon the Norwegian Researches 1900–1904. Report on Norwegian Fishery and Marine Investigations, 2: 1–360.

Hillersøy, G., and Lorentsen, S.-H. 2012. Annual Variation in the Diet of Breeding European Shag (Phalacrocorax Aristotelis) in Central Norway. Waterbirds, 35: 420-429.

Hipfner, J. M., Blight, L. K., Lowe, R. W., Wilhelm, S. I., Robertson, G. J., Barrett, R. T., Anker-Nilssen, T., et al. 2012. Unintended consequences: how the recovery of sea eagle *Haliaeetus* spp. populations in the northern hemisphere is affecting seabirds. Marine Ornithology, 40: 39-52.

Holm, M., Holst, J. C., and Hansen, L. P. 2000. Spatial and temporal distribution of post-smolts of Atlantic salmon (Salmo salar L.) in the Norwegian Sea and adjacent areas. Ices Journal of Marine Science, 57: 955-964.

Holst, J. H., Røttingen, I., and Melle, W. 2004. Climate and ecosystem variability. . *In* The Norwegian Sea ecosystem, 1 edn, pp. 447–506. Ed. by H. R. Skjoldal. Tapir Academic Press, Trondheim.

Homrum, E., Óskarsson, G., and Slotte, A. 2016. Spatial, seasonal and interannual variation in growth and condition of Norwegian Spring Spawning herring during 1994-2015. ICES WD to WKPELA 2016. 41pp.

Horton, T. W., Block, B. A., Drumm, A., Hawkes, L. A., O'Cuaig, M., Maoiléidigh, N. Ó., O'Neill, R., et al. 2020. Tracking Atlantic bluefin tuna from foraging grounds off the west coast of Ireland. Ices Journal of Marine Science, 77: 2066-2077.

Huse, G., Fernö, A., and Holst, J. 2010. Establishment of new wintering areas in herring co-occur with peaks in recruit to repeat spawner ratio. Marine Ecology-progress Series - MAR ECOL-PROGR SER, 409: 189-198.

ICES. 2011. Report of the Working Group on Mackerel and Horse Mackerel Egg Surveys (WGMEGS), 11–15 April 2011, San Sebastian, Spain. ICES CM 2011/SSGESST:07. 109 pp.

ICES. 2014. Report of the Benchmark Workshop on Pelagic Stocks (WKPELA), 17–21 February 2014, Copenhagen, Denmark. ICES CM 2014/ACOM: 43. 341 pp.

ICES. 2016. Final Report of the Working Group on the Integrated Assessments of the Norwegian Sea (WGINOR), 7-11 December 2015, Reykjavik, Iceland. ICES CM 2015/SSGIEA:10. . 149 pp.

ICES. 2017. Report of the Benchmark Workshop on Widely Distributed Stocks (WKWIDE), 30 January–3 February 2017, Copenhagen, Denmark. ICES CM 2017/ACOM:36. 196 pp.

ICES. 2018. Report of the Working Group on Widely Distributed Stocks (WGWIDE), 28 August- 3 September 2018, Torshavn, Faroe Islands. ICES CM 2018/ACOM: 23. 488 pp. .

ICES 2019a. Cruise report from the International Ecosystem Summer Survey in the Nordic Seas (IESSNS) 28th June – 5th August 2019. Working Document to ICES Working Group on Widely Distributed Stocks (WGWIDE), Santa Cruz, Tenerife, Spain, 28 August – 3 September 2019.: 51.

ICES. 2019b. Interbenchmark Workshop on the assessment of northeast Atlantic mackerel (IBPNEAMac). ICES Scientific Reports. 1:5. 71 pp.

ICES. 2019c. Working Group on Ecosystem Assessment of Western European Shelf Seas (WGEAWESS). ICES Scientific Reports. 1:64. 75 pp. .

ICES. 2019d. Working Group on International Deep Pelagic Ecosystem Surveys (WGIDEEPS). ICES Scientific Reports, 1: 31pp.

ICES 2019e. Working Group on Mackerel and Horse Mackerel Egg Surveys (WGMEGS). ICES Scientific Reports. 1:66. 233. 233.

ICES. 2019f. Working Group on Widely Distributed Stocks (WGWIDE). ICES Scientific Reports. 1:36. . 948 pp.

ICES 2019g. Workshop on a Research Roadmap for Mackerel (WKRRMAC). ICES Scientific Reports. 1:48. . 23.

ICES. 2020a. Arctic Fisheries Working Group (AFWG). ICES Scientific Reports. 2:52. 577 pp. http://doi.org/10.17895/ices.pub.6050.

ICES. 2020b. Blue whiting (Micromesistius poutassou) in subareas 1–9, 12, and 14 (Northeast Atlantic and adjacent waters). In Report of the ICES Advisory Committee, 2020. ICES Advice 2020, whb.27.1-91214. https://doi.org/10.17895/ices.advice.5881

ICES 2020c. Cruise Report from the International Ecosystem Summer Survey in the Nordic Seas (IESSNS), 1st July – 4th August 2020. Working Document no 3 to ICES Working Group on Widely Distributed Stocks (WGWIDE), ICES HQ, Copenhagen, Denmark, (digital meeting) 26. August – 1. September 2020.

ICES. 2020d. Cruise report from the International Ecosystem Survey in the Nordic Seas (IESNS) in May – June 2020. Working Document no 10 to ICES Working Group on Widely Distributed Stocks (WGWIDE), ICES HQ, Copenhagen, Denmark, (digital meeting) 26. August – 1. September 2020.

ICES. 2020e. Mackerel (Scomber scombrus) in subareas 1–8 and 14, and Division 9.a (the Northeast Atlantic and adjacent waters). In Report of the ICES Advisory Committee, 2020. ICES Advice 2020, mac.27.nea. https://doi.org/10.17895/ices.advice.5907.

ICES. 2020f. Working Group on North Atlantic Salmon (WGNAS). ICES Scientific Reports. 2:21. 358 pp. http://doi.org/10.17895/ices.pub.5973.

ICES. 2020g. Working Group on the Integrated Assessments of the Norwegian Sea (WGINOR; outputs from 2019 meeting). ICES Scientific Reports. 2:29. 46 pp. .

ICES. 2020h. Working Group on Widely Distributed Stocks(WGWIDE).ICES Scientific Reports. 2:82. 1019pp.http://doi.org/10.17895/ices.pub.7475.

Jansen, T. 2016. First-year survival of North East Atlantic mackerel (Scomber scombrus) from 1998 to 2012 appears to be driven by availability of Calanus, a preferred copepod prey. Fisheries Oceanography, 25: 457-469.

Jansen, T., and Burns, F. 2015. Density dependent growth changes through juvenile and early adult life of North East Atlantic Mackerel (Scomber scombrus). Fisheries Research, 169: 37-44.

Jensen, A. J., Ó Maoiléidigh, N., Thomas, K., Einarsson, S. M., Haugland, M., Erkinaro, J., Fiske, P., et al. 2012. Age and fine-scale marine growth of Atlantic salmon post-smolts in the Northeast Atlantic. Ices Journal of Marine Science, 69: 1668-1677.

Kristiansen, I., Hátún, H., Petursdottir, H., Gislason, A., Broms, C., Melle, W., Jacobsen, J. A., et al. 2019. Decreased influx of Calanus spp. into the south-western Norwegian Sea since 2003. Deep Sea Research Part I: Oceanographic Research Papers, 149: 103048.

Laursen, K., and Møller, A. P. 2014. Long-Term Changes in Nutrients and Mussel Stocks Are Related to Numbers of Breeding Eiders Somateria mollissima at a Large Baltic Colony. Plos One, 9: e95851.

Lorentsen, S.-H., Anker-Nilssen, T., and Erikstad, K. E. 2018. Seabirds as guides for fisheries management: European shag *Phalacrocorax aristotelis* diet as indicator of saithe *Pollachius virens* recruitment. . Marine Ecology Progress Series 586:193–201.

Lorentsen, S.-H., and May, R. 2012. Inter-breeding movements of common guillemots (Uria aalge) suggest the Barents Sea is an important autumn staging and wintering area. Polar Biology, 35: 1713-1719.

Lorentsen, S. H., Anker-Nilssen, T., Erikstad, K. E., and Rov, N. 2015. Forage fish abundance is a predictor of timing of breeding and hatching brood size in a coastal seabird. Marine Ecology Progress Series, 519: 209-220.

Mesquita, M. d. S., Erikstad, K. E., Sandvik, H., Barrett, R. T., Reiertsen, T. K., Anker-Nilssen, T., Hodges, K. I., et al. 2015. There is more to climate than the North Atlantic Oscillation: a new perspective from climate dynamics to explain the variability in population growth rates of a long-lived seabird. Frontiers in Ecology and Evolution, 3.

Mitchell, P. I., Newton, S. F., Ratcliffe, N., and Dunn, T. E. 2004. Seabird populations of Britain and Ireland., T & A D Poyser, London.

Nøttestad, L., Boge, E., and Ferter, K. 2020a. The comeback of Atlantic bluefin tuna (Thunnus thynnus) to Norwegian waters. Fisheries Research, 231: 105689.

Nøttestad, L., E., B., and R.B, M. 2020b. Fishing capacity on Atlantic bluefin tuna (Thunnus thynnus) by purse seine vessels fishing in the Norwegian Exclusive Economic Zone from 2014 to 2019. Col. Vol. Sci. Pap. ICCAT, 77 pp. 215-225.

Nøttestad, L., Utne, K., Óskarsson, G., Jonsson, S. P., Jacobsen, J., Tangen, O., and Anthonypillai, V. 2016. Quantifying changes in abundance, biomass, and spatial distribution of Northeast Atlantic (NEA) mackerel (Scomber scombrus) in the Nordic seas from 2007 to 2014. 359-373 pp.

Olafsdottir, A. H., Slotte, A., Jacobsen, J. A., Oskarsson, G. J., Utne, K. R., and Nøttestad, L. 2015. Changes in weight-at-length and size-at-age of mature Northeast Atlantic mackerel (Scomber scombrus) from 1984 to 2013: effects of mackerel stock size and herring (Clupea harengus) stock size. ICES Journal of Marine Science: Journal du Conseil.

Olafsdottir, A. H., Utne, K. R., Jacobsen, J. A., Jansen, T., Óskarsson, G. J., Nøttestad, L., Elvarsson, B. Þ., et al. 2019. Geographical expansion of Northeast Atlantic mackerel (Scomber scombrus) in the Nordic Seas from 2007 to 2016 was primarily driven by stock size and constrained by low temperatures. Deep Sea Research Part II: Topical Studies in Oceanography, 159: 152-168.

Pedreschi, D., Bouch, P., Moriarty, M., Nixon, E., Knights, A. M., and Reid, D. G. 2019. Integrated ecosystem analysis in Irish waters; Providing the context for ecosystem-based fisheries management. Fisheries Research, 209: 218-229.

Planque, B., and Mullon, C. 2020. Modelling chance and necessity in natural systems. Ices Journal of Marine Science, 77: 1573-1588.

Reiertsen, T. K., Erikstad, K. E., Anker-Nilssen, T., Barrett, R. T., Boulinier, T., Frederiksen, M., Gonzalez-Solis, J., et al. 2014. Prey density in non-breeding areas affects adult survival of black-legged kittiwakes Rissa tridactyla. Marine Ecology Progress Series, 509: 289-.

Rey, F. 2012. Declining silicate concentrations in the Norwegian and Barents Seas. Ices Journal of Marine Science, 69: 208-212.

Sandvik, H., Reiertsen, T. K., Erikstad, K. E., Anker-Nilssen, T., Barrett, R. T., Lorentsen, S. H., Systad, G. H., et al. 2014. The decline of Norwegian kittiwake populations: modelling the role of ocean warming. Climate Research, 60: 91-102.

Siegelman-Charbit, L., and Planque, B. 2016. Abundant mesopelagic fauna at oceanic high latitudes. Marine Ecology Progress Series, 546: 277-282.

Skagen, D. W., Skern-Mauritzen, M., Dankel, D., Enberg, K., Kjesbu, O. S., and Nash, R. D. 2013. A simulation framework for evaluating fisheries management decisions using environmental information. ICES Journal of Marine Science, 70: 743-754.

Skjoldal, H. R., Dalpadado, P., and Dommasnes, A. 2004. Food webs and trophic interactions. *In* The Norwegian Sea ecosystem, pp. 447-506. Ed. by H. R. Skjoldal. Tapir Academic Press, Trondheim.

Skjoldal, H. R. e. 2004. The Norwegian Sea Ecosystem, Tapir Academic Press.

Solvang, H. K., and Planque, B. 2020. Estimation and classification of temporal trends to support integrated ecosystem assessment. Ices Journal of Marine Science, 77: 2529-2540.

Utne, K. R., Huse, G., Ottersen, G., Holst, J. C., Zabavnikov, V., Jacobsen, J. A., Oskarsson, G. J., et al. 2012. Horizontal distribution and overlap of planktivorous fish stocks in the Norwegian Sea during summers 1995-2006. Marine Biology Research, 8: 420-441.

Waldeck, P., and Larsson, K. 2013. Effects of winter water temperature on mass loss in Baltic blue mussels: Implications for foraging sea ducks. Journal of Experimental Marine Biology and Ecology, 444: 24-30.

Wiborg, K. F. 1954. Investigations of Zooplankton in Coastal and Offshore Waters of Western and Northwestern Norway. In Report on Norwegian Fishery and Marine Investigations, Vol. XI. No. 1.

Yashayaev, I., and Loder, J. W. 2017. Further intensification of deep convection in the Labrador Sea in 2016. Geophysical Research Letters, 44: 1429-1438.

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Annex 2: Resolutions

2018/MA2/IEASG13 **The Working Group on Integrated Assessment of the Norwegian Sea** (WGINOR), chaired by Per Arneberg, Norway and Anna H. Ólafsdóttir*, Iceland, will work on ToRs and generate deliverables as listed in the Table below.

	MEETING DATES	VENUE	REPORTING DETAILS	COMMENTS (CHANGE IN CHAIR, ETC.)
Year 2019	25-29 November	Bergen, Norway	Interim report by 15 January 2020 to IEASG	New incoming Co-Chair, Anna H. Ólafsdóttir, Iceland
Year 2020	23-27 November	By correspondence	Interim report by 15 January 2021 to IEASG	
Year 2021	22-26 November	Reykjavík Iceland	Final report by 15 January 2022 to IEASG	

Terms of Reference a) – f):

ToR	Description	Background	Science Plan Codes	Duration	Expected Deliverables
a	Perform integrated assessment of the pelagic ecosystem in the Norwegian Sea and develop a framework for identifying warning signals for management.	Addresses needs in the Science Plan for developing understanding of the ecosystem and its responses to human impact and other challenges. In addition, start developing a framework for ecosystem-based advice that can be used by WGWIDE, OSPAR and similar recipients.	6.5	years 1-3	WG report to SCICOM and ACOM January following each year
b	Utilize multispecies and ecosystem models to evaluate effects of single and multi-species harvest control rules on fishing yield and ecosystem state of the pelagic ecosystem in the Norwegian Sea.	Addresses needs in the Science Plan for developing ecosystem-based advice for sustainable use of marine ecosystems resources.	5.3	years 2-3	WG report to SCICOM and ACOM January following year 2 and 3
c	Initiate development of forecast products (1-5 years) for key indices of ocean climate in the Norwegian Sea.	Aims at providing better understanding of links between the physical environment and productivity of the pelagic ecosystem in support of integrated ecosystem assessment.	1.2	years 1-3	WG report to SCICOM and ACOM January following each year
d	Develop a foodweb assessment of the pelagic ecosystem in the Norwegian Sea, including hindcasts and conditional forecasts of the main species or trophic groups.	Aims at providing better understanding of energy flow in the foodweb of the pelagic ecosystem in support of integrated ecosystem assessment.	5.2	years 1-3	WG report to SCICOM and ACOM January following each year

e	Establish a dialogue between WGINOR and relevant pelagic fisheries stakeholders and managers in Norway, Faroe Island and Iceland.	Aims at steering the work of the group so that it addresses management needs.	6.4	years 1-3	WG report to SCICOM and ACOM January following each year
f	Update the ecosystem overview based on the ICES guidelines.	Summarizes key achievements in developing an understanding of the ecosystem and its responses to human impact and other challenges.	6.5	year 3	WG report to SCICOM and ACOM January following year 3

Summary of the Work Plan:

Year 1	Initiate work with ToRs c,d and e and framework for warning signals in ToR a. Do interim IEA as part of ToR a.
Year 2	Continue work on ToRs c,d and e. Start work with the climate change part of ToR f. Start work with ToR b. Do interim IEA and assess warning signals as a part of ToR a.
Year 3	Do full IEA with assessment of warning signals as part of ToRa. Update the ecosystem overview. Continue work on ToRs b, c, d, and e.

Supporting information

Priority	**WGINOR aims to conduct and further develop Integrated Ecosystem Assessment for the Norwegian Sea, as a step towards implementing the ecosystem approach, addressing core priorities in the ICES strategic plan.**
Resource requirements	**Term of Reference a)** **The two international fish-plankton surveys in the Norwegian Sea have in recent years been developed in the direction of ecosystem surveys that capture several key components of the ecosystem. This provides a firm foundation for performing an integrated assessment of the Norwegian Sea pelagic ecosystem. A framework for assessing warning signals will be developed with input from relevant projects at the involved institutions.** **Term of Reference b)** **This will build on model approaches developed for this ToR during several years within WGINOR.** **Term of Reference c)** **This will be based on ongoing research projects and oceanographic information collected during cruises in the Norwegian Sea and surrounding waters and supplied by satellite-based monitoring. Resources must be found in the participating institutions to complete development of the forecast system.** **Term of Reference d)** **The basis for developing the model-based foodweb assessment is the data from the ecosystem cruises and model work done in the involved institutions. The work will draw on ongoing projects with a similar scope. Some resources must also be found in the involved institutions to complete the work.** **Term of Reference e)** **This will be based on experiences made during fishing industry scoping exercise at IMR, Bergen, Norway in 2018 and will not require additional resources.** **Term of Reference f)** **Update of the elements of the ecosystem overview established before 2019 will be done based on existing projects and management initiatives, such as the Norwegian ecosystem-based management plan for the Norwegian Sea. The new elements focusing on climate change will be developed with a basis in ongoing projects and other assessment processes, such as IPCC. Additional resources will be required in the participating institutions to**

	complete the latter work, in particular related to projections and assessments of anticipated effects of climate change in future.
Participants	**The Group is normally attended by some 15-20 members and guests.**
Secretariat facilities	**None.**
Financial	**No financial implications.**
Linkages to ACOM and groups under ACOM	**WGINOR has provided text to the section on “Ecosystem considerations for widely distributed and migratory pelagic fish species” in the WGWIDE report.**
Linkages to other committees or groups	-
Linkages to other organizations	**The work done in the group is highly relevant to other assessment initiatives, in particular the Norwegian ecosystem-based management plan for the Norwegian Sea and OSPAR.**

Annex 3: Agenda of the 2020 meeting

Agenda for WGINOR meeting 23 - 27 November 2020, online

Monday 23 November (CET time zone)

9:00 – 9:15 Welcome and housekeeping.

9:15 – 9:45 Meeting participants introduction round.

ToRa, Integrated Assessment.

9:45 – 10:30 Development of short status report for management.

It is suggested to produce a yearly short status report for the Norwegian Sea ecosystem that can be used by management in Norway to follow up the Norwegian ecosystem-based management plan of the Norwegian Sea. With small adjustments (and little extra resources used), the report can also be tailored for Icelandic and Faroese management. The report should not exceed 15 pages and provide un update of status and change for key aspects of the ecosystem. Two issues need to be discussed; (1) an adjustment of the ToRs to accommodate this if the group wants to include this as an operational product, and (2) a draft protocol for the report. The draft protocol will be sent to WGINOR members before the meeting.

10:30 – 10:50 Coffee break

10:50-12:20 Ecosystem status for 2020, presentations (which will form basis for the short report):

10:50-11:20 Ocean climate, Øystein Skagseth,

11:20-11:50 Plankton, Cecilie Broms, Hildur Pétursdóttir and Inga Kristiansen,

11:50-12:20 Pelagic fish, Sigurvin Bjarnason.

12:20-13:20 Lunch

13:20-15:00 Ecosystem status for 2020 continued:

13:20-13:40 Seabirds, Svein-Håkon Lorentsen or Tycho Anker-Nilsen,

13:40-14:00 Marine mammals, Anne Kirstine Frie.

14:00-14:30 Discussion on issues related to ecosystem status (to be continued on Thursday with the warning signal analyses).

Tuesday 24 November (CET time zone)

ToRa, Integrated Assessment continued.

9:00-10:00 Discussion on framework for ecosystem-based advice that can be used by WGWIDE, OSPAR and similar recipients, chaired by Per Arneberg.

Science highlights.

10.00-10:15 Status of the SIS harvesting project (where much of the research following up the WGINOR work plan is done). Will give an overview of the project and more details on issues not covered in other parts of the meeting, Erik Askov Mousing.

10:15-10:30 Mackerel workshop held in September and follow up plan, Aril Slotte.

10:30-10:50 Coffee break

Science highlights continued:

10:50-11:10 Norwegian Sea Gyre, Hjálmar Hátún,

11:20-11:30 On age-disaggregated distribution of NSS herring, Sólvá Eliasen,

11:10-11:20 On copepods north of the Faroes - title coming later, Inga Kristiansen,

11:30-11:40 Short break or catching up if delayed,

11:40-12:00 Managing Ethical Norwegian Seascape Activities (MENSA), Mimi Lam,

12:00-12:20 Spatio-temporal distribution of NEA mackerel catches from 1998-2017, Nikolaos Nikolioudakis.

12:20-13:20 Lunch

ToRb, Multispecies harvest control rules.

13:20-13:40 Ecosystem-based harvest control rules for Norwegian and US ecosystems (https://www.frontiersin.org/articles/10.3389/fmars.2020.00652/full), Cecilie Hansen.

13:40-15:00 Presentation and discussion of plan developed in SIS harvesting for development of ecosystem-based management strategies for the Norwegian Sea using av ecosystem MSE framework, Alfonso Perez-Rodriguez.

Wednesday 25 November (CET time zone)

ToRc, Climate forecast.

9:00-9:45 Presentation and discussion on work done on this within SIS harvesting, Øystein Skagseth.

ToRd, Foodweb assessment.

9:45-10:30 Presentation and discussion on work done on this within SIS harvesting, Benjamin Planque.

10:30-10:50 Coffee break

ToRf, Ecosystem overview.

10:50-11:00 Presentation of work process with the ICES Ecosystem Overview (EO) revisions, Gro van der Meeren.

11:00-12:20 Introduction of the draft version of the EO diagram of pressures, activities, and impact. i.e. the wire diagram. Gro van der Meeren.

12:20-13:20 Lunch break

13:20-14:10 Discussion on report card template (Benjamin's table)

Thursday (CET time zone)

Science highlights continued.

9:00-9:15 Estimated top–down effects of mackerel and herring predation on *Calanus* using models EwE and Norwecom, Kjell Rong Utne.

9:15-9:35 An appraisal of the drivers of Norwegian spring-spawning herring (*Clupea harengus*) recruitment (https://onlinelibrary.wiley.com/doi/full/10.1111/fog.12510), Benjamin Planque.

9:35-9:50 Fishing *Calanus finmarchicus* in the Norwegian Sea; Ecosystem effects, fishing patterns and efficiency, Cecilie Hansen.

9:50-10:10 Break

ToRa continued.

10:10-10:40 Updated ecosystem warning signal analysis for the Norwegian Sea ecosystem, Hiroko Solvang and Per Arneberg.

10:40-11:40 Discussion about significance of individual warning signals, Hiroko Solvang.

11:45-12:45 Lunch

12:45-13:15 Discussion on how to present results of warning signal analysis to stakeholders, management and other ICES groups (e.g. WGWIDE).

13:15-15:00 Work with report.

Friday (CET time zone)

ToRf, Ecosystem overview continued.

9:00-10:25 Revising the EO diagram of pressures, activities, and impact. i.e. the wire diagram. Plenary discussion lead by Gro van der Meeren.

10:25-10:50 Coffee break

10:50-12:20 Working with report.

12:20-13:20 Lunch

13:20-14:20 E-evaluation form and remaining issues on report including deadlines. Closing of meeting.

Annex 4: Norwegian Sea ecosystem status summary

This document gives a short summary of the current state and recent change of different components of the Norwegian Sea ecosystem while also briefly discussing possible causes of state and change. It is issued for the first time in 2021 and is planned to be updated yearly. The ecosystem status summary is intended for a wide audience, including scientists, teachers, students, decision-makers and the general public interested in the Norwegian Sea ecosystem and marine environmental issues more general. It is prepared by the ICES Working Group on integrated ecosystem assessment for the Norwegian Sea (WGINOR). It represents a summary of scientific information prepared by the group and does not constitute ICES advice.

Highlights

- Water flowing into the Norwegian Sea has been colder and fresher the last 3-4 years than previously, but overall cooling has been limited due to reduced heat loss, the latter caused by increased strength of westerly winds.
- Annual primary production has been higher and spring blooms longer in the last part of the years since the start of the current satellite monitoring in 2003, possibly due to increased inflow of cold and fresh Arctic water.
- Zooplankton biomass declined from around 2005 to 2010 and has since remained fairly stable.
- The biomasses of Norwegian spring-spawning herring, mackerel and blue whiting have all declined in recent years. Recruitment of blue whiting has been poor in recent years while a strong year class is about to enter the Norwegian spring-spawning herring stock.
- Pelagically feeding seabirds breeding along the Norwegian coast have declined substantially since the start of monitoring in 1980, and common guillemot, one of these species, is at high risk of extinction as a breeding species in the area.
- For marine mammals, a long-term shift in summer distribution from the Norwegian Sea to the Barents Sea has occurred in recent years. Pup production is at low or declining levels for hooded, grey and harp seals. Levels of bycatch have been unsustainable in the harbour porpoise population but appears to have declined to sustainable levels for the period 2013 to 2018.

Summary

	Topic	Overall trend	Situation in 2020	Certainty	Possible implications
	Ocean climate	General warm and saline conditions prevailed from the early 2000s until 2015-2016. Since then the water has become markedly fresher and cooled slightly.	Relative cooling but still warm	Highly certain: dedicated monitoring with good spatial coverage exists.	Increase in nutrients after 2016
	Primary production	The annual new primary production increased by 35% from 2003 to 2019, and the length of spring bloom increased by 15 days.	Comparable to the 7 preceding years	Highly certain: the phytoplankton estimates are based on satellite data covering the whole productive season with high geographic solution.	Increased food resources for herbivores 2012-2020
	Zooplankton biomass	The spring biomass of mesozooplankton declined from 1995 to 2010 and has been stable during the last 10 years. Summer biomass has been stable or increasing in different sub-areas during the last 10 years.	Biomass in 2020 was at the same levels as the last years.	Moderately certain: plankton is patchily distributed, which leads to uncertain estimates. The uncertainty is not reported.	Reduced food resources for planktivorous feeders, including pelagic fish for the recent decade
	Zooplankton spatial distribution	The spring distribution of zooplankton has gone from having higher biomasses in arctic water in the west to become evenly distributed in the Norwegian Sea.	In 2020 the zooplankton was evenly distributed in spring but had higher biomass southeast of Iceland and north of Faroe Islands in summer.	Moderately certain: The surveys do not cover the full distribution areas of all the species	Affect distribution of planktivorous fish

	Topic	Overall trend	Situation in 2020	Certainty	Possible implications
	Pelagic fish biomass	The biomass of NSS herring, blue whiting and mackerel stocks have declined in recent years due to fishing above scientific advice in all stocks, and poor recruitment in blue whiting and NSS herring over several years.	Pelagic fish biomass declined by 23% (blue whiting), 15% (NSS herring), and 1% (mackerel) from 2019 to 2020. Compared with 2019, recruitment increased by 240% (NSS herring) and 77% (blue whiting). No recruitment estimates for mackerel is reported for 2020.	Highly certain for herring and blue whiting, moderately certain for mackerel: estimates are based on quantitative stock assessments	Direct implications for fisheries opportunities
	Pelagic fish spatial distribution	In mid-2000´s mackerel distribution began expanding westward, into Icelandic and Greenlandic waters but has retracted since 2015.	No mackerel in Greenlandic waters and low levels in the south-eastern part of Icelandic waters.	Highly certain: based on ecosystem surveys in the Nordic Seas in spring (May) and summer (July)	Direct implications for fisheries opportunities
	Seabirds	Substantial declines for most species, including common guillemot, Atlantic puffin and black-legged kittiwake.	No clear signs of improvements, except common guillemot numbers are seemingly relatively stable in (sub-) colonies where smaller numbers can breed in shelter to avoid predation.	Highly certain: Trends are derived from dedicated monitoring	Many colonies are at risk of extinction, and some have already disappeared
	Marine mammals	Decline or sustained low levels of pup production several seal species.	There are no new estimates for 2020	Highly certain: trends in pup production are based on dedicated surveys	Foodweb structure and long-term viability of marine mammal populations

Climate

Current status and recent changes

Variation in ocean climate is important for the state of Norwegian Sea ecosystem (for examples, see sections for zooplankton and seabirds). The Norwegian Sea ocean climate and how it varies is determined by the amount of Atlantic water flowing into the area (which is generally warm and saline), the amount of Arctic water flowing in (which is generally colder and fresher), the properties of these water masses (e.g. how warm and saline the Atlantic water is)[1], and heat loss from the sea to the air[2].

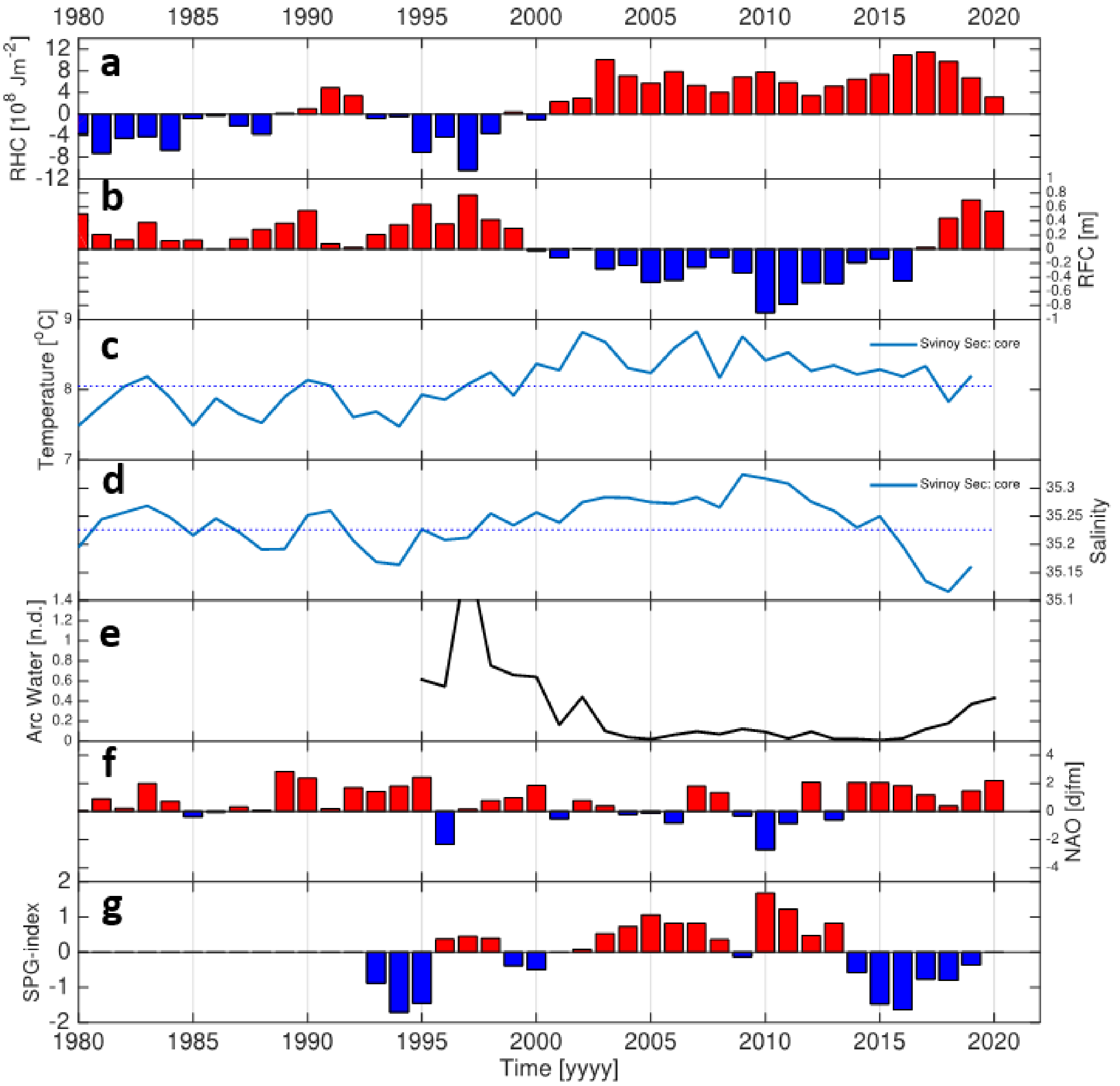


Figure 1. A subset of climate indicators for the Norwegian Sea: a) Relative heat content and b) Relative Freshwater Content; Svinøy section Atlantic Water core c) temperature and d) salinity; e) Arctic Water influence in the Norwegian Sea, f) The North Atlantic Oscillation (NAO) winter index, and g) the Sub-polar Gyre (SPG) index (please note that strong gyre is represented by negative values and weak gyre with positive values)

To describe ocean climate and how it varies, total heat content and freshwater content in the Norwegian Sea is estimated from measurements of temperature and salinity. These data show a trend from cold and fresh waters in the mid-1990s to a until about 2003 when the state changed to warm and saline, which prevailed until about 2015 (Figure 1 a, b). Since 2015, the freshwater content has increased considerably but heat content decreased only slightly. The inflowing Atlantic water, which is monitored in the Svinøy section (at about 63N) largely follows these changes (Figure 1 c, d). Further, the amount of Arctic Water in the Norwegian Sea, that had been decreasing since the 1990, and had been at a low state since about 2003, have shown a prominent increasing trend starting in 2016-2017 (Figure 1e). Thus, the Atlantic inflowing water has become cooler and the amount of Arctic water flowing into the area has increased during the recent years.

Possible reasons for recent changes

The Subpolar Gyre is located south of the Norwegian Sea, centered in the Labrador and Irminger seas. The strength of this gyre influences the properties (e.g. temperature, salinity and nutrients) of the Atlantic water flowing into the Norwegian Sea. When the gyre is strong, it brings in increased amounts of cold and fresh water from the western part of the North Atlantic. The warm and saline water in the Golf Stream is then diluted, causing the Atlantic water flowing into the Norwegian Sea to become colder and fresher. When the gyre is weak, the inflowing Atlantic water becomes more influenced by the warmer and relatively saline water from the Gulf Stream.

In addition, atmospheric conditions also influence the ocean climate in the Norwegian Sea. Important variability in atmospheric conditions can be measured through the North Atlantic Oscillation (NAO) index. When the NAO-index is in a positive phase, the Subpolar Gyre tends to be strengthened, and inflowing Atlantic water thus becoming colder and fresher. At the same time, heat loss from sea to air also tends to be reduced with a positive NAO-index.

The change from fresh and cold conditions in the 1990s to warm/saline conditions after 2003 can thus be attributed to a switch from a relative strong to a weak Subpolar Gyre from 1995 to 1996, and hence as a result warmer and more saline Atlantic source water flowing into the Norwegian Sea (Figure 1g). At the same time, the NAO-index was positive (Fig 1f), reducing the heat loss from sea to air. The positive NAO-index over the period 2014-2020 also explains the recent (2017-2019) strong freshening (Figure 1b) that is further accompanied by minor cooling (Figure 1a[3]). In addition to fresher inflowing Atlantic water, the overall freshening is probably also influenced by expansion of Arctic Water from the west to the east into the Norwegian Sea. In particular, there are indications that the influence of the East Icelandic Current, which flows from the east side of Iceland towards the Faroe Islands and brings with it Arctic water, has increased over the recent years.

Phytoplankton

Current status and recent changes

Annual primary production was higher, and spring blooms were longer, in the later years of the 2003 to 2019 time series, compared to earlier in the time series (Figure 2). The primary production rates are calculated based on variables (e.g. colour) measured by the MODIS satellite[4] and represent the production available to other organisms in the ecosystem.

The annual production estimates from the last seven years of the period was higher than the previous years by approximately 35%. In addition, the length of spring bloom increased by on average 17 days. Longer spring blooms are associated with longer grazing period and consequently higher input of organic matter and energy into the pelagic foodweb[5].

Possible reasons for recent changes

The phytoplankton data from the later part of the period suggest a more favourable situation for herbivores compared to the years before 2013. It should be noted that the time interval covered by the satellite data are too short to distinguish long time-trends from the natural variation[6]. Fresher Arctic water into the Nordic Seas has increased stabilizing stratification of the surface layer[3]. More stable stratification may be the main reason for the higher productivity observed in the last decade.

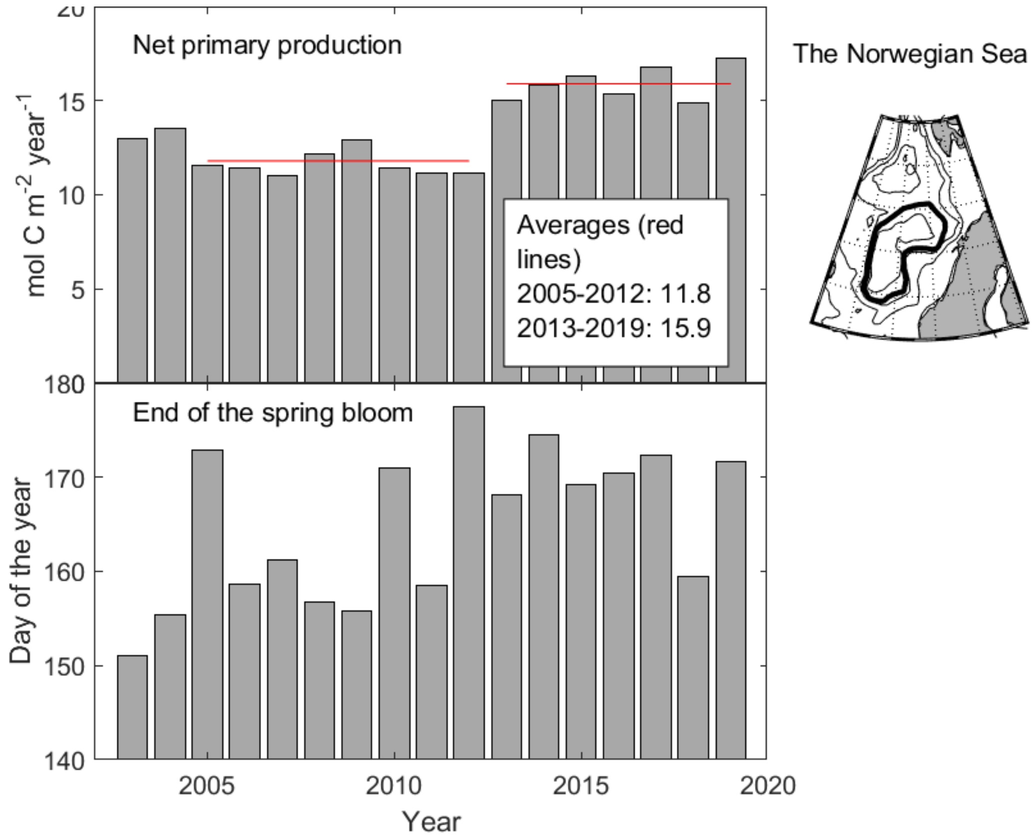


Figure 2. Estimated net yearly primary production (upper panel) and date for end of spring bloom (lower panel) in the Norwegian Sea.

Zooplankton

Current status

Recent zooplankton biomass in the Norwegian Sea, including areas north of Faroe Islands and east of Iceland, is in general at the same level as previous years. This applies both for the zooplankton biomass in spring (May) and summer (July and August). There are however differences in the amount of zooplankton between subregions of the Norwegian Sea (see Figure 3). Biomasses are similar in all subareas in spring but are higher in the southern part of the Norwegian Sea and the Jan Mayen Arctic front area during summer.

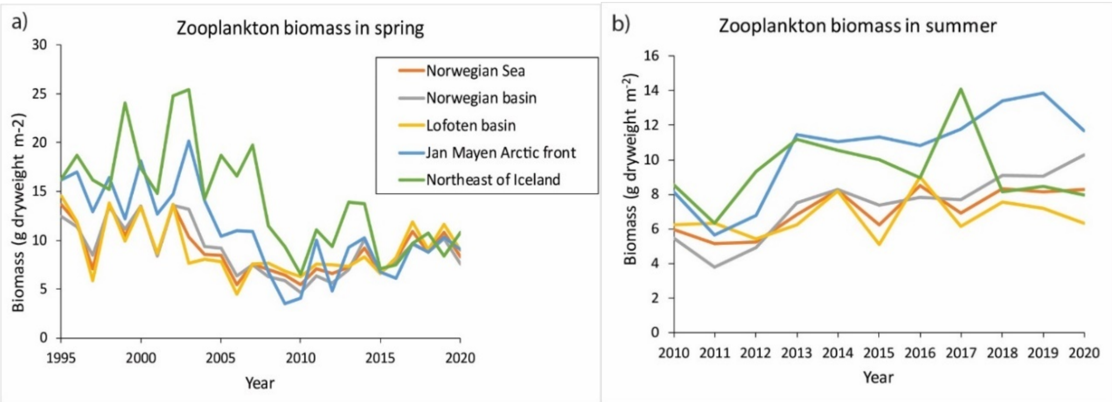
Recent changes

There has been two main changes in spring zooplankton biomass during the last three decades: 1) The biomass level has decreased throughout the area, and 2) the previously higher zooplankton level in Arctic water northeast of Iceland has been reduced to the same level as in the Atlantic water in central Norwegian Sea.

For the period 1995 to mid-2000 the plankton index in spring was relatively high, with fluctuations between years (Figure 3a). Since around mid-2000 the index decreased and has since been at lower levels. The largest decline has taken place in Arctic water east of Iceland, where the reduction has been approximately 50 % from the "high-biomass" period to the "low-biomass" period. During the last decade, the amount of zooplankton has been stable both in spring (Figure 3a) and summer (Figure 3b, for which there is data only for the last 10 years) and showing a slight increase over the entire area.

Possible reasons for recent changes

The reasons for the changes in zooplankton biomass are not obvious. It is worth noting that the period with lower zooplankton biomass coincides with higher-than-average heat content in the Norwegian Sea[7] (see climate section) and reduced inflow of Arctic water into the southwestern Norwegian Sea[8]. Timing effects, such as match/mismatch with the phytoplankton bloom, can also affect the zooplankton abundance. The high biomass of pelagic fish (see pelagic fish section) feeding on zooplankton has been suggested to be one of the main causes for the reduction in zooplankton biomass. However, carnivorous zooplankton and not pelagic fish may be the main predators of zooplankton in the Norwegian Sea[9], and we do not have good data on the development of the carnivorous zooplankton stocks.



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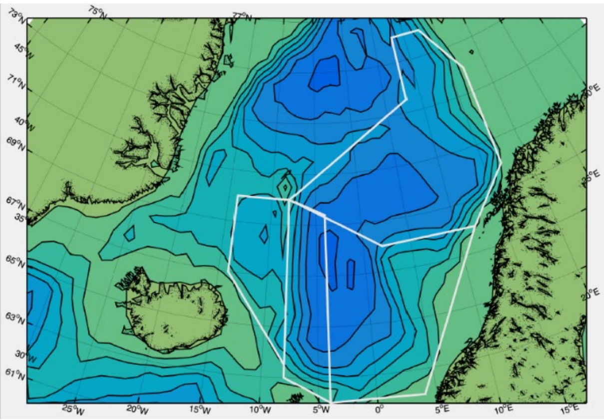


Figure 3. Indices of zooplankton biomasses (g dry weight m^{-2}) in the upper 200 m of the water column in the Norwegian Sea and adjacent waters, a) in May during the time period 1995-2020 b) in July/August during the time period 2010-2020. The total area has been divided into 4 sub-areas, shown in panel c); Red: southern Norwegian Sea including the Norwegian Sea Basin; Blue: the Northern Norwegian Sea including the Lofoten Basin; Black: the Jan Mayen Arctic front area; Green: the area East of Iceland; Grey: the mean index of the sub-areas southern- and northern Norwegian Sea.

Pelagic Fish

Current status

Three fish stocks dominate the pelagic ecosystem of the Norwegian Sea: Norwegian spring-spawning herring (NSSH, *Clupea harengus*), North East Atlantic (NEA) mackerel (*Scomber scombrus*), and blue whiting (*Micromesistius poutassou*). In 2020, estimated spawning-stock biomass (SSB) was quite similar for all three stocks, ranging from 3.2 to 3.7 million tonnes, and combined SSB for all three stocks was 11.2 million tonnes[10] (Figure 4a).

Combined catch of the three stocks was 3.1 million tonnes in 2019, of which approximately half was blue whiting and quarter each for herring and mackerel. Current exploitation level, relative to biological reference points, show that fishing pressure on herring and blue whiting is above management plan targets and above maximum sustainable yield, but within limits for sustainable harvest. Mackerel exploitation is within limits for maximum sustainable yield. There is no international management plan for mackerel. Stock status, for all three stocks, is good as SSB is above all biological reference points related to the risk of impaired reproductive capacity. However, herring SSB is very close to biological reference limits[10].

Recent changes

Since the late 1980's, combined SSB of the three stocks peaked at 15.6 million tonnes in 2016 and had declined by 34% in 2020. Timing of stock size peak and decline rate differ between stocks. Herring SSB peaked in 2008 and had declined by 53% in 2020. Mackerel SSB peaked in 2014 and has declined by 29%. Blue whiting SSB last peaked in 2016 and has since declined by 48%.

For all three stocks the most obvious change in ecology in recent years is the large-scale expansion and retraction of mackerel summer feeding distribution westward into Icelandic and Greenland exclusive economic zones. In the mid-2000s, mackerel began expanding its distribution westward into Icelandic waters. By 2013 mackerel had entered Greenland waters, and distribution range peaked in 2014 with mackerel occupying most of the Irminger Sea. High abundance of mackerel remained in the western area during summers 2015-2017, as its distribution range in the Irminger Sea retracted. By summer of 2019 no mackerel was measured in the Greenland waters and in 2020 negligible mackerel was measured in Icelandic waters[10].

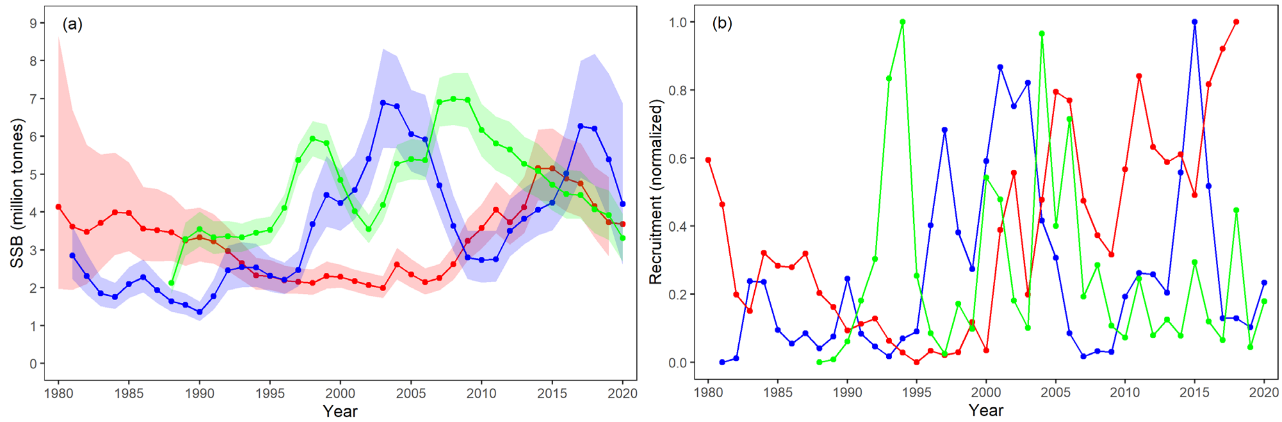


Figure 4. a) Estimated spawning-stock biomass (lines) including 95% confidence intervals (shaded areas) for Norwegian spring-spawning herring (green), mackerel (red) and blue whiting (blue) from 1980 to 2020 (a; ICES 2020). b) Estimated year-class size at recruitment for Norwegian spring-spawning herring (age 2; green) and blue whiting (age 1; blue) from 1981 to 2020[11], values normalized to the maximum of one and minimum of zero.

Possible reasons for recent changes

Herring SSB is dominated by recruitment of large year-classes at irregular intervals with many years of small year-classes between. After the large 2002- and 2004-year classes, the recruitment has been below average. Since 2018, surveys have indicated an incoming strong 2016 year-class. The magnitude will be known when the year class is fully recruited at around age seven (in 2023). Fishing above advised level has accelerated stock decline during a period of low recruitment. Since 2013, when sharing arrangements were no longer agreed upon, annual commercial catch has on average been 29% higher than the advised total allowable catch (TAC). Annual commercial catches of mackerel have on average been 40% higher than the advised TAC since 2014. During the same period, all new year-classes have been above average size, which has reduced the impact of excessive fishing. Blue whiting's sharp decline in SSB is caused by excessive fishing, with catches exceeding the advised TAC by 31% since 2016, in combination with all year-classes recruited since 2017 being small. The blue whiting fishery mostly targets ages 3-5 years; hence the stock can sharply decline when several years of poor recruitment coincide with excessive fishing.

The reasons why mackerel has retracted from the western area from 2015 onwards remain poorly understood. During this period, estimated mackerel stock size has declined by approximately 30%, zooplankton abundance has remained within the range observed during the period 2010-2017, and the western area remains warm enough for mackerel presence (> 8-9 °C; ICES, 2020).

Seabirds

Current status and recent changes

Five species of seabirds feeding in the pelagic (3) and coastal (2) parts of the ecosystem, are selected as indicator species for the eastern part of the Norwegian Sea, i.e. along the central part of the Norwegian coast (hereafter eastern Norwegian Sea).

The pelagic species are represented by the black-legged kittiwake (*Rissa tridactyla*, hereafter kittiwake), Atlantic puffin (*Fratercula arctica*, hereafter puffin) and common guillemot (*Uria aalge*). The main reason for selecting these species is that they feed in different parts of the pelagic ecosystem. The kittiwake obtains its food (first-year herring, sandeels, gadoids, lanternfish, crustaceans, and pteropods) within the upper half meter of the sea surface. The common guillemot typically feeds at depths down to 80 m and may eat very small fish such as 0-group cod but feed its chick mainly 10-20 cm long saithe, haddock, sandeel and herring that are brought one by one to the colony. The puffin usually brings loads of smaller fish to its chick and typically feeds at depths down to 30 m, relying mainly on first-year herring, sandeel and gadoids.

Representatives of the coastal species are the common eider (*Somateria mollissima*, hereafter eider) and the European shag (*Phalacrocorax aristotelis*, hereafter shag). The eider mainly feed on benthic prey like crustaceans, molluscs and echinoderms. The shag is a fish specialist which typically dive in shallow waters and feeds on gadoids and/or sandeels.

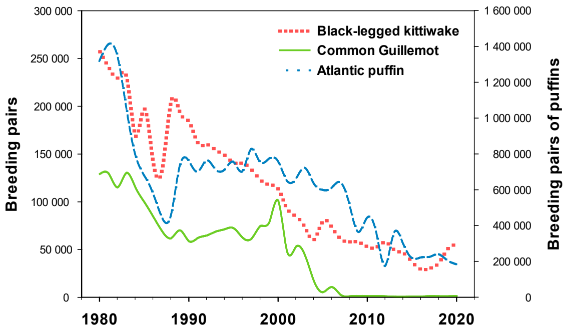
For the three pelagic species, time series of their population development in the eastern Norwegian Sea (Figure 5) were derived from their estimated breeding numbers in 2013[12] and annual monitoring of trends in selected breeding colonies (Runde (62.4°N), Sklinna (65.2°N), Røst (67.5°N) and Anda (69.1°N, only kittiwake and puffin). The remote island of Jan Mayen (71.1°N) in the north-western Norwegian Sea holds only < 10,000 pairs of kittiwakes, < 5000 pairs of puffins and < 1000 pairs of common guillemots. Monitoring started in 2011, and has been done for common guillemot only, which has shown a declining trend.

The breeding population of kittiwakes in the eastern Norwegian Sea has declined by 78% since monitoring started in 1980. Its outlook is grim, with several large colonies already gone and many more risking extinction within a few decades. In the same area and period, the breeding population of puffins has declined by 75% and that of common guillemots by as much as 99%. The remaining population of common guillemots breeds in shelter of predation and are currently relatively stable, but the species is at high risk of extinction as a breeding species along a large part of the Norwegian mainland coast.

For the two coastal species, trends in breeding populations in the eastern Norwegian Sea (Figure 5) are monitored in selected areas along the mainland coast (Trondheimsfjorden (63.4°N, only eider), Sklinna (65.2°N), Ranfjorden (66.2°N, only eider), and Røst (67.5°N).

The breeding population of eiders in the eastern Norwegian Sea has declined by about 80% since the first counts in the mid-1980s. In contrast, shag populations in both colonies monitored increased from the mid-1980s to around 2005 but have decreased markedly thereafter.

a)



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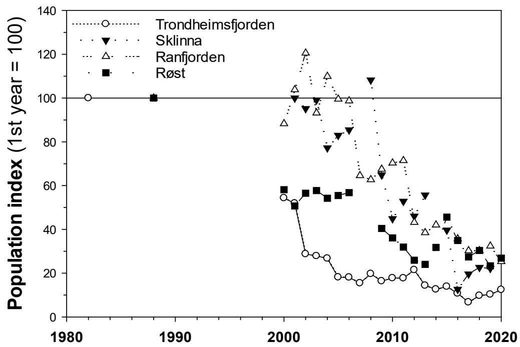

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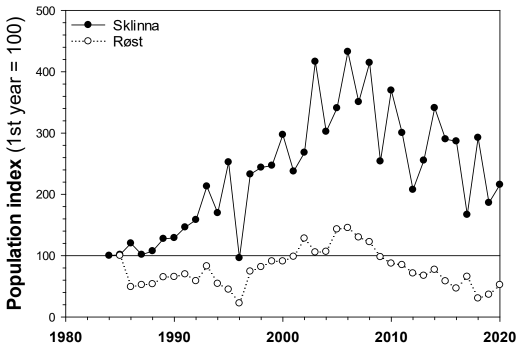


Figure 5. Population trends for seabirds breeding in the Norwegian part of the eastern Norwegian Sea since 1980, divided by (a) pelagic feeding species black-legged kittiwake (red line), common guillemot (green line) and Atlantic puffin (blue line), (b) coastal benthic feeding common eider and (c) coastal fish-feeding European shag.

Possible reasons for recent changes

The largest changes in seabird numbers in the eastern Norwegian Sea are linked to ocean climate variability[13,14] and most likely mediated through substantial changes in prey abundance and availability with dire consequences for reproductive success and recruitment[15-20]. To some degree, this has also affected survival rates[21-23], which in addition can occasionally be severely hit by extreme weather events[24-26]. Still, an increasing number of studies document effects of other natural and man-induced changes that may also contribute to the variation in seabird breeding performance. This includes factors such as competition with fisheries[19,27,28] and increased predation from white-tailed eagles[29,30], as well as contaminants (e.g. Bårdsen et al 2018[31]) and human disturbance[32]. The magnitude of seabird bycatch in some of Norway's most important fisheries has also been quantified in a series of recent studies[33,34].

Marine mammals

Current status and recent changes

Nine marine mammal species are particularly closely connected with core ecological processes and human activities in the Norwegian Sea area: Minke (*Balaenoptera acutorostrata*), fin (*Balaenoptera physalus*), humpback (*Megaptera novaeangliae*) and sperm whales (*Physeter macrocephalus*) dominate in biomass, but are mainly present in summer and autumn; Hooded seals (*Cystophora cristata*) and bottlenose whales (*Hyperoodon ampullatus*) have a partially arctic distribution, while harbour porpoises (*Phocoena phocoena*), grey (*Halichoerus grypus*) and harbour seals (*Phoca vitulina*) are resident on the continental shelf of Norway. Killer whales (*Orcinus orca*) may occur all over the Norwegian Sea year-round but are mainly associated with the herring and mackerel migrations. All nine marine mammal species have been significantly affected by historic harvesting levels, but only minke whales, grey and harbour seals are currently hunted.

Commercial sealing is believed to have reduced the abundance of the Northeast Atlantic hooded seal population by more than 80% from the mid-1940s to 1980. After that, abundance models have shown a continued slow decline, despite full protection since 2007[35]. Harbour and grey seals are subject to a quota regulated hunt and some incidental bycatch along the Norwegian coast[36,37]. Like hooded seals, these populations are censused with 5-year intervals and hunting quotas are set annually to ensure predefined viable population levels. Over the past decade, declines observed in Central Norway have led to full protection in some areas[36,37].

Fin and humpback whales have shown strong recoveries in the Northeast Atlantic over the past decades[38,39], but many appear to travel through the Norwegian Sea to the Barents Sea ecoregion. Northeast Atlantic minke whales have maintained healthy and stable population sizes under the recent harvesting regime, but distribution among ecoregions may vary between years[40]. All these three baleen whale species are pelagic feeders with variable preferences for crustaceans and small fish.

Relative abundance indicators suggest stable occurrence of the deep diving sperm whales over the period 2002-2018[38,39]. During the same period, abundance estimates for both harbour porpoises and killer whales have been highly variable in the Norwegian sea area but show no clear trend. Abundance trends are not available for bottlenose whales, but primary observations of this deep diving species doubled during the previous whale survey cycle compared to previous years[38].

Moan et al. (2020)[41] reported that the annual bycatches of harbour porpoises in Norwegian waters had ranged from 1151 to 6144 in 2006 to 2018, with an average of about 2900, and that this was unsustainable. In 2013 to 2018, however, a significant reduction seems to have prevailed to an annual average of about 1600, which is sustainable. Possible reason for this is reduced effort in the monkfish fishery.

New surveys have shown continued low levels of pup production in both grey seals and hooded seals[37].

Possible reasons for recent changes

Bycatches in bottom-set gillnets are a suspected culprit for the reductions in grey seal pup production along the Norwegian coast[37,42], but seal predation by killer whales could also play a role[43].

The lack of recovery in the Northeast Atlantic hooded seal population is not well understood. It is, however, a fact that the maximum abundance of this population was recorded prior to the development of modern offshore fisheries in the 1950s and 60s, which could have changed the carrying capacity for hooded seals. Information on hooded seal diet is scarce but several commercial prey species have been identified from analyses of stomach content and fatty acids[44-46]. Changes in the availability and condition of sea ice used for haul-out off east Greenland may also have affected the energy balance of hooded seals and are likely linked to increased predation rates by polar bears[47,48].

References

1. Helland-Hansen B, Nansen F. The Norwegian Sea. Its physical oceanography based upon the Norwegian Researches 1900–1904. *Report on Norwegian Fishery and Marine Investigations* 1909; **2**(2): 1–360.

2. Mork KA, Skagseth Ø, Ivshin V, Ozhigin V, Hughes SL, Valdimarsson H. Advective and atmospheric forced changes in heat and fresh water content in the Norwegian Sea, 1951–2010. *Geophys Res Lett* 2014; **41**(17): 6221-8.

3. Mork KA, Skagseth Ø, Søiland H. Recent Warming and Freshening of the Norwegian Sea Observed by Argo Data. *Journal of Climate* 2019; **32**(12): 3695-705.

4. Behrenfeld MJ, Falkowski PG. Photosynthetic rates derived from satellite-based chlorophyll concentration. *Limnology and Oceanography* 1997; **42**(1): 1-20.
5. Børsheim KY, Milutinović S, Drinkwater KF. TOC and satellite-sensed chlorophyll and primary production at the Arctic Front in the Nordic Seas. *Journal of Marine Systems* 2014; **139**: 373-82.
6. Henson SA, Beaulieu C, Lampitt R. Observing climate change trends in ocean biogeochemistry: when and where. *Global Change Biology* 2016; **22**(4): 1561-71.
7. ICES. Working Group on the Integrated Assessments of the Norwegian Sea (WGINOR; outputs from 2019 meeting). ICES Scientific Reports. 2:29. 46 pp., 2020.
8. Kristiansen I, Hátún H, Petursdottir H, et al. Decreased influx of Calanus spp. into the south-western Norwegian Sea since 2003. *Deep Sea Research Part I: Oceanographic Research Papers* 2019; **149**: 103048.
9. Skjoldal HR, Dalpadado P, Dommasnes A. Food webs and trophic interactions. In: Skjoldal HR, ed. The Norwegian Sea ecosystem. Trondheim: Tapir Academic Press; 2004: 447-506.
10. ICES. Working Group on Widely Distributed Stocks(WGWIDE).ICES Scientific Reports. 2:82. 1019pp.http://doi.org/10.17895/ices.pub.7475, 2020.
11. ICES. Working Group on Widely Distributed Stocks (WGWIDE). ICES Scientific Reports. 1:36. , 2019.
12. Fauchald P, Barrett RT, Bustnes JO, et al. Sjøfugl og marine økosystemer. Status for sjøfugl og sjøfuglenes næringsgrunnlag i Norge og på Svalbard. NINA Rapport 1161, 2015.
13. Irons DB, Anker-Nilssen T, Gaston AJ, et al. Fluctuations in circumpolar seabird populations linked to climate oscillations. *Global Change Biology* 2008; **14**(7): 1455-63.
14. Descamps S, Anker-Nilssen T, Barrett RT, et al. Circumpolar dynamics of a marine top-predator track ocean warming rates. *Global Change Biology* 2017; **23**(9): 3770-80.
15. Durant JM, Anker-Nilssen T, Stenseth NC. Trophic interactions under climate fluctuations: the Atlantic puffin as an example. *Proceedings Biological sciences* 2003; **270**(1523): 1461-6.
16. Cury PM, Boyd IL, Bonhommeau S, et al. Global Seabird Response to Forage Fish Depletion—One-Third for the Birds. *Science* 2011; **334**(6063): 1703-6.
17. Bustnes JO, Anker-Nilssen T, Erikstad KE, Lorentsen SH, Systad GH. Changes in the Norwegian breeding population of European shag correlate with forage fish and climate. *Marine Ecology Progress Series* 2013; **489**: 235-44.
18. Sandvik H, Reiertsen TK, Erikstad KE, et al. The decline of Norwegian kittiwake populations: modelling the role of ocean warming. *Climate Research* 2014; **60**(2): 91-102.
19. Lorentsen SH, Anker-Nilssen T, Erikstad KE, Rov N. Forage fish abundance is a predictor of timing of breeding and hatching brood size in a coastal seabird. *Marine Ecology Progress Series* 2015; **519**: 209-20.
20. Sandvik H, Barrett RT, Erikstad KE, et al. Modelled drift patterns of fish larvae link coastal morphology to seabird colony distribution. *Nat Commun* 2016; **7**.
21. Harris MP, Anker-Nilssen T, McCleery RH, Erikstad KE, Shaw DN, Grosbois V. Effect of wintering area and climate on the survival of adult puffin Fratercula arcticai in the eastern Atlantic. *Marine Ecology Progress Series* 2005; **297**: 283-96.
22. Gimenez O, Anker-Nilssen T, Grosbois V. Exploring causal pathways in demographic parameter variation: path analysis of mark–recapture data. *Methods in Ecology and Evolution* 2012; **3**(2): 427-32.
23. Reiertsen TK, Erikstad KE, Anker-Nilssen T, et al. Prey density in non-breeding areas affects adult survival of black-legged kittiwakes Rissa tridactyla. *Marine Ecology Progress Series* 2014; **509**: 289-.
24. Anker-Nilssen T, Aarvak T, Bangjord G. Mass mortality of Atlantic puffins *Fratercula arctica* off central Norway, spring 2002: causes and consequenses. *Atlantic Seabirds* 2003; **5**: 51-71.
25. Mesquita MdS, Erikstad KE, Sandvik H, et al. There is more to climate than the North Atlantic Oscillation: a new perspective from climate dynamics to explain the variability in population growth rates of a long-lived seabird. *Frontiers in Ecology and Evolution* 2015; **3**(43).
26. Anker-Nilssen T, Harris M, Kleven O, Langset M. Status, origin, and population level impacts of Atlantic Puffins killed in a mass mortality event in southwest Norway early 2016. 2018; **30**.
27. Lorentsen S-H, Anker-Nilssen T, Erikstad KE. Seabirds as guides for fisheries management: European shag *Phalacrocorax aristotelis* diet as indicator of saithe *Pollachius virens* recruitment. . *Marine Ecology Progress Series* 2018; **586**: 193–201.
28. Sydeman WJ, Thompson SA, Anker-Nilssen T, et al. Best practices for assessing forage fish fisheries-seabird resource competition. *Fisheries Research* 2017; **194**: 209-21.
29. Anker-Nilssen T, Aarvak T. Effects of White-tailed Eagles on the reproductive performance of Black-legged Kittiwakes; indications from a 26-year study in North Norway. In: Stienen, E., Ratcliffe, N., Seys, J.,

Tack, J. & Dobbelaere, I. (eds.). Seabird Group 10th International Conference Belgium, 27–30 March 2009. VLIZ Special Publication 42. Flanders Marine Institute, Oostende, Belgium., 2009.
30. Hipfner JM, Blight LK, Lowe RW, et al. Unintended consequences: how the recovery of sea eagle *Haliaeetus* spp. populations in the northern hemisphere is affecting seabirds. *Marine Ornithology* 2012; **40**: 39-52.
31. Bårdsen B-J, Hanssen SA, Bustnes JO. Multiple stressors: modeling the effect of pollution, climate, and predation on viability of a sub-arctic marine bird. *Ecosphere* 2018; **9**(7): e02342.
32. Reiertsen TK, Erikstad KE, Barrett RT, S.-H. L, Holmøy MJ. Effektstudie av turisme på sjøfugl. Hvordan påvirker ferdsel hekkende sjøfugl på Hornøya? [Study of the effects of tourist-related traffic on breeding seabirds at Hornøya]. NINA Rapport, 1528. Norwegian Institute for Nature Research., 2018.
33. Fangel K, Bærum KM, Christensen-Dalsgaard S, Aas Ø, Anker-Nilssen, Tycho. Incidental bycatch of northern fulmars in the small-vessel demersal longline fishery for Greenland halibut in coastal Norway 2012–2014. *ICES Journal of Marine Science* 2016; **74**(1): 332-42.
34. Bærum KM, Anker-Nilssen T, Christensen-Dalsgaard S, Fangel K, Williams T, Vølstad JH. Spatial and temporal variations in seabird bycatch: Incidental bycatch in the Norwegian coastal gillnet-fishery. *PLoS One* 2019; **14**(3): e0212786.
35. ICES. ICES/NAFO/NAMMCO Working Group on Harp and Hooded Seals (WGHARP). ICES Scientific Reports. 1:72. , 2019.
36. Øigård TA, Frie AK, Nilssen KT, Hammill MO. Modelling the abundance of grey seals (Halichoerus grypus) along the Norwegian coast. *ICES Journal of Marine Science* 2012; **69**(8): 1436-47.
37. Bjørge A. The Norwegian Marine Mammal Scientific Advisory Board 2019 (Rapport fra forskerutvalg om sjøpatedyr, 2019). Rapport fra havforskningen 2020-19, 2019.
38. Leonard DM, Øien NI. Estimated Abundances of Cetaceans Species in the Northeast Atlantic from Two Multiyear Surveys Conducted by Norwegian Vessels between 2002–2013. NAMMCO Scientific Publications 11. https://doi.org/10.7557/3.4695, 2020.
39. Leonard DM, Øien NI. Estimated Abundances of Cetacean Species in the Northeast Atlantic from Norwegian Shipboard Surveys Conducted in 2014–2018. NAMMCO Scientific Publications 11. https://doi.org/10.7557/3.4694, 2020.
40. Solvang HK, Skaug HJ, Øien NI. Abundance estimates of common minke whales in the Northeast Atlantic based on survey data collected over the period 2008–2013. Paper SC/66a/RMP8 presented to the Scientific Committee of the International Whaling Commission. Unpublished., 2015.
41. Moan A, Skern-Mauritzen M, Vølstad JH, Bjørge A. Assessing the impact of fisheries-related mortality of harbour porpoise (*Phocoena phocoena*) caused by incidental bycatch in the dynamic Norwegian gillnet fisheries. *ICES Journal of Marine Science* 2020; **77**(7-8): 3039-49.
42. NAMMCO. Report of the NAMMCO Scientific Committee Working Group on By-catch,29 February,Marine Research Institute,Reykjavik, Iceland. , 2016.
43. NAMMCO. Report of the NAMMCO Working Group on Coastal Seals 2016 1-4 March 2016. Reykjavik, Iceland, 2016.
44. Hammill MO, Stenson GB. Estimated Prey Consumption by Harp seals (Phoca groenlandica), Hooded seals (Cystophora cristata), Grey seals (Halichoerus grypus) and Harbour seals (Phoca vitulina) in Atlantic Canada. *Journal of Northwest Atlantic Fishery Science* 2000; **26**: 1-23.
45. Haug T, Nilssen KT, Lindblom L, Lindstrøm U. Diets of hooded seals (Cystophora cristata) in coastal waters and drift ice waters along the east coast of Greenland. *Marine Biology Research* 2007; **3**(3): 123-33.
46. Tucker S, Bowen W, Iverson S, Blanchard W, B. Stenson G. Sources of variation in diets of harp and hooded seals estimated from quantitative fatty acid signature analysis (QFASA). *Marine Ecology-progress Series* 2009; **384**: 287-302.
47. McKinney MA, Iverson SJ, Fisk AT, et al. Global change effects on the long-term feeding ecology and contaminant exposures of East Greenland polar bears. *Glob Chang Biol* 2013; **19**(8): 2360-72.
48. Øigård TA, Haug T, Nilssen KT. Current status of hooded seals in the Greenland Sea. Victims of climate change and predation? *Biological Conservation* 2014; **172**: 29-36.

Annex 5: Plan for working with multispecies harvest control rules in the project "Sustainable multispecies harvest from the Norwegian Sea and adjacent ecosystems"

Sustainable multispecies harvest from the Norwegian Sea and adjacent ecosystems

Testing of preliminary ecosystem-based management strategies for the Norwegian Sea using an ecosystem MSE framework

1.- Introduction

Currently, most fishery resources are managed according to well-defined exploitation rules (so called Harvest Control Rules, HCR), which have been thoroughly tested in terms of productivity and risk, and that ideally should have been agreed by all the stakeholders (Rindorf et al. 2017b). These HCRs are defined based on biological reference points that, within the framework of the International Council for the Exploration of the Sea ICES, respond to precautionary criteria and maximum sustainable yield. It is well known that these biological reference points are determined by, and reflect, the productivity of the stock, which in turn depends on individual growth, survivorship, age at maturation, reproductive potential as well as migratory processes. However, despite the awareness of fisheries scientists that all these elements vary with changes in ecological interactions, it is not yet common assessing the impact that biotic and abiotic ecological interactions have on the productivity of stocks and hence in the risk assessment of HCRs. Trophic interactions, especially in the years of life, can have a strong impact on the dynamics of commercial stocks (Bax 1998). The magnitude and shape of these trophic interactions are determined by various factors such as the abundance of other alternative prey species, the size relationship between the predator and the prey, or the spatial overlap, which is very often determined by oceanographic conditions (Johannesen et al. 2012). Sometimes, preference for these oceanographic features is different between prey and the predator, especially in relation to temperature. Therefore, for a correct evaluation of the performance of an HCR in terms of productivity and risk, it is necessary to develop simulations in which these interactions are considered.

The Norwegian Sea is a very productive system in which the stocks of pelagic fish are of special relevance: mackerel, herring and blue whiting, which are the main fishing resource. Furthermore, the exploitation of *C.finmarchicus* has recently started, but the quota level is expected to increase considerably in the next years. There are previous works that indicate the importance of the top–down and bottom–up relationship between these four stocks (Trenkel et al. 2014, Bachiller et al. 2015), affecting their productivity and distribution. Furthermore, the Norwegian Sea ecosystem has a very intense interaction with other large ecosystems like the Barents Sea, North Sea, Greenland Sea, Iceland Sea, Hebrides Sea and other southern seas. Therefore, it is necessary developing a framework that allows simulating these interactions and testing ecosystem-based management strategies (EBMS) designed to adapt management decisions to a changing biotic and abiotic environment. These are the objectives of this project, which will be developed within the WP3 of the SIS Høsting project. In the next sections, the lines of work that will be developed are summarized, the ecological and fishing interactions that will be considered during the development of this project will be described, as well as the workplan, milestones and deliverables.

2.- WP3: Foodweb interactions, output and management advice

The Norwegian parliament has recently asked the government to initiate development towards ecosystem-based management of fisheries in Norwegian waters. On reply to this request, Huse et al. (2018) described the requirements to identify the stocks for which a multispecies management approach would be advisable. The group of pelagic fish stocks mackerel-herring-blue whiting in the Norwegian Sea was pointed as a fisheries system that could be the focus for ecosystem-based management. The WP3 aims at integrating the results from WP1, WP2, WP3 itself, as well as information from other ongoing projects, to follow up with key research needs that have been identified for development of ecosystem-based fisheries management in the Norwegian Sea, as suggested by Huse et al. (2018).

Within this WP3 there are two main lines:

1.- General warning signals: There are important gaps in our knowledge of ecosystem dynamics and the factors influencing the pelagic fish stocks that cannot be closed in the short-medium term. However, this should not stop us from applying the available knowledge for ecosystem-based advice by widening the perspective and look at the ecosystem as a whole, asking whether there are signs of development that give reason for concern and that should be considered in the stock advisory process.

2.- Questions about specific relationships: If key relationships between ecosystem components and a fish stock are known, ecosystem-based advice can be developed through explicit use of this knowledge to, for example, take into account information about the influence of predators, competitors, general productivity or aspects of the physical environment. It is expected that this second line of work will provide the necessary input to design the Management Strategy Evaluation MSE framework and the HCRs to be tested in that framework.

The specific relationships that will be studied are:

- Predation interaction mackerel-herring larvae
  The effect of mackerel predation on recruitment of NSS herring depends on spatial overlap between mackerel and herring larvae, predation rates for mackerel that overlap and relationship between abundance of 0 group herring and 2-year-old herring. Results from WP2 on the spatial distribution of pelagic fish will be used to model (using the NORWECOM.E2E model) the overlap in spatial distribution of mackerel and NSS herring larvae. Information from other projects will be used to set estimates for predation rates on larvae. The Atlantis model will be used to assess the relationship between abundance of 0 and 2 group herring. Using this as a starting point, different scenarios will be modelled where effects of different HCR for mackerel on NSSH recruitment will be explored. We can then use the mackerel assessment and stock advice as a starting point and explore how FMSY can be modified to increase probabilities for good NSS herring recruitment (while being high in the sustainable range for mackerel FMSY).

- Effects of top–down processes on production at lower trophic levels
  Simultaneously with the reduction in zooplankton biomass in the Norwegian Sea, the total stock size of the pelagic planktivorous NSS herring, NEA mackerel and blue whiting was at historically high levels. Their annual consumption of zooplankton has been estimated to 135 million tons (Bachiller et al., 2018), higher than previously assumed. Based on Calanus spp. (and other) production estimates, 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 (Skjoldal et al., 2004; Huse et al., 2012). Due to their high abundance, pelagic fish can potentially have a strong ecological impact on the ecosystem. Knowledge of how predation by NEA mackerel and NSS herring can influence abundance and distribution of zooplankton will be important regarding multispecies management. The potential impact of top–down control on the zooplankton production will be investigated using the NORWECOM.E2E model.

- Competition for food among the three pelagic fish stocks under the influence of a changing environment
  Work by Huse et al. (2012) showed that there are some signs of interspecific competition between mackerel, NSS herring and blue whiting and much stronger signs of intraspecific competition, in particular for herring and blue whiting (since this study, the geographic distribution of mackerel has expanded considerably, suggesting that these relationships may have changed, calling for a reanalysis using updated time series). In the North Sea, changes in zooplankton species composition (towards increased dominance of Calanus helgolandicus) have also affected competition among fish species. Related to this, changes in overall production may have effects on production in the fish stocks in the Norwegian Sea. However, exploring how changes in primary productivity may affect productivity in other parts of the ecosystem is not straightforward, as this may depend on how the trophic structure of the entire foodweb is affected.
  The first step for this task is to identify relevant research questions that can be helpful in disentangling the complexities underlying the task, identify how these questions can be addressed and finally how findings can be used in management strategy evaluations.

These three are the main three topics that will be explored within the WP3 and will be incorporated into the MSE framework for ecosystem-based HCR testing. However, as shown in the Figure 1, there are several other interactions that, if the necessary information is obtained from WP1, WP2 and WP3, as well as other sources would be incorporate in the simulation testing. Among these interactions are especially relevant the predation of cod on juvenile herring in the Barents Sea, and the predation of juvenile herring on herring larvae. Other interactions that might be studied are the predation of cod on juvenile herring and the cannibalism adult herring-herring larvae.

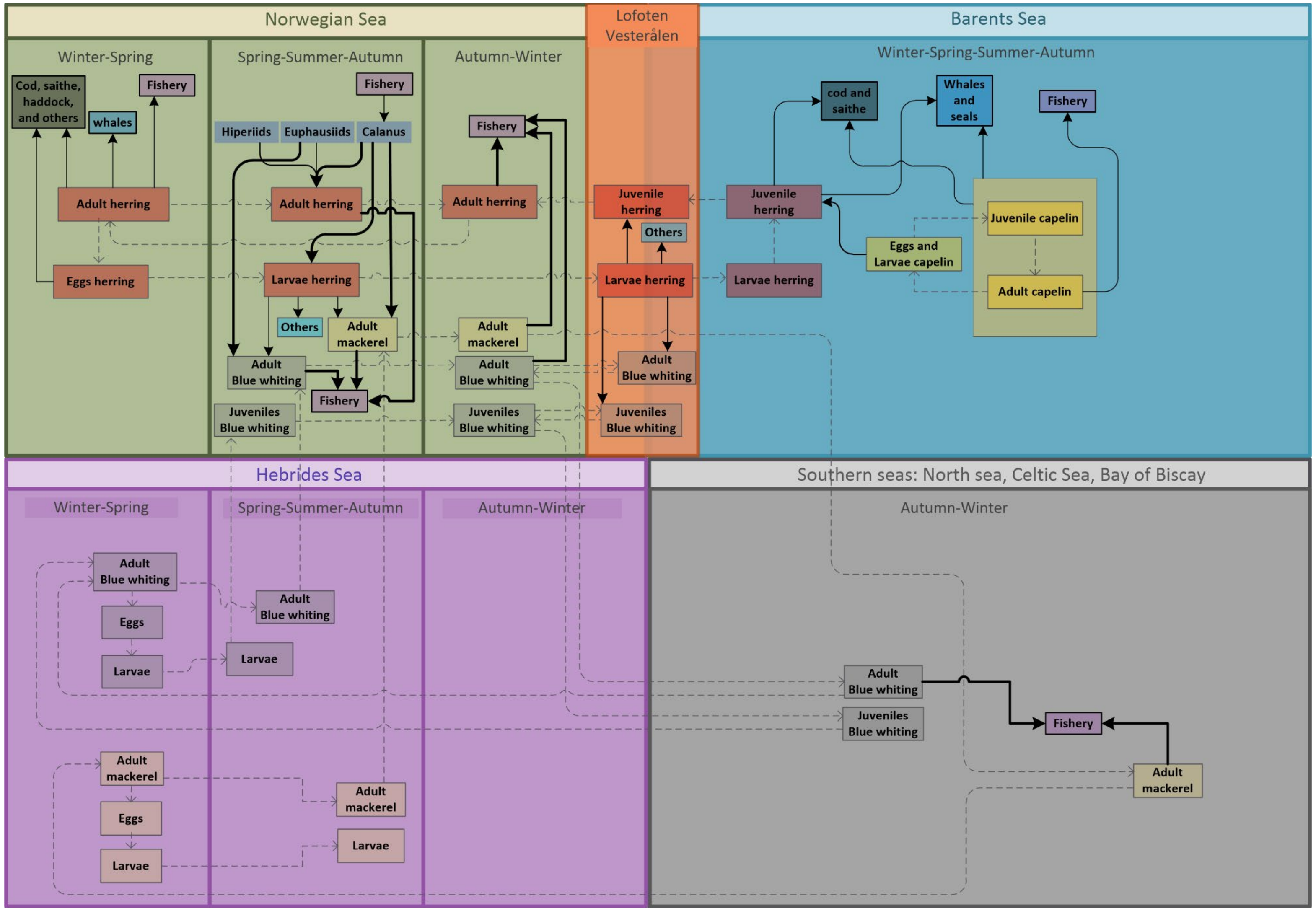


Figure 1.- Conceptual model showing the most important interactions between the main species in the Norwegian Sea and the commercial fishery, as well as the interactions with other northern and southern marine ecosystems.

3.- MSE framework and ecosystem EBMS testing:

For the design of an MSE framework, ecosystem HCRs, and the evaluation of EBMS, the ICES guidelines (based in WKGMSE2, 2019) will be followed as closely as possible.

3.1.- ICES guidelines for MSE framework design and simulations:

On February of 2019, in Ispra (Italy), took place the second ICES workshop on guidelines for management strategy evaluations (ICES 2019). A review of the methodological and technical revision included all aspects involved in MSE. Special attention was paid to:

- Evaluation of performance in the short-term versus the long-term
- Appropriate range of scenarios to consider in the MSE and how to deal with outcomes from multiple scenarios, including “worst-case” scenarios
- Review risk definition and computation in MSE
- Evaluate the "short-cut" approaches versus “full-feed-back” simulation
- Presentation of MSE results properly describing the process, standardizing outputs to present results, etc

Based on these guidelines, an MSE simulation procedure is composed of the following blocks (Figure 2):

- An **operating model (OM),** which will include:
  - A **biology and fishery model** capturing the underlying dynamics of the population and its exploitation.
  - An **observation model** that extracts, with error, information from the operating model that is used in the estimation model and decision process.
  - An **implementation model**, which translates the decided removals into actual removals from the real stock.
- A **management procedure (MP)** includes:
  - An **estimation model**, that assesses stock status based on available information; this could include an assessment (or proxy for this) or an empirical approach (e.g. a bio-mass index or CPUE).
  - A **decision model**, in which a decision on removals (typically a TAC) is derived from the outcome of the estimation model.

The only communication between the OM and MP should be through the data that the OM passes to the MP, and the management regulation (e.g. TAC) that the MP passes back to the OM. Furthermore, performance of the MP is evaluated through performance statistics, which are defined based on management objectives.

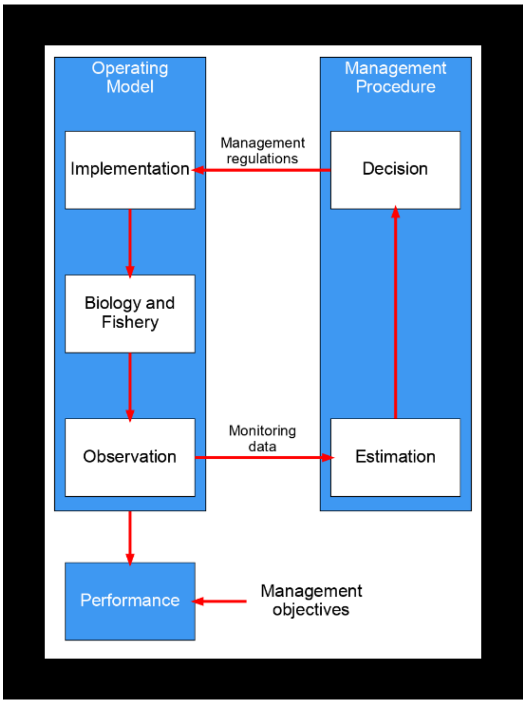


Figure 2.- A conceptual overview of the MSE modelling process (Punt et al. 2016)

3.1.1.- Biology and fishery components of the Operating Model (OM)

Regarding the OM, some of the main conclusions from WKGMSE2 were:

- In relation to the design of the OM, initially, for the selection of candidate HCRs the OM can be simpler. In a second stage, the OM has to simulate more closely the observed data, which involves an intense dedication in conditioning the OM model and assessing uncertainty.
- During conditioning of the OM, many of the parameter estimates are obtained by fitting to historical data within a stock assessment, although some parameters may be considered fixed. This together with the validation tests (see section below) will ensure that the parameter values used in the projection period are consistent with the available data and current understanding of the system.
- Uncertainty estimates for parameters in the OM can be based on samples obtained from bootstrapping, Bayesian posterior distributions, or variance-covariance and MCMC approaches that can consider several sets of parameter values and correlations between them. This parameter uncertainty will allow defining several possible model parameter configurations (as many as iterations).
- Additional key uncertainties in the conditioning process can be explored using different OMs, which can be developed to evaluate the effects of deviations from the baseline model. This can include alternative assumptions, models, and error structures considered when selecting the uncertainties to include in the OM, so that the robustness of the management strategies to such uncertainties can be evaluated.

Among the processes or components that will need to be defined in the OM for which the WKGMSE2 provided guidelines are:

- Initial population matrix
- Recruitment

- Fishery selection curve at age/length
- Weight at age/length
- Natural mortality
- Maturity
- Confounding between variables/correlated processes
- Ecosystem, biological and technical interactions

Some challenges and approaches to deal with the configuration of this components are presented in section 3.3 and will be part of the workplan presented in section 4.

3.1.2.- Observation and estimation models

ICES identified two types of Harvest rules models (where the assessment of the stock is done and the HCR is applied), model-based harvest rules and empirical harvest rules. In the model-based harvest rule, in the MP it is necessary to reproduce the stock assessment process. In turn, this option has two types, full MSE and shortcut MSE.

The full MSE involve multiple difficulties, among them: a high computing capacity, convergence problems and the need to explore diagnostics to decide on the final configuration of the assessment model, which usually requires from human intervention and hence cannot be simulated. The shortcut MSE approach applies the assessment error and bias to the stock status data obtained from the OM. Simulating the observation-assessment errors and bias it is not an easy task. Some of the main aspects to deal with for the development of a shortcut MSE are treated in section 3.3.2.

3.1.3.- Decision model

This component of the MP uses the assessment results to produce the management action to be taken in response to the perceived status of the stock and fishery, according to a predetermined process. On many occasions, a harvest control rule will be applied to establish a level of removals (TAC) from the population. Common types of harvest rules are:

- F-regimes: TAC derived from F, TAC as a fraction of measured biomass, direct effort regulation.
- Catch regimes: permanent quotas plus protection rule.
- Escapement regimes: leave sufficient spawning biomass after harvest to prevent recruitment impairment.

The output from the decision model could include recommendations for:

- Total allowable catch (TAC) or effort (TAE).
- Area or seasonal closures.
- Mesh or hook size restrictions.

The harvest rule often includes several components applied in a sequential manner:

- A mathematical rule that prescribes a 'primary' TAC (or other management measure). For example, a translation of an exploitation rate into a TAC
- Stabilizing terms, which modify the 'primary' TAC by constraining the change in TAC from year to year, perhaps with exceptions (such as may be applied e.g. if stock biomass is perceived to be low)
- Other modifying terms, for example a fixed maximum and/or minimum TAC

The basis on which the harvest rule is applied is often the SSB estimate at some time, according to the most recent assessment. There are other potential measures (e.g. estimates of total-stock biomass, survey index, estimates of recruitment, observed mean length or age, estimated biomass of other stocks...) which may be used alone or in combination, or applied under different conditions. The basis may come from an assessment and short-term forecast but may also be derived directly from a survey or fishery data.

Typically, the HCRs are defined from a single species approach, and all the guidelines in the WKGMSE2 report were provided from that perspective. In our work, we pretend to explore ecosystem-based HCRs, which not necessarily but very likely will need the exploration of HCRs for a given stock which configuration will depend on the status and the HCR applied to other stocks. This approach will require much more complex combined HCRs and a more sophisticated decision model. The approach, challenges and tasks are presented in section 3.3.3.2.

3.1.4.- Implementation model

This is the step where the TAC derived from the harvest rule is converted to removals accounted for by the OM. For an age-structured OM, the TAC (or another measure derived in the decision model), needs to be converted to removals from the true stock in numbers-at-age. The selectivity and weight-at-age values needed for these calculations correspond to the true ones (i.e. those specified in the biological and fishery components of the OM) and normally deviate from those assumed in the decision process.

3.1.5.- Validation

Validation of all the models within the MSE framework is needed to ensure that the model describes the system realistically enough for the intended purpose. The absolute validation of ecosystem models is impossible, however, confidence in the model can be gained through the application of the tools available for validation. The available tools are very diverse, from informal tools based on consultations with experts to formal tools based on mathematical methods like inference or induction. Balci (1997) provides an exhaustive list of the methods available to validate models. Alternative methods may also be helpful. Global sensitivity analysis (Saltelli et al. 2008), for example, is a useful tool to validate models and it is a recommend by the European Commission in the implementation of impact assessment of management plans. This approach identifies the factors that have the highest impact on the output variance. In terms of validation, it is a useful tool to test if the model is really behaving as expected and if the range of scenarios defined is sufficiently broad.

As indicated, all the models within the MSE framework will need to be validated. The steps that will be necessary to validate the MSE framework within the SIS Høsting project are presented in section 3.3.6.

3.2.- The ENAC model

The ENAC MSE framework was programmed in FORTRAN and consisted of four different submodels; an operational model (OM), an observation model (OBM), a harvest models (HM) and a resource OM (ROM) (Figure 3). All submodels have monthly time-steps. The OM represents the perceived "real world" where the dynamics of the stocks are described by recruitment, growth, maturation and mortality. The OBM 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 TAC is calculated based on F, and the quotas are split into seasons to as the fisheries vary throughout the year. The model setup is presented in figure 3. After an initializing period of 20 years to build up the stocks, the model is run for 100 year.

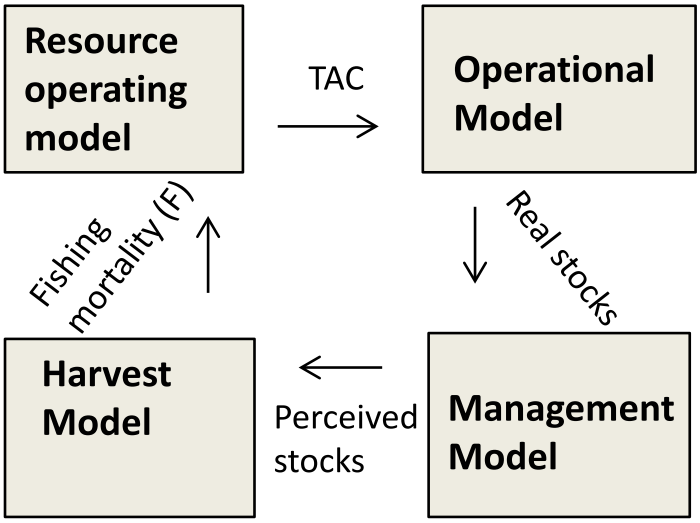


Figure 3.- Flowchart showing the four models that form the ENAC MSE framework

The ENAC model was developed as an extension of the model published by Skagen et al. (2013) applied to real fish stocks. However, several modifications were introduced, with the greatest difference being the climate effect on biological processes. The ENAC model was a multispecies model for the Norwegian Sea using the MSE approach. It was focused on the most important pelagic fish species in the areas, and their interspecific interactions. Zooplankton was not included in the model directly. Instead individual growth was reduced with increasing stock sizes to represent competition for prey. The effect of species interactions in the stock dynamics was analysed, with and without fisheries included in the model. It was also explored how a set of alternative HCRs would affect the stock dynamics and the fisheries, among them an HCR that would increase the harvest rate when the total biomass of fish reaches an upper limit. Finally, the effect of climate variability and mackerel predation on recruitment success for herring and blue whiting was also modelled.

3.2.1.- The operational model

The OM projects the stocks forward in time using functions of recruitment, growth, maturation and mortality. Each process is handled using established equations with random variation to ensure a realistic representation of the modelled fish stocks. The model is both age and length structured. The stocks are modelled by using Super Individuals (SI) (Scheffer et al. 1995) with Attribute Vectors (AV). A SI represents several identical individuals. Next, a very general description for the main processes and features is presented.

Recruitment was modelled with either Hockey stick or a Beverton and Holt recruitment function, with a deterministic part derived from α and β parameters and SSB for the species in question, a random multiplier applied to the deterministic part and occasional spasmodic events. The random multiplier has a log normal distribution which is truncated to avoid extreme values. For each species there were three different regimes with specific recruitment parameters. Both the time period each regime should be valid, and the selection of regimes were selected randomly in the model.

Growth was modelled using von Berfalanffy Growth Function (VBGF) (Haddon 2010). For each time-step t, a superindividual will grow according to the Beverton and Holt equation with $L\infty$, K and L0 parameters. The model either used a constant or a variable K, depending on the scenario run.

The weight at a given length was calculated with a length-weight relationship model, where α and β are species-specific parameters retrieved from fishbase.

The probability for a superindividual to be mature was determined by a logistic function where the probability to mature increases with fish length.

Mortality is separated into natural mortality (M) and fishing mortality (F). M is species-specific with values given by ICES (2012). Blue whiting and mackerel have the same M throughout the lifespan while herring have an M of 0.9 for age 0-2, and 0.15 thereafter.

F is multiplied with a length specific selection according to a logistic function with a species-specific L50.

3.2.2.- <u>The management model</u>

Input and output in this model are the number of individuals separated into length groups. The input values from the OM are multiplied with a random number according to a normal distribution with mean of 1 and a sigma value of 0.1 before the data are sent to the HM. The purpose of this model is to include that managers never know the actual number of fish in a stock, but instead receive estimates on survey indices.

3.2.3.- <u>The Harvest Model</u>

The input is number of fish per length group from the management model for the last year of the assessment period, and the output is an F for each species the year after (output from a short-term projection). The processes included are the same as in the OM; recruitment, growth, maturation and mortality. This model projects the stock one year forward and calculates the spawning-stock biomass (SSB) and total-stock biomass (TSB) the following year. These variables are used to calculate F according to a HCR.

3.2.4.- <u>Resource Operating Model</u> (ROM)

Input to the ROM is an F from the HM and the output is catches in number. The output is calculated using the standard Baranov's catch equation (Hilborn and Walters 1992), according to the current length l of the super individual.

3.2.5.- <u>Initializing the models</u>

The model is first run for a number of years equal to the maximum age (20 years) to build up a realistic population structure for the initial year of the simulation period. Recruitment in this period is equal to the α-parameter including random variation with a lognormal distribution. This can imply higher recruitment in the initializing period than later, depending on the stock-recruit function. A fixed F-value of 0.2 is applied as the OM is not linked with the HM during the building of the stock structure. All biological processes are as described under the OM, but there are no interactions between the species and no effect of climate variability.

3.2.6.- <u>Simulations</u>

The ENAC framework was designed to run each simulation over 500 iterations, each of 100 years. The approach was disregarding from the analyses the first 50 years of each iteration, to let the system stabilize to a given HCRs. The simulations were evaluated according to long term yield, TAC stability and the risk of stock collapse.

3.3.- SIS-ENAC MSE framework:

The ENAC framework will be used as a starting point to develop the MSE framework. This framework contains all the components required for an MSE and fulfils with most of the requirements described in the WKGMSE2 report. However, it will require the introduction of modifications in the overall structure, and deep modifications in some elements before the ecosystem HCRs can be tested. In this section the MSE framework that will be developed for the SIS Høsting project is presented, and the changes that will be necessary and the associated workplan, milestones and deliverables are described.

The development of the framework will require the joint efforts of a programmer with deep knowledge in FORTRAN and a fisheries expert in stock assessment and MSE, and will be developed specially during the first year (2021) (see the workplan section 4), but also during the second year of the project. This will be very dependent on when the output from WP1, WP2 and WP3 is available.

3.3.1.- Overall structure

Although in general the design of the ENAC framework fits considerably well the ICES guidelines (WKGMSE2, 2019), there is need for a review, since it might be necessary reordering the different modules that form the framework to fulfil with the overall structure proposed by WKGMSE2, with an OM integrating the biological-fishery, implementation and observation models, and a MP, where the assessment, the HCR and the decision model are contained. For example, the observation model, which in ENAC is located within the management model, should be moved within the OM. This and other structural changes should be introduced, which will facilitate the compliance with other requirements presented in the ICES guidelines.

3.3.2.- Building the Operating Model (OM):

As indicated in the previous section and showed in figure 2, the OM will be formed by a biology-fishery model, an observation model and the implementation model. These three models will have to be re-designed in the MSE framework.

3.3.2.1.- Biology-fishery model

Complexity trade-off: The objective of this task is to develop an OM to assess the performance of ecosystem-based management strategies (EBMS) for several species, accounting for uncertainty in a large number of biological, ecological, fisheries, data collection and implementation of management measures. Therefore, it is necessary to develop models that are complex enough to account for the most important ecological processes, but they must be simple enough to be feasible from time-consumption and computational-power perspective. Furthermore, only those processes with marked influence in the dynamic of the populations, or with a special interest from the management perspective should be considered, to avoid an excessive accumulation of error with all the modelled processes. It should fall within what is called MICE models (Models of Intermediate Complexity for an Ecosystem approach). Meeting this balance between model complexity, uncertainty evaluation capacity, and evaluation of ecological processes is a complex matter, and it will continually be a matter of critical discussion throughout the development of this model.

Conditioning of the model: Regarding parameterization of the biology-fishery model, as it is described in section 3.2.5, the OM in the ENAC framework was run 20 years to build up a realistic population structure for the initial year of the simulation period. This is an appropriate approach when the goal is assessing the performance of management strategies in the long term at population equilibrium. However, if the intention is complying with the ICES guidelines regarding the evaluation of performance in the short and medium term (see section 3.1), then it is necessary that the biology-fishery model reproduces as close as possible the observed data and the population dynamic that occurred during the historic period. This approach requires a great effort in the conditioning of the model, in the collection of the necessary data, in the definition / optimization of model parameters and validation of the model. When working at the ecosystem level, important assumptions often must be made because the appropriate knowledge of certain processes is not available, and it is usually difficult to obtain the data necessary to evaluate the performance of the model. For this reason, the conditioning of the biological-fishing model is a complex issue. Bearing in mind that this is a particularly complex section, in this project the first objective is to condition the OM as precisely as possible, to try to evaluate management strategies in the short, medium and long term. If, despite efforts, this is not possible, the strategy presented in section 3.2 will be followed, where the model will be run a number of years to obtain reasonably adequate population levels, which will be discarded for subsequent analysis, in which the focus will be in the performance of the HCRs in the long term.

Flexibility in the definition of goals: This is a project with great potential for development, but extremely complex due to limited data and information. For this reason the focus on the design of the objectives, and therefore the work plan, for the development of the OM and the rest of the sections of the MSE framework and the ecosystem HCRs testing process, will be from simple to complex, developing first what is expected with some certainty, and setting more advanced goals as long as the initial steps have been completed successfully. In this line, for the development of the biological-fishing OM, different possible models of increasing complexity are defined below.

Model M1: Pelagic fish stocks

This model will cover two of the three goals of the WP3 in relation to specific relationships:

- Predation interaction mackerel-herring larvae
- Competition for food among the three pelagic fish stocks under the influence of a changing environment

This Model M1 is intended to be the most basic model; it will simulate the dynamic of herring, mackerel and Blue whiting stocks. Most of the code and structure from the ENAC model will be used as a foundation of the model (see section 3.2.1). However, it will still need improvement in terms of the biological, ecological and fisheries input information that will be used to define the structure and parameterization of the model. Most of the parameters defining the biological processes (growth, maturation, recruitment, natural mortality), ecological processes (trophic and competition interactions), as well as fishery related processes, will be reviewed and updated with the most up-to-date knowledge.

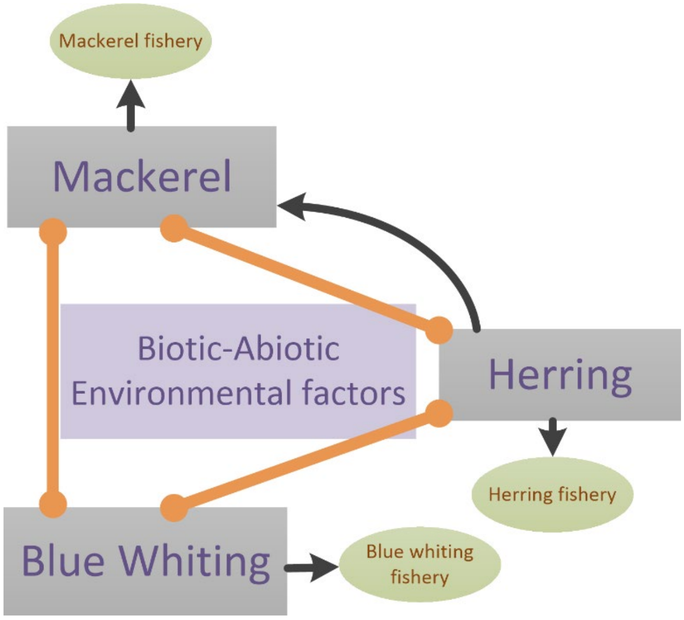


Figure 4.- Conceptual model showing the main interactions between the stocks within the Model M1. The orange arrows indicate competency interactions, while the black lines indicate predation or fishing. Predation of herring by mackerel occurs during the larval stages.

Spatial modelling, migrations: Despite the biology-fishery model is not spatially defined, the most relevant processes involving migrations in and out of the Norwegian Sea for the three stocks will be simulated. The factors affecting the migratory processes and how this is translated into variations in the proportion of the stocks arriving or leaving the Norwegian Sea will be explored in the WP2. Hence the progress achieved in this WP will determine the degree of complexity and realism that can be simulated in the MSE framework. Between the most relevant aspects that will need to be implemented are the migration (or drift) of herring larvae to the Barents Sea, that will come back to the Norwegian sea at the age 3-5. The annual migration of mackerel and adult Blue whiting, as well as the juvenile portion of Blue within stock that stays all year around in the Norwegian Sea will also be modelled.

Initial population matrix: Taking the abundance values by age from the assessment is a possibility if we start the stocks blue whiting at age 1, mackerel at age 0 and herring at age 2, which is the minimum age in the assessments for these three stocks (maximum ages in the assessment is 10+ for blue whiting, 12+ for mackerel and 12+ for herring). However, if the intention is that herring enters the population at age zero, then some kind of assumption will have to be made. One possibility could be taking the abundance values from the assessment for ages 2-12 + and reconstructing the values for ages 0 and 1 assuming that the N at age follows a negative exponential curve. However, if predation by Barents Sea cod on juvenile herring is also simulated in the OM (see the model M3 below) the number of individuals for juvenile ages on herring (ages 0 to 5 approx.) should be increased. How to do it is something to investigate.

Recruitment submodel: For herring, the recruitment model in ENAC relates the SSB with the recruits at age 2, and includes several of the elements advised by ICES, like uncertainty and spasmodic events. However, this is one of the submodels affecting the population dynamic that will have to be modified. One of the main goals of this project is assessing the impact of mackerel predation on larval stages of herring in the Norwegian sea. This interaction is mediated by different biotic and abiotic factors that will be studied in the WP2. Although it is not yet decided how this process will be modelled and simulated, simple approach would be considering different regimes of mackerel predation on larvae, that would be simulated with different herring

SSB-Recruitment models. However, if the intention is assessing the impact of combined HCRs for mackerel and herring in the productivity and risk of collapse of herring, it is necessary having a SSB-Recruitment model for herring that incorporates mackerel biomass, plus the relevant environmental factors, as a driver variable. If the SSB-Recruitment model predicts recruitment at age 2 or at larval stages is something that will be decided once the results from the WP2 are available. A way to relate predation of mackerel with level of recruitment at the larval stage would be using the output from Norwecom to parameterize a lavae predation rate from mackerel as a function of a number of environmental variables like water temperature, mackerel abundance, availability of other prey items, etc. In this case the Total Egg Production might be calculated as a function of herring SSB, and from that estimate, with assumptions about egg mortality, obtaining total larvae estimations to which the mackerel predation would be applied. A very different option would be defining an SSB-Recruitment relation at age 2 affected by total mackerel biomass (García et al., in prep). Once that relationship is defined, the ICES guidelines in relation to simulation of uncertainty and spasmodic recruitment events will be implemented in the MSE framework.

Growth submodel: The von Berfalanffy growth model from the ENAC framework will be maintained. However, the parameter values will be recalculated, and it will be explored the possibility of relating the values of the parameters K, L0 and L∞ with abiotic (temperature) and biotic factors (food availability, interspecific competition and intraspecific competition (density-dependence)). There are previous studies that show effects of intraspecific competition in blue whiting, and interspecific competition between herring and mackerel (Utne, pers.comm). These and other results from WP1, WP2 and WP3 could be implemented to reflect the effect of competition for limited sources of food. In this model the dynamic of the prey is not modelled. However, different scenarios of prey availability (time series of prey biomass) will be run. In a previous research project, it was developed for herring a von Bertalanffy growth model that allows incorporating explanatory variables other than age, and is able of producing uncertainty estimates based in the analysis of data. This model should be explored.

Length-Weight relationship: The length-weight relationship parameters will be calculated using the available data form surveys and commercial fisheries. The temporal changes in these parameters will be analysed, its relationship with the fish condition and the parameter K of the growth model.

Maturity submodel: As indicated in the ICES guidelines, when possible, the connection between the different processes modelled should be implemented in the MSE framework. It has been shown in several studies, that most of the changes in the maturation process due to phenotypic plasticity are produced by changes in growth rates (Pérez-Rodríguez et al. 2013). Other variables that may affect in the age and length at maturation is the water temperature. The possibility of connecting the parameters of the growth model (most likely the K parameter) with the parameters of the logistic maturity curve will be explored.

Residual natural mortality: In the ENAC model the values given by ICES (2012) were used. This values will be reviewed and new approaches might be taken, like applying life history traits based M curves (Gislason et al. 2010). This is a very uncertain parameter, and hence, an element where it will be important testing how the different management strategies perform with different assumption of M. The introduction of predation mortality on herring larvae by mackerel will result in an extra natural mortality-at-age 0 (in case that the recruitment relationship is finally modelled at age 0).

Fishing selectivity curve: In ENAC, the F at age is calculated using the general F and a selectivity curve at length. As indicated in section 3.1, the selectivity curve of the fishing fleet is necessary in 4 different elements of the MSE framework: the operational model (biological-fishing), the evaluation model, the short-term forecast, and the implementation model. In the ENAC framework, the selectivity function was invariable for these four components. This will be one of the complex tasks to be carried out in relation to the simulation of the fishing activity in the OM. As indicated in the section 3.3.2.2, since the MSE shortcut option is most likely to be taken, it will not be necessary to simulate the data collection in detail (observation model).

<u>Technical interactions between fleets targeting different stocks:</u> Based in the input from experts on these stocks (Kjell Utne and Guðmundur J. Óskarsson):

- Bycatch mackerel and herring in the blue whiting fishery can be considered negligible because, in the first place most of the blue whiting catch occurs in the Hebrides Sea (North West Ireland) during the spawning period, and secondly blue whiting fishery happens at depths of 200-600 meters where there is no mackerel or herring.
- Bycatch mackerel and blue whiting in herring fishery: it is also negligible because most herring catches occur during the winter (wintering area and spawning area), when most of blue whiting is in the spawning grounds in the south, and mackerel has not yet arrived to the Norwegian Sea. Also, most herring catches are made with purse-seine, which is very selective.
- Bycatch herring and blue whiting in mackerel fishery: Blue whiting is not caught, but there is a potential problem with herring bycatch. Iceland and Faroe island, trawl for mackerel in the Norwegian Sea, with bycatch of herring. However, there is not suitable data that can be used to test how important the bycatch of herring in the mackerel fishery is, however, based in expert knowledge it is expected to be of minor relevance.

Accordingly, no technical interactions will be modelled in the OM.

<u>Uncertainty in the knowledge of the ecosystem functioning:</u> As indicated in the ICES guidelines for MSE, the uncertainty in the knowledge of the ecosystem should be considered when assessing the performance of the proposed management strategies. This uncertainty can be simulated by resampling a very high number of times from a parameter space for all the submodels (growth, maturation, recruitment, etc) and running simulations. In addition, different configurations of the model structure reflecting the different possibilities for the biological, ecological and fisheries processes will be used to run the same group of scenarios.

<u>Generation of other data types:</u> Other metrics may be required for management (e.g. environment metrics related to population dynamics) and evaluation of these could be conducted by either including mechanistic models linked to population dynamics (modelling change in climate or variables that might directly or indirectly impact the population dynamics) or following an empirical approach to evaluate the impact of climate change and environmental variation ("what if" scenarios).

<u>*Model M2: Pelagic fish stocks and C.finmarchicus*</u>

The model M2 would cover the three main goals of the specific relationship analysis aimed at the WP3. In this model, the effects of top–down processes on production at lower trophic levels will be added to the model M1. This configuration of the OM would allow assessing the combined management strategies for the fisheries on pelagic fish and *C.finmarchicus* at the same time.

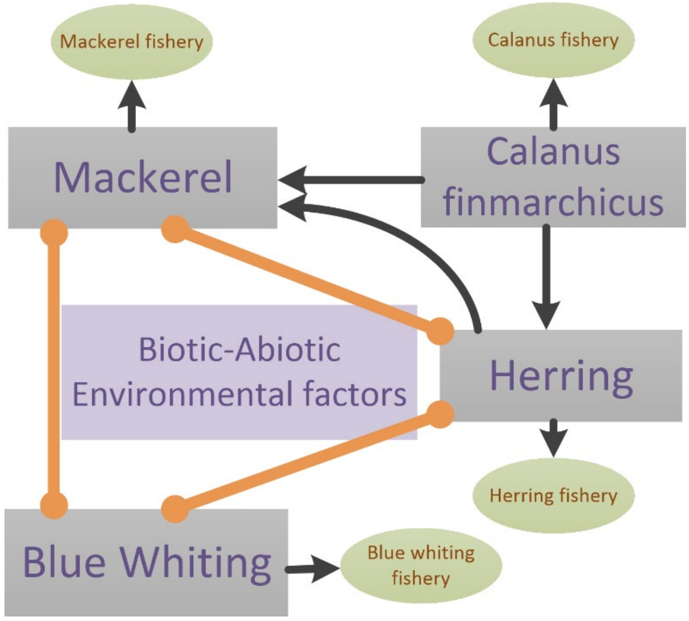


Figure 5.- Conceptual model showing the main interactions between the stocks within the Model M2. The orange arrows indicate competency interactions, while the black lines indicate predation or fishing. Predation of herring by mackerel occurs during the larval stages.

If the M1 model is completed successfully, the next step would be to model the dynamics of *C.finmarchicus* as well as the three pelagic fish stocks. The biology of this stock is quite different in relation to pelagic species since all the spawning biomass dies the year they reproduce, and they go through a period of diapause, when they will not be available for fishing or predation. All the parameters necessary to model recruitment, growth, maturation, natural mortality, reproduction, as well as the trophic interactions it maintains with the three species of pelagic fish (especially mackerel and herring), and the parameters that regulate fishing activity will be obtained from Norwecom model. Progress on WP1 will be determinant to improve the modeling of C.fimarchicus and its fishery.

In this model, the time series of prey availability that in the M1 model determined the degree of competition and the effect on growth parameters will be replaced by the biomass of Copepods. In this way, that shared food source has its own dynamic.

Model M3: Connection Norwegian Sea and Barents Sea ecosystems

In this model M3 the intention is modelling the influence of the Barents Sea cod on the dynamic of herring via predation on juvenile herring, which is modulated by the abundance of an alternative prey, capelin. The goal is obtaining an OM that can be used to test combined management strategies in the Norwegian and Barents Sea for the most important pelagic and demersal fish stocks. The development of this model will be started only when the model M2 perform satisfactorily.

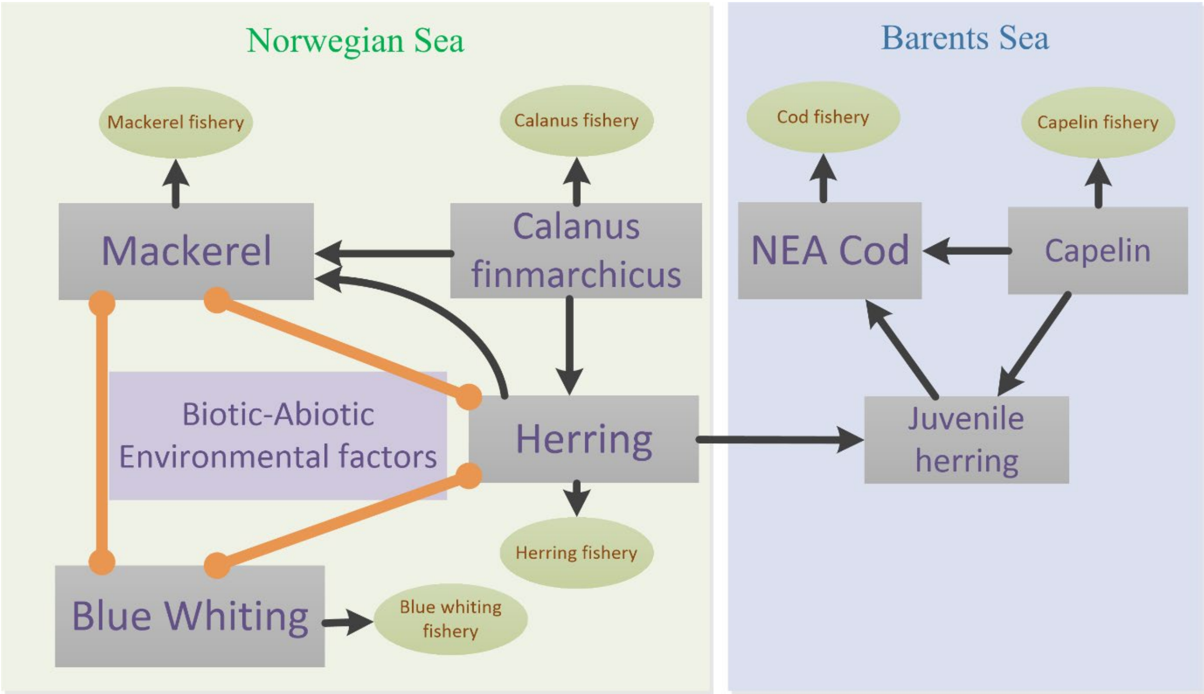


Figure 6.- Conceptual model showing the main interactions between the stocks within the Model M3. The orange arrows indicate competency interactions, while the black lines indicate predation or fishing. Predation of herring by mackerel occurs during the larval stages, while predation on herring by cod occurs during the juvenile stages. Predation of capelin by juvenile herring occurs during the larvae period.

As shown in figure 1, the larvae or early juveniles of NSSH that survive to all the sources of mortality in the Norwegian Sea enter into the Barents Sea at the end of the first year of life. These larvae-early juveniles will grow and will stay in the southern areas of the Barents Sea until they are between 3 and 5 years old. During that time, they can be preyed by juvenile-adult cod. At the same time, they can be predators of capelin larvae, affecting the recruitment and dynamic of this stock. It has been found with empirical data that the SSB-Recruitment relationship in capelin changes with the abundance of herring in the Barents Sea (Daniel Howell, personal communication). Capelin is in turn the most important prey item for cod. Hence there is a complex interdependent relationship between these three stocks, where predation on capelin larvae by herring can affect the availability of juvenile-adult capelin for cod, and this in turn would affect the strength of predation of cod on herring. In addition, migration of early juvenile herring to the Barents Sea depends on the level of recruitment of herring in the Norwegian Sea. The parameterization of the cod and capelin stock models will be defined based in the current stock assessments. The parameters to model the predation rate of juvenile herring by cod as a function of biotic and abiotic environmental variables will be obtained from the NoBa Antlantis model. The proportion of larvae-early juvenile that drift from the Norwegian sea to the Barents Sea and becomes available for cod predation is a very important element for which there is not a clear solution and that will have to be discussed with the stock experts. It seems that neither Norwecom nor NoBa Atlantis will help on this matter.

<u>Natural mortality:</u> in this model the assumptions about natural mortality will have to be reconsidered for juvenile herring, since here the predation from cod is explicitly modelled, and hence should be removed from the residual natural mortality.

Although not optimal, an alternative to fully modelling the cod stock might be running different time series of natural mortality, with the intention of simulating different scenarios of cod predation mortality.

3.3.2.2.- Observation model

As presented in section 3.1, there are two options to simulate the assessment within the MSE framework: model-based and shortcut. The model-based MSE involves great complexity, and a large number of assumptions that are most likely not met. The MSE shortcut option has also limitations, but it is simpler to develop and, if properly developed, it would adequately simulate the real evaluation process. Therefore, this will be the option to follow in this MSE framework. The error and bias in the assessment for each of the stocks in the OM must be simulated as closely as possible, following the ICES guidelines (WKGMSE2, 2019).

In the case of the MSE shortcut, an observation model is not necessary, since the data (abundance, weight and proportion of mature ones) go directly from the biological-fishing model to the evaluation model, where corrective factors are applied to simulate the error and bias, as described in section 3.3.3.1.

3.3.2.3.- Implementation model

As indicated in the step 3.14, in the implementation model the TAC derived from the harvest rule is converted to removals that will be implemented in the biology-fishery model. For an age-structured OM, the TAC (or another measure derived in the decision model), needs to be converted to removals from the true stock in numbers-at-age. The selectivity and weight-at-age values needed for these calculations correspond to the true ones (i.e. those specified in the biological and fishery components of the OM) and normally deviate from those assumed in the decision process.

An implementation model should account for the effects of differences between the intended pattern of removals derived from the harvest rule and the actual removals. Such differences can be caused by variable discarding practices, misreported catch, the implementation of different catch share management systems, bycatch in other fisheries not regulated by the TAC (for example industrial bycatch), or un-modelled fleet behaviour. The extent to which assumptions shall be made about overfishing (or under-fishing) of quotas is an open question that may have to be clarified with the experts of the different stocks. In some cases, set quotas have been consistently exceeded in the past, and the robustness of the rule to such persistent bias should be examined.

The Resource OM in the ENAC framework is the equivalent to the Implementation model of the ICES guidelines. The ENAC framework will be reviewed and the necessary changes will be introduced. It is important to note that the implementation model will have to be developed independently for each stock.

3.3.3.- Building the Management Procedure (MP)

3.3.3.1.- Estimation model

The estimation model in the ICES guidelines is equivalent to the management model in the ENAC framework. As explained in section 3.2.2, in the ENAC framework the assessment of the population status was conducted with the so-called shortcut MSE in the ICES guidelines. However, the simulation of the error and bias was excessively simplistic, since the output values from the OM were multiplied by a random number according to a normal distribution with mean of 1 and sigma 0.1 before the data were sent to the management model, which is not enough to reproduce the real assessment. The simulation of the assessment for all the stocks will require an important investment of time and effort, and will be one of the main elements to improve in the MSE framework. The ICES guidelines (ICES 2019) will be followed to estimate error and bias and apply the appropriate methodology.

3.3.3.2.- Decision model

The Decision model in the ICES guidelines is equivalent to the Harvest model in the ENAC framework. In the single species MSE, the output from the estimation model for a given species is taken as input in the decision model, a short-term projection is run, a population indicator (usually SSB) is obtained from this run and used in a HCR to decide the fishing measure, usually an F that is translated afterwards into fishing catches (TAC).

In this project the intention is developing an MSE framework that can be used to test ecosystem-based management strategies (EBMS) for a group of interacting stocks (in the case of the Model M3: mackerel, herring, blue whiting, *C.finmarchicus* and cod). These EBMS are still to be designed; once the OM is performing satisfactorily, this will be the task where most of the effort will be concentrated. However, in parallel, within the OM the decision model will have to be modified as the EBMS are designed.

One possibility for the decision model might be a “discrete” approach, where a separate MP is developed for each of the stocks (see figure 7), with independent single species-based assessment and decision models. In this case, the biotic (abundance of alternative prey, predators or competitors, etc) and abiotic (oceanographic conditions: currents, water temperature, etc) would inform each of the single species MPs to decide the structure (for example, if one versus two stage HCRs, other structure might be possible) and the reference points of the HCR.

A more advance MSE framework might be including all the estimation models and decision model in a single MP (see figure 8). While the estimation models, as well as the short-term forecast in the decision model would be still be independent for each species, the selection of the HCR for each species would be made also considering biotic and abiotic environment information, but unlike the previous option, in this case the HCRs for all the stocks are selected at once within the decision process following a set of predefined rules or selection functions. For this, different options might be possible. One option could be that the ecosystem-based management strategy (EBMS) is formed by the set of rules (or selection model) and a pool of combinations of HCRs for the different species. These HCRs would differ in the values of the reference points and/or the structure. Another option might be a more “continuous” approach, where the EBMS would be formed by a set of selection functions that would define how the structure of the different HCRs and the values of the reference points should be as a function of the biotic and abiotic environmental conditions.

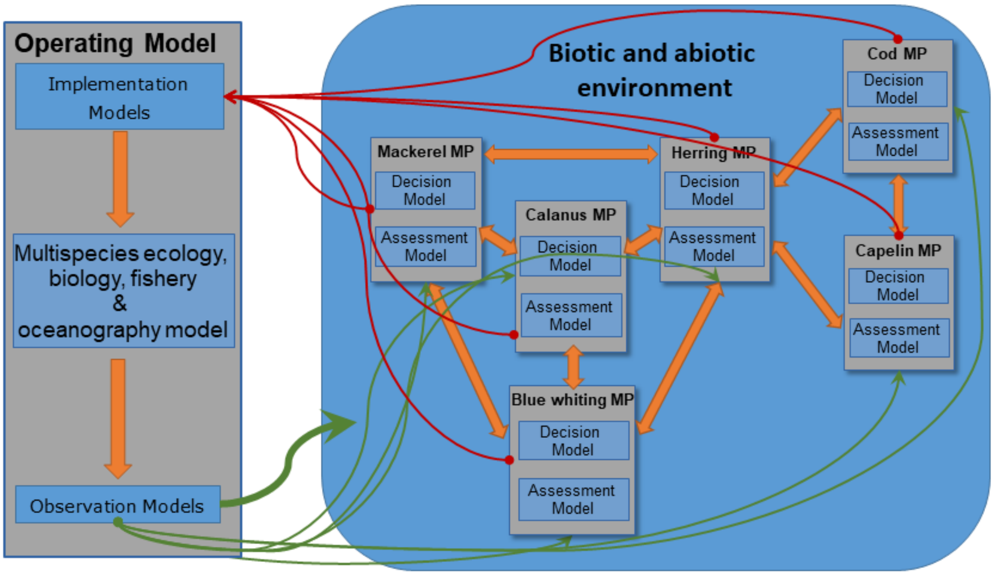


Figure 7.- Possible structure of the MSE framework, where each species will have a different MP, and the abiotic and biotic environment will force through decision rules or functions within each MP, the HCR to be applied for each stock.

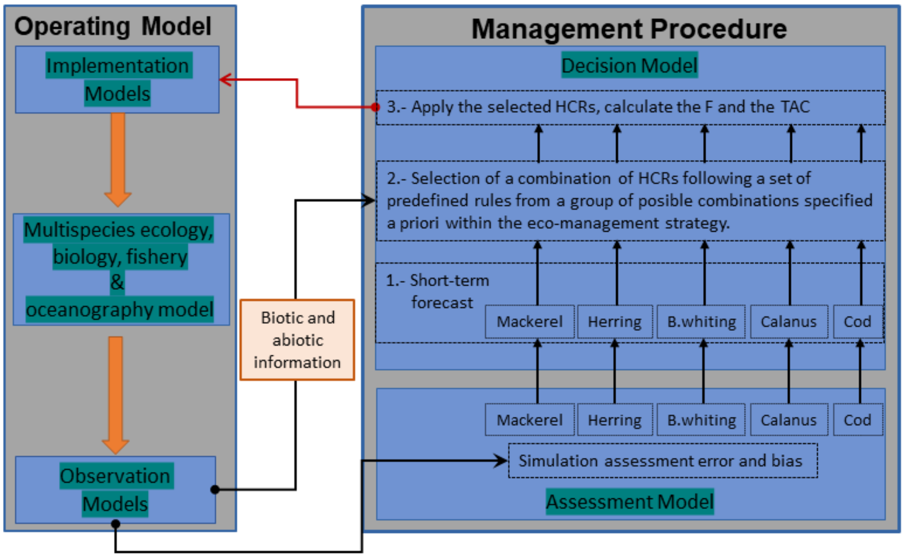


Figure 8.- Other possible structure of the MSE framework, where a single management procedure is designed for all the stocks at the same time, and where the abiotic and biotic environment will force through a single decision model, the HCR to be applied for each stock.

3.3.4.- Definition of Biological reference points, design of HCRs and EBMS

Once the MSE framework is ready, the most important task will still remain, which is the design of an ecosystem based management strategy, which should consist of a set of rules or functions that determine the combinations of HCRs to be used to provide scientific advice (F level and TAC), or alternatively, a set of functions that determine the values of the reference points for all the HCRs for the different stocks. In both cases (“discrete” or “continuous” option), it will be necessary to determine the relationship between the biotic and abiotic conditions and the values of the reference points for each species.

There are two groups of reference points within the ICES framework:

- Precautionary reference points: B_{lim}, B_{pa}, $MSYB_{trigger}$
- Sustainable exploitation reference points: within the ICES single species approach this parameter is F_{msy}. However, this parameter is not possible under a multispecies approach and ecosystem based HCR, and here it will be necessary a different approach, such as the pretty Good multispecies yield (Rindorf et al. 2017a), although other approaches are possible since this is a field in development and there are no fixed rules still in ICES.

One possible approach to define the shape and reference points of the HCRs that fulfil the management objectives (precautionary approach and multispecies optimal yield, explained below in section 3.3.5), as well as the relationship with the environmental biotic and abiotic conditions could be using the MSE framework to estimate the SSB and yield for several combinations of Fs for the different stocks under different environmental scenarios (food availability, water temperature, or other factors that in WP1, WP2 or WP3 are proved to be highly influential). The ICES guidelines would be followed, and in this stage the same F would be applied in the simulated period, regardless of the level of SSB (constant F HCRs). This simulations will allow:

1) Estimating the precautionary reference points Blim, Bpa and MSYBtrigger (following the ICES guidelines (ICES 2017)), that might be variable with the environmental conditions.
2) Exploring the possible combinations of F that, under specific environmental conditions, already show capacity to comply with the precautionary approach.

The next step would be selecting a very small subgroup of combinations of HCRs that already in the deterministic simulations complied with the precautionary approach, and perform a risk analysis to test which of this combinations are still precautionary (less than 5% probability of being below Blim) when considering uncertainty at different levels. Most likely recruitment, growth and stock assessment will be the processes where uncertainty and errors will be introduced. The possibility of exploring uncertainty in these and/or other processes will be very limited by the time and computational capacity, since the number of simulations needed grows exponentially with the processes for which uncertainty want to be assessed.

Finally, different EBMS will be designed. Those combinations of HCRs that fulfilled the precautionary approach in the previous step can be used in different ways depending on the priorities in relation to the catches for the different species, and also the way the change in the combinations of HCRs is modelled in relation to the environmental conditions (in the recent past, since we cannot predict the conditions in the future).

The performance of an EBMS must be tested by comparing a series of performance indicators against a series of objectives, which ideally should be set in agreement with all the stakeholders interested in any of the stocks. This is especially important when the EBMS are to be designed, since the management decisions for a stock will likely have consequences in the dynamic and productivity of other stocks. It will be hence necessary assessing the trade-offs at the ecological, social and economic levels. However, it is not clear that the input of the stakeholders is appropriate and/or necessary at the stage of development that this project is right now. It would be very convenient at this moment having the flexibility to explore different performance indicators and management objectives depending on how the MSE framework and the whole project evolves.

The management objectives at this stage will be based in the precautionary approach and the multispecies optimal sustainable yield. Based in the precautionary approach the EBMS should be designed in a way that, when running a risk assessment simulating variable environment (in relation to biotic and abiotic factors affecting the productivity of the commercial stocks of interest), the stocks shouldn´t go bellow Blim more than 5% of the iterations (ICES 2019). However, due to the interactions between the stocks, it is possible that there are not possible combinations of HCRs that allow all the stocks being above Blim at the same time under specific environmental conditions (low food availability, cold temperatures…), as it has been found in previous studies (Pérez-Rodríguez et al. 2019). In this case, different management scenarios should be explored, where different stocks are "sacrificed" in terms of risk of collapsing. Most likely there will be several combinations of HCRs (F levels for the different stocks) able to maintain all stocks (or the stocks that are selected to be maintained above Blim) above Blim with a probability higher than 95%. In this case, the best combination of HCRs will be selected based in productivity criteria, which might be maximizing the total catch for all stocks together, or maximizing the catch of a given stock, or maximizing the catch while minimizing the interannual variability. Hence, several possible criteria can be implemented, and hence, several different EBMS will be designed.

This is a highly complex task that will require of an extraordinary computation capacity. In first place due to the exponential growth in the number of F combinations that must be tested in the deterministic stage as the number of stocks to be evaluated increases. In second place, to carry out an MSE and risk assessment to those selected combinations of HCRs and EBMS, different sources of uncertainty will need to be assessed (as indicated in section 3.1, mostly recruitment, growth and assessment error). For these reasons, it will be essential to develop the code in the most effective way, being able to run in parallel to reduce computing time. But this will not be enough, and it will be necessary having access to a supercomputer. The capacity to explore possibilities for HCRs and EBMS, as well as assessing the uncertainty will depend absolutely on this computational capacity.

3.3.6.- <u>Validation</u>

As explained in section 3.1, it will be necessary to validate the operation of all the components of the MSE framework, especially the biology-fishery model and the implementation model within the OM, and the estimation models within the MP. There are different approaches to carry out this validation, which are explained in section 3.1. Other options (graphics, statistics ...) that are possible will also be incorporated into the pool of statistics to be calculated.

<u>Biology and fishery model validation</u>

If the future is intended to reflect past dynamics, as represented in the OM, then validation needs to ensure this aim has been achieved.

The following are examples of how this may be checked:

• Comparison of historical and simulated recruitment against SSB, check distributional form (e.g. via Q-Q and cumulative distribution plots), autocorrelation, and fluctuating and episodic recruitment.

• Ensuring that there are no unexpected discontinuities between the past and future dynamics in the OM.

• Ensuring that the model can replicate the recent past by hindcast projections, i.e. runs where the OM starting some years back in time and condition it to reproduce the historical development of the stock. The hindcast projection is then compared with the realized values of key statistics/input data.

Observation model validation: this model in principle will not be developed in this project.

Estimation model validation

Since the shortcut approach combines the observation and estimation models in order to approximate the estimation model behaviour, validation should ensure future assessment behaviour is consistent with that observed historically.

Decision model validation

A first practical test of any decision model is that it can be programmed (i.e. if a request for an evaluation of a decision rule is received, then one must be able to convert this decision rule into computer code). Further validation tests could include running the MSE with perfect knowledge and compare this with the management decision model including observation and assessment error to check the impact of the errors. It may be that the management strategy is not precautionary even under perfect knowledge. This is also useful as a code check.

4.- Tasks, milestones, deliverables and workplan calendar

All the work described in the previous sections could be organized in three tasks. Next, this three tasks are presented, and the deliverables and milestones are indicated. Finally, a workplan calendar for all the tasks is attached, indicating the milestones and deliverables.

- Task 1: development of the MSE framework
  This task includes the development of all the components of the MSE framework as described in the previous sections, including the different versions of the OM.
  - Deliverables: MSE framework with at least one option for the biology-fishery model within the OM.
- Task 2: Design and testing of EBMS
  This task includes the definition of the reference points, the structure of the HCRs, and their relationship with the biotic and abiotic variables that are considered relevant.
  - Milestones:
    - Candidate HCR combinations selected deterministic simulations
    - Combinations of HCRs for different environmental conditions that comply with the precautionary approach
  - Deliverables:
    - Production and risk assessment of at least one EBMS.
- Task 3: Production of scientific articles and reports
  A scientific article will be prepared with the methodology and the results.
  - Deliverable:
    - Contribution to the SIS Hosting final report describing the work developed in this sub-project and the results obtained.
    - Peer reviewed scientific paper with the framework and the most relevant results.

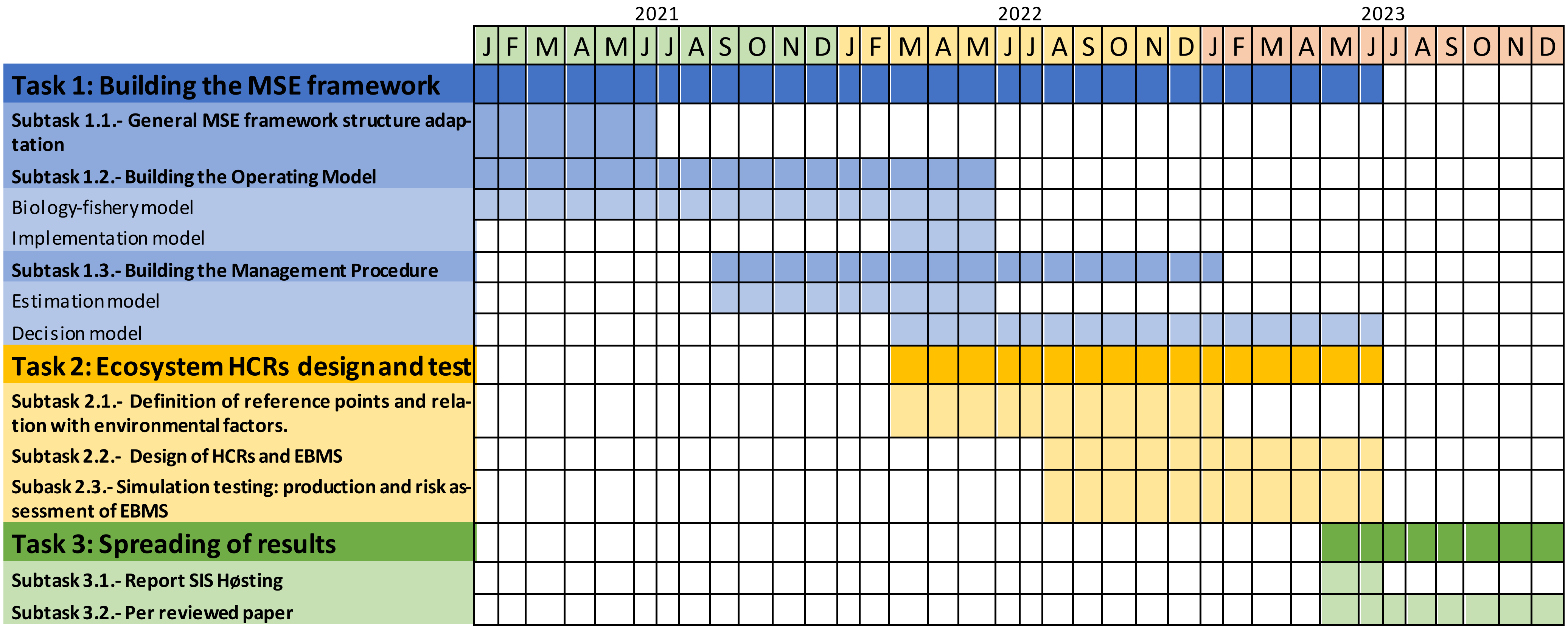
5.- Potential problems and limitations

- That the results of the WP1, WP2 and WP3, which will provide the necessary information to set and parameterize the models (mainly the biological-fishing operating model), are delivered too late (2022 or even 2023).

- That the WP1, WP2 and WP3 do not deliver the necessary results to configure and parameterize the models, or that they deliver the results in a format that is not useful for the MSE framework and ecosystem HCR testing.

- Computing power capacity: As explained above, it will be necessary having access to a supercomputer.

Table 1.- Workplan



2021 2022 2023

	Programmer	Fisheries expert	Programmer	Fisheries expert	Programmer	Fisheries expert
Task 1: Building the MSE framework	300	550	200	300		
Task 2: Ecosystem HCRs design and test			100	300		
Task 3: Spreading of results					100	300

6.- References:

Bachiller, E., U. Cotano, L. Ibaibarriaga, M. Santos, and X. Irigoien. 2015. Intraguild predation between small pelagic fish in the Bay of Biscay: impact on anchovy (Engraulis encrasicolus L.) egg mortality. Marine Biology **162**:1351–1369.

Balci, O. 1997. Verification validation and accreditation of simulation models. Pages 135-141 *in* Proceedings of the 29th conference on Winter simulation.

Bax, N. J. 1998. The significance and prediction of predation in marine fisheries. ICES Journal of Marine Science **55**:997-1030.

Gislason, H., N. Daan, J. Rice, and J. Pope. 2010. Size, growth, temperature and the natural mortality of marine fish. Fish and Fisheries **11**:149-158.

Haddon, M. 2010. Modelling and quantitative methods in fisheries. CRC press.

Hilborn, R., and C. Walters. 1992. Quantitative fisheries stock assessment: choice, dynamics and uncertainty. Springer Science Bussines Media.

ICES. 2017. ICES Technical Guidelines: ICES fisheries management reference points for category 1 and 2 stocks. ICES Advice 2017 **Book 12**.

ICES. 2019. Workshop on Guidelines for Management Strategy Evaluations (WKGMSE2). ICES Scientific Reports **1**:162.

Johannesen, E., U. Lindstrøm, K. Michalsen, M. Skern-Mauritzen, P. Fauchald, B. Bogstad, and A. Dolgov. 2012. Feeding in a heterogeneous environment: spatial dynamics in summer foraging Barents Sea cod. Marine Ecology Progress Series **458**:181-197.

Pérez-Rodríguez, A., D. Howell, and I. Umar. 2019. EU SC05 project: "Multispecies Fisheries Assessment for NAFO". Estimation of multispecies based HCRs and use of a multispecies MSE framework to assess the risk of collapse and the fishery-ecological trade-offs. NAFO SCR Doc. 19/017.

Pérez-Rodríguez, A., J. Morgan, F. Saborido-Rey, and M. Koen-Alonso. 2013. Disentangling genetic change from phenotypic response in reproductive parameters of Flemish Cap cod Gadus morhua. Fisheries Research **138**:62-70.

Punt, A. E., D. S. Butterworth, C. L. de Moor, J. A. De Oliveira, and M. Haddon. 2016. Management strategy evaluation: best practices. Fish and Fisheries **17**:303-334.

Rindorf, A., C. M. Dichmont, P. S. Levin, P. Mace, S. Pascoe, R. Prellezo, A. E. Punt, D. G. Reid, R. Stephenson, C. Ulrich, M. Vinther, and L. W. Clausen. 2017a. Food for thought: pretty good multispecies yield. ICES J. Mar. Sci. **74**:475-486.

Rindorf, A., C. M. Dichmont, J. Thorson, A. Charles, L. W. Clausen, P. Degnbol, D. Garcia, N. T. Hintzen, A. Kempf, and P. Levin. 2017b. Inclusion of ecological, economic, social, and institutional considerations when setting targets and limits for multispecies fisheries. ICES Journal of Marine Science **74**:453-463.

Saltelli, A., M. Ratto, T. Andres, F. Campolongo, J. Cariboni, D. Gatelli, M. Saisana, and S. Tarantola. 2008. Global sensitivity analysis: the primer. John Wiley & Sons.

Scheffer, M., J. Baveco, D. DeAngelis, K. A. Rose, and E. van Nes. 1995. Super-individuals a simple solution for modelling large populations on an individual basis. Ecological Modelling **80**:161-170.

Skagen, D. W., M. Skern-Mauritzen, D. Dankel, K. Enberg, O. S. Kjesbu, and R. D. Nash. 2013. A simulation framework for evaluating fisheries management decisions using environmental information. ICES Journal of Marine Science **70**:743-754.

Trenkel, V. M., G. Huse, B. MacKenzie, P. Alvarez, H. Arrizabalaga, M. Castonguay, N. Goñi, F. Grégoire, H. Hátún, and T. Jansen. 2014. Comparative ecology of widely distributed pelagic fish species in the North Atlantic: implications for modelling climate and fisheries impacts. Progress in Oceanography **129**:219-243.

Annex 6: Report from workshop for revision of the ecosystem overview, 1 February 2021

EO Wire diagram. Report from WGINOR workshop February 1, 2021.

List of participants and their affiliation and expertise are as follows:

Name	Institution	Expertise
Cecilie Broms	Institute of Marine Research	Zooplankton
Knut Yngve Børsheim	Institute of Marine Research	Primary production
Anne Kirstine Frie	Institute of Marine Research	Marine mammals
Bjørn Einar Grøsvik	Institute of Marine Research	Pollution
Elvar Hallfredsson	Institute of Marine Research	Deepwater fish
Cecile Hansen	Institute of Marine Research	Ecosystem models
Inigo Martinez	ICES secretariat	
Xiaozi Liu	Institute of Marine Research	Fisheries, cross disciplines
Gro van der Meeren	Institute of Marine Research	General ecology, fish
Erik Askov Mousing	Institute of Marine Research	General ecology / models
Nikolaos Nikolioudakis	Institute of Marine Research	Pelagic fish
Leif Nøttestad	Institute of Marine Research	Pelagic fish
Alfonso Perez-Rodriguez	Institute of Marine Research	Fisheries
Ann Holly Perryman	Institute of Marine Research	Ecosystem models
Benjamin Planque	Institute of Marine Research	General ecology, deepwater fish
Lise Doksæter Sivle	Institute of Marine Research	Underwater Noise
Øystein Skagseth	Institute of Marine Research	Oceanography
Mette Skern-Mauritzen	Institute of Marine Research	General ecology, marine mammals
Fabian Zimmermann	Institute of Marine Research	Pelagic fish
Mimi Lam	University of Bergen	Fisheries, cross disciplines
Eydna Homrum	Faroe Marine Research Institute	Pelagic fish
Anna Ólafsdóttir	Marine and Freshwater Research Institute	Pelagic fish
Per Arneberg	Institute of Marine Research	General ecology

Take-home messages from the workshop:

- Knowledge quality assessment should be included.
- Key knowledge gaps; e..g contribution of the different sectors to litter, other?
- Sectors difficult to assess: military.

2. STUDY AREA AND ASSESSMENT APPROACH

The assessment region included the Norwegian Sea, following the delineation used in the Norwegian cross sector management plan. This region excludes the nearshore coastal areas inside the territorial baseline (is this the right term?, Figure 1). As a consequence, coastal sectors and pressures, such as aquaculture, were assessed to have little relevance for the region, compared to previous assessments for the ICES EOs.

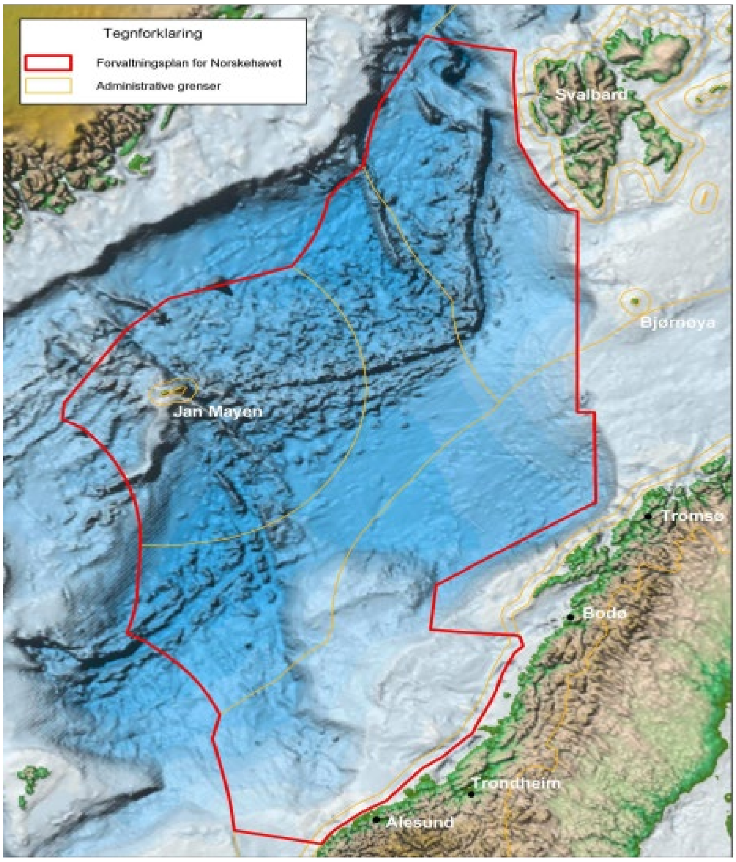


Figure 1. The Norwegian Sea ecoregion. The red polygon shows the region included in the Norwegian Sea cross sectors management plan, which is also used as the geographic scope of this risk assessment.

The workshop applied a simplified ODEMM approach (Pederschi et al. 2019), as outlined in the 2019 WGEAWESS report (ICES 2019). The approach relies on first identifying all relevant sectors and pressures in the ecoregion impacting ecosystem components. Thereafter, each linkage between sector, pressure and ecosystem component are scored based on the spatial overlap between sector, pressure and ecosystem component, the frequency of impact and the degree of impact, according to the criteria shown in Table 1.

Table 1. Criteria used for scoring of each sector – pressure – ecosystem component linkage in the Norwegian Sea.

Criteria	Definition	Categories	Score
Extent	spatial overlap between a sector/pressure and an ecological characteristic – regardless of how often it occurs	NO refers to No Overlap and is of no further concern	0
		Site (>0-5% overlap)	0.03
		Local (5-50%)	0.37
		Widespread (>50%)	1
Frequency	timing of the interaction (i.e. between a given sector, pressure, characteristic pathway) – regardless of the magnitude of the interaction	Rare (e.g. occurs in one month per year)	0.08
		Occasional (e.g. occurs in 4 months per year)	0.33
		Common (e.g. occurs in 8 months per year)	0.67
		Persistent (e.g. occurs in every month of the year)	1
Degree of Impact (DoI)	generic sensitivity of an ecological characteristic to a pressure – regardless of extent or frequency	Low (severe effect not expected)	0.01
		Acute (immediate severe effect; e.g. death)	1
		Chronic (severe effect likely after multiple occurences)	0.13

Before the workshop, WGINOR members (N=11) identified the relevant sectors and pressures impacting the ecosystem components in the Norwegian Sea in an excel support table. In addition, pressures that were likely to have strongest impact was discussed as the WGINOR meeting. Due to limited time available at the workshop to assess sectors, pressures and impacts, the following measures were taken:

- A 'strawman' assessment was performed by Mette Skern-Mauritzen, scoring all sector-pressure-ecosystem components linkages identified by the WGINOR members. Key information for this scoring was available maps (Arealverktøy for forvaltningsplanene - BarentsWatch and the Norwegian Fisheries Directorate Alle tema (fiskeridir.no)), in addition to relevant papers and reports
- At the workshop, the group went through each of the scorings, organized pressure by pressure.
- The most important pressures, in terms of impact, were prioritized, acknowledging that the limited time available would not allow a full assessment of all pressures. On the workshop, the group went through and scored the following pressures; Abrasion, contaminants, litter, underwater noise, invasive species and species extraction, thus covering all key pressures previously identified by WGINOR.
- Non-living resources, sealing, siltation/smothering and organic matter was assessed further by Mette Skern-Mauritzen after the workshop; ensuring that assessments of overlaps and frequency of impacts from the sectors were consistent with group assessments of sector activities across space and time.

2.1 **Impact risk**

The scores on spatial overlap, frequency of impact and degree of impact were transformed into numerical categories (see Table 1, scores) and multiplied (overlap*frequency*degree of impact) to calculate the ***Impact risk*** for each sector-pressure-impacted ecosystem component linkage (Table 2). The sum of these Impact risks across sectors, pressures, or ecosystem components were used to obtain a *relative measure* on contribution of the sectors or pressures to the risks of impact. These ***Sums of Impact risks*** were finally used to guide the scoring of the ICES EO tables. This is further discussed in section 4.

Table 2. Scoring of sector – pressure – impacted ecosystem component linkages. The example shows how seismic and maritime transport is linked to the pressure noise and impacts on seabirds and marine mammals. Each line reflect one sector-pressure-ecosystem component, associated with on Impact risk score (i.e. overlap*frequency*Degree of Impact). Scorings as in Table 1.

Sector	Pressure	Ecosystem component	Overlap	Frequency	Degree of Impact	Impact risk
Seismic	Noise	Marine mammals	W 1	O 0.33	C 0.13	0.0429
Maritime transport	Noise	Marine Mammals	L 0.37	O 0.33	C 0.13	0.016

3. RESULTS

3.1 Pressures

Statistics for the different pressures assessed is presented in Table 3 and Figure 2. Of the pressures, noise, litter and contaminants had the largest number of links. However, both the average and sum of impact risks were highest for species extraction, followed by contaminants, noise, abrasion and litter.

Table 3. Statistics on pressures from assessment of Impact risks.

Pressure	N links	Sum impact risk	Mean of impact risks > 0
Species extraction	12	1.32	0.11
Contaminants	32	0.585	0.018
Noise	62	0.279	0.005
Abrasion	16	0.194	0.012
Litter	40	0.081	0.002
Sealing	4	0.065	0.016
Siltation/Smothering	6	0.063	0.011
Non-living resources	4	0.025	0.006
Organic matter/NP	2	< 0.001	< 0.001
Invasive species	0	0	0

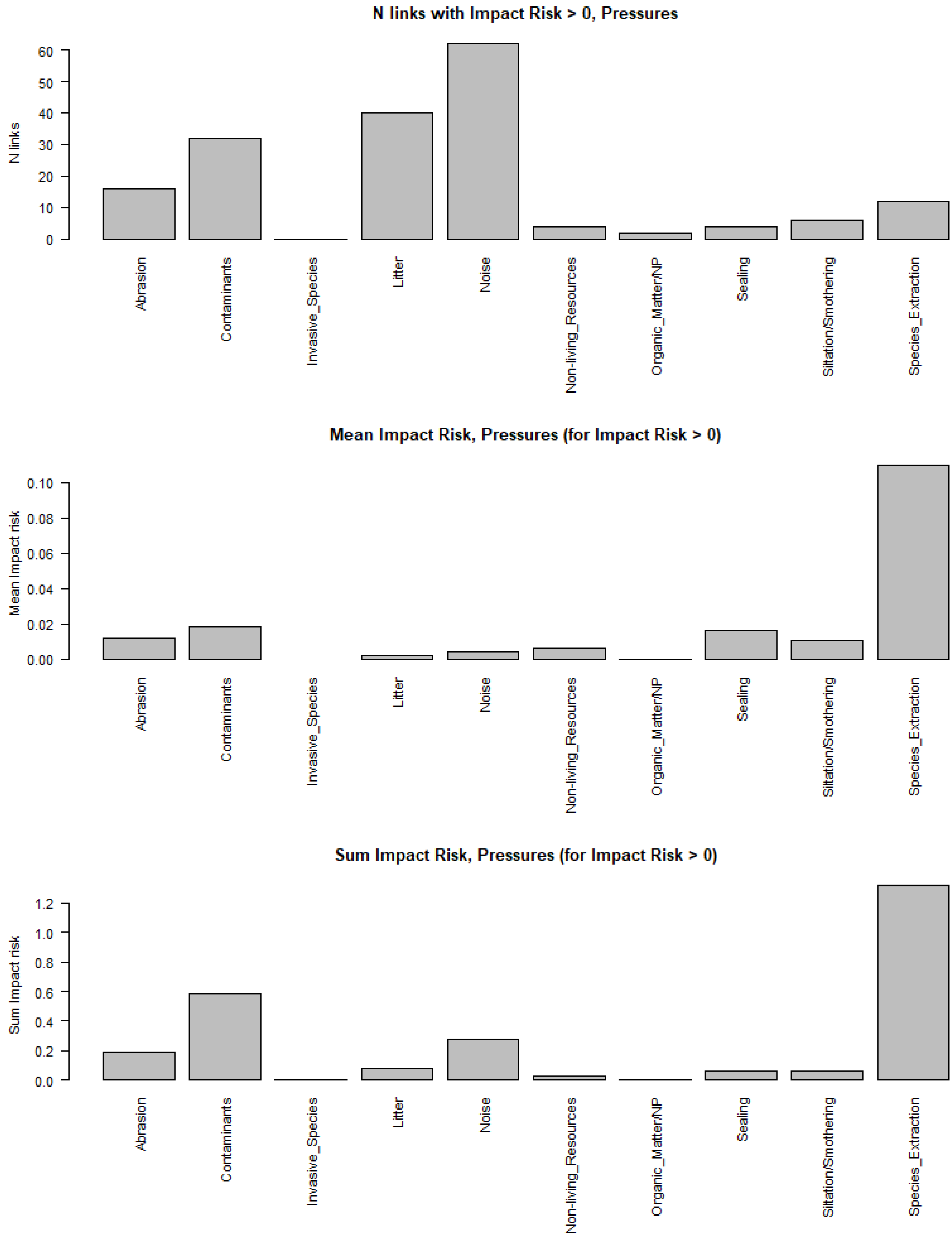


Figure 2. Statistics on pressures from assessment of Impact risks. Top panel: Number of links for each pressures where impact risk > 0. Middle panel: Mean of impact risks for linkages with impacts risk > 0. Bottom panel: Sum of all impact risks from each pressure.

3.2 Sectors

Among the sectors, fisheries, non-renewable (oil and gas), seismic, maritime transport and tourism/recreation was associated with most links (Table 4). Fisheries also contributed to most risk to the ecosystem, followed by agriculture, land-based industry, oil and gas and seismic activity. The reasons for the relatively high-risk scores on agriculture and land-based industry is long distance transfer of pollutants. Hence, these are not impacts by sectors on land bordering the ecoregion, and it needs to be discussed how this should be represented in the EO wire diagram. If we disregard the long-distance impacts, the key sectors in the Norwegian Sea in terms of impact risk are fisheries, oil and gas, seismic activity and marine transportation. Aquaculture has been included as one of the key sectors in previous Norwegian Sea EOs. However, following the Norwegian Aquaculture Risk Assessment report, pollution or organic material from aquaculture does not spread kilometers offshore and into the assessed ecoregion (Grefserud et al. 2021, Figure 1), and is therefore assessed to have very limited impact on the ecosystem components here.

Table 4. Statistics on sectors from assessment of impact risks: N links are number of links associated with that sector; Sum risk is the sum of all impact risks associated with that sector, and mean risk is the mean of all impact risks associated with that sector.

Sector	N links	Sum impact risk	Mean of impact risks > 0
Fishing	29	1.397	0.048
Agriculture	4	0.28	0.07
Land-based Industry	4	0.28	0.07
Non-renewable (oil & gas)	20	0.26	0.013
Seismic	20	0.104	0.005
Maritime transport	20	0.102	0.005
Tourism/Recreation	23	0.055	0.002
Aggregates	8	0.05	0.006
Military	12	0.043	0.004
Research	15	0.035	0.002
Hunting	1	0.002	0.002
Waste Water	8	0.002	< 0.001
Aquaculture	7	< 0.001	< 0.001
Coastal Infrastructure	7	< 0.001	< 0.001

3.3 Ecosystem components

Among the ecosystem components, benthos and habitat is associated with most impact links, while fish, marine mammals and seabirds are associated with highest sum of impact risk (Table 5). Typically, benthos and habitats are linked to local physical disturbance, while the impact on fish and marine mammals are linked to wide-ranging sectors and pressures, including fisheries, noise and litter.

Table 5. Statistics on ecosystem components from assessment of impact risks: N links are number of links associated with that ecosystem component; Sum risk is the sum of all impact risks associated with that ecosystem component, and mean risk is the mean of all impact risks associated with that ecosystem component (considering risk > 0 only).

Ecosystem characteristic	N links	Sum impact risk	Mean of impact risks > 0
Fish	26	1.203	0.046
Marine mammals	25	0.404	0.016
Seabirds	24	0.298	0.012
Benthos	32	0.272	0.008
Habitats	32	0.253	0.008
Foodweb	18	0.162	0.009
Zooplankton	15	0.019	0.001
Productivity	6	0.001	< 0.001

3.4 Attributing pressures to sectors

In Tables 6 to 10, we have ranked the sectors contributing to each of the top 5 pressures, as assessed from the sum of Impact risks.

Table 6. Sectors contributing to risk associated with species extraction.

Sector	N links	Sum impact risk	Mean of impact risks > 0
Fishing	7	1.258	0.18
Tourism/Recreation	1	0.03	0.03
Research	3	0.03	0.01
Hunting	1	0.002	0.002

Table 7. Sectors contributing to risk of impacts from contaminants.

Sector	N links	Sum impact risk	Mean risk of impact > 0
Agriculture (long-distance)	4	0.28	0.07
Land-based Industry (long-distance)	4	0.28	0.07
Non-renewable (oil & gas)	6	0.023	0.004
Fishing	3	< 0.001	< 0.001
Maritime transport	3	< 0.001	< 0.001
Tourism/Recreation	3	< 0.001	< 0.001
Military	3	< 0.001	< 0.001
Research	3	< 0.001	< 0.001
Seismic	3	< 0.001	< 0.001

Table 8. Sectors contributing to risk of impacts from noise

Sector	N links	Sum impact risk	Mean risk of impact > 0
Seismic	7	0.098	0.014
Maritime transport	7	0.055	0.008
Fishing	7	0.047	0.007
Military	7	0.038	0.005
Non-renewable (oil & gas)	6	0.037	0.006
Tourism/Recreation	7	0.003	< 0.001
Research	7	0.001	< 0.001
Aquaculture	7	< 0.001	< 0.001
Coastal Infrastructure	7	< 0.001	< 0.001

Table 9. Sectors contributing to risk of impacts from abrasion

Sector	N links	Sum impact risk	Mean risk of impact > 0
Non-renewable (oil & gas)	2	0.06	0.03
Aggregates	2	0.04	0.02
Maritime transport	2	0.04	0.02
Fishing	2	0.02	0.01
Tourism/Recreation	2	0.02	0.01
Military	2	0.005	0.002
Research	2	0.005	0.002
Seismic	2	0.005	0.002

Table 10. Sectors contributing to risk of impacts from litter

Sector	N links	Sum impact risk	Mean risk of impact > 0
Fishing	8	0.069	0.009
Maritime transport	8	0.006	0.001
Waste water	8	0.002	< 0.001
Tourism/Recreation	8	0.002	< 0.001
Seismic	8	0.001	< 0.001

3.5 Attributing Impact risk on ecosystem components to pressures

In Table 11, we have partitioned the sum of risk to each ecosystem component by the 5 top pressures.

Table 11. Attributing impact risk to the different ecosystem components to the top 5 pressures.

Pressure		Habitats	Benthos	Produc-tivity	Zooplank-ton	Fish	Seabirds	Ma-rine_Ma mmals	Foodweb
Species ex-traction	N links	2	2	0	1	3	1	2	1
	Sum risk	0.058	0.040	0.000	0.010	1.040	0.020	0.023	0.130
	Mean Risk	0.029	0.020	0.000	0.010	0.347	0.020	0.011	0.130
Contami-nants	N links	1	1	0	0	9	9	9	3
	Sum risk	0.004	0.004	0.000	0.000	0.024	0.264	0.264	0.024
	Mean Risk	0.004	0.004	0.000	0.000	0.003	0.029	0.029	0.008
Noise	N links	9	9	0	9	9	9	9	8
	Sum risk	0.017	0.024	0.000	0.008	0.108	0.006	0.109	0.007
	Mean Risk	0.002	0.003	0.000	0.001	0.012	0.001	0.012	0.001
Abra-sion	N links	8	8	0	0	0	0	0	0
	Sum risk	0.097	0.097	0.000	0.000	0.000	0.000	0.000	0.000
	Mean Risk	0.012	0.012	0.000	0.000	0.000	0.000	0.000	0.000
Litter	N links	5	5	5	5	5	5	5	5
	Sum risk	0.001	0.031	0.001	0.001	0.031	0.007	0.008	0.001
	Mean Risk	0.000	0.006	0.000	0.000	0.006	0.001	0.002	0.000

4.0 Transfer of assessment results to ICES scoring tables

The ***Sum of impact risks*** from the ODEMM assessment were used to score of pressures, sectors and ecosystem components in the ICES EO tables (see below). The values were not directly transferable, as the scoring of exposure, frequency and degree of impact differed between the simplified ODEMM approach and the current version of EO tables. Hence, we used the sum of impact risks to guide a subjective scoring in the ICES EO tables.

The first EO table to be scored, is the importance of the different pressures (Table 12). We propose to include the five most important pressures as assessed from ODEMM; Selective species extraction, contaminants, noise, abrasion and litter, with sum of Impact risk ranging from 0.08 – 1.32, accounting for 96% of the sum of Impact risk scores. The sum of impact risk was < 0.07 for the remaining pressures not included (Table 1, Figure 2). Max impact in the ICES table of pressures is 6. We suggest to give the top pressure species extraction a score of 4, as key stocks (mackerel, blue whiting and Norwegian spring spawning herring) are at or above B_{pa}, other smaller stocks are predominantly sustainable harvested, mixed fisheries is a limited challenge, while bycatch of marine mammals and seabirds is an issue. The other pressures are scored relative to the top pressure based on their sum of Impact risk scores (Table 12).

Table 12. ICES EO Table 1. Proposed Total impact scores for the key pressures in the ICES Ecosystem Overviews (in column Total impact), guided by sum of impact risks from the ODEMM exercise (green column).

Pressure	Probability of occurence (1 = not likely to occur, to 3 = frequent or recurrent)	Magnitude (1 = low, 3= high) Magnitude of the pressure, i.e. in space and/or severity of impact (1 = low, to 3 = high).	Total Impact (Max =6)	Sum Impact risk
Selective extraction of species			4	1.32
Contaminants			3	0.585
Noise			2	0.279
Abrasion			2	0.194
Litter			1	0.081

In ICES EO Table 2 (Table 13) each pressure is attributed to the different sectors. Maximum link strength in the EO table is 3. We propose to assign a link strength of 3 to impact risks > 0.5, link strength of 2 to Impact risks < 0.5 & > 0.01 and link strength of 1 to Impact risks < 0.01 & > 0 (Figure 3).

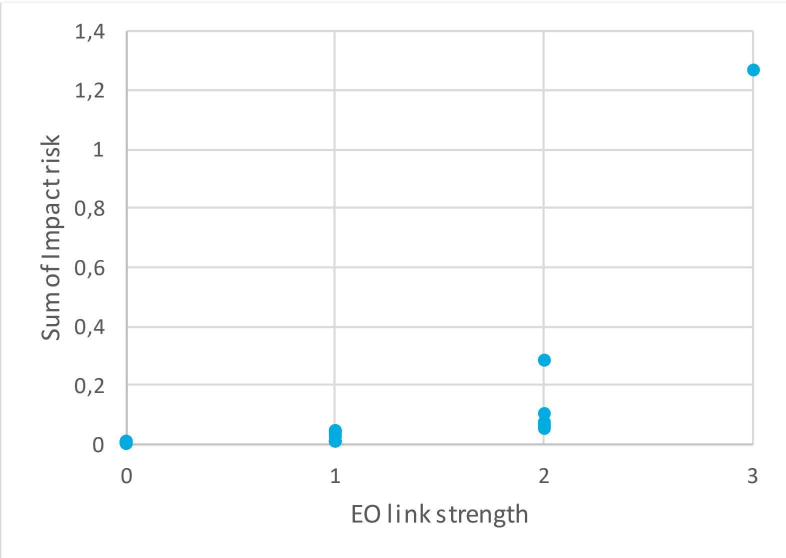


Figure 3. The relationship, for each sector-pressure combination, as suggested EO scoring of link strengths (x-axis) relative to ODEMM sum of impact risks (y-axis).

Table 13. ICES EO Table 2. Linking sectors to each of the top pressures; Strength of link shows suggested EO scores, guided by sum of impact risks from the ODEMM exercise (green column). Note that "Litter" will not be included in the wire diagram, as it is not on the list of top pressures decided by WGINOR at the 2019 annual meeting.

Pressure	Sector	Strength of link; 1 = weak link, to 3 = strong link	Sum impact risk	Notes on exclusion in the diagram
Species extraction	Fishing	3	1.258	
	Tourism/Recreation	1	0.03	Not in wire diagram because it is <5% of max impact from an activity for this pressure (which is fishing here)
	Research	1	0.03	Not in wire diagram because it is <5% of max impact of an activity for this pressure
	Hunting	0	0.002	
Contaminants	Agriculture	2	0.28	
	Land-based Industry	2	0.28	
	Non-renewable (oil & gas)	1	0.023	We discussed leaving this out of the wire diagram, but we leave it in since it is about 10% of a level 2 score. Note that we do not what a 3 is here, so we cannot compare directly with this and therefore extrapolate by comparing with a 2.
	Fishing	0	< 0.001	
	Shipping	0	< 0.001	
	Tourism/Recreation	0	< 0.001	
	Military	0	< 0.001	
	Research	0	< 0.001	
	Seismic	0	< 0.001	
Noise	Seismic	2	0.098	
	Shipping	2	0.055	
	Fishing	2	0.047	
	Military	1	0.038	
	Non-renewable (oil & gas)	1	0.037	
	Tourism/Recreation	1	0.003	We exclude this from the wire diagram, because it is an order of magnitude

				lower than something that is alreadya 1
	Research	0	0.001	
	Aquaculture	0	< 0.001	
	Coastal Infrastructure	0	< 0.001	
Abrasion	Non-renewable(oil & gas)	2 change to 1	0.06	Based on professional knowledge and discussion, participants at the meeting 22.03.21 concluded that this value is too high and should be ranked as 1 not to be higher than fishing. Note: assessment is changed here
	Aggregates	1 change to 0	0.04	Based on professional knowledge and discussion, participants at the meeting 22.03.21 concluded that this should be taken out, as it is likely reflecting future impact from mining. Note: assessment is changed here
	Shipping	1	0.04	Based on professional knowledge and discussion, participants at the meeting 22.03.21 concluded that this value is too high and that this link should not be included in the wire diagram
	Fishing	1	0.02	
	Tourism/Recreation	1	0.02	Based on professional knowledge and discussion, participants at the meeting 22.03.21 concluded that this value is too high and that this link should not be included in the wire diagram
	Military	1	0.005	Leave this out, as it is <10% of category 2
	Research	1	0.005	Leave this out, as it is <10% of category 2
	Seismic	1	0.005	Leave this out, as it is <10% of category 2
Litter	Fishing	2	0.069	
	Shipping	1	0.006	

	Waste water	0	0.002
	Tourism/Recreation	0	0.002
	Seismic	0	0.001

In ICES EO Table 3 (Table 14), risk of impact from each pressure to the different ecosystem components are scored. Maximum link strength in the EO table is 3. Due to relatively limited impact on the Norwegian Sea ecosystem, we propose to assign a maximum score of 2 to the most impacting pressures. We suggest to give stressors associated with sum of impact risk for any ecosystem component > 1 an EO link strength of 3 (only applying to impacts of species extraction on fish), while link strength of 2 and 1 are given to impacts > 0.02 and 0.001, respectively (Figure 4).

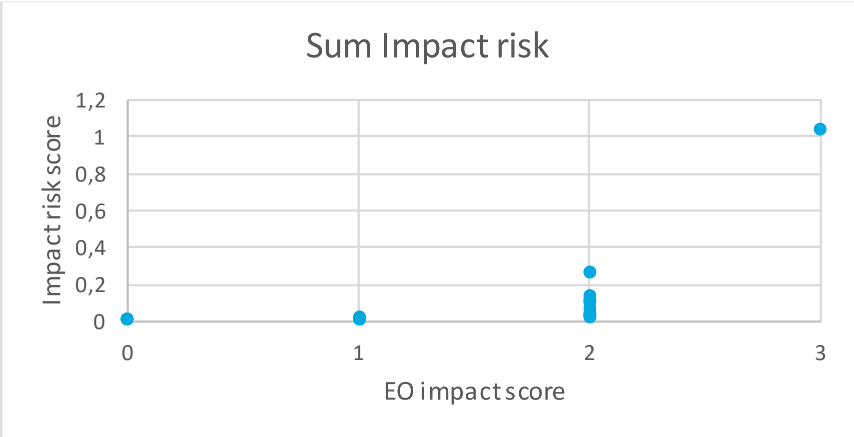


Figure 4. The relationship, for each pressure-ecosystem component link, as suggested EO scoring of link strengths (x-axis) relative to ODEMM sum of impact risks (y-axis).

Table 14. ICES EO Table 3. Linking the top pressures to each ecosystem component; Strength of link shows suggested EO scores, guided by sum of impact risks from the ODEMM exercise (green column).

Pressure	Ecosystem component	Strength of link, 1 = weak link, to 3 = strong link	Sum Impact risk	Anna and Per revision on strength of links 23.03.21. For some lines, there are change in the actual assessment, and for some it is indicated that the link should be excluded from the wire diagram
Selective species extraction	Habitats	2, change to 0	0.058	This should be 0, because this is covered under abrasion
	Benthos	2, change to 0	0.0399	This should be 0, because this is covered under abrasion
	Productivity	0	0	
	Zooplankton	1	0.0099	Exclude from wire diagram. < 3 % of max value. Also only tiny fishing targeting zooplankton currently.
	Fish	3	1.0399	

	Seabirds	2, change to 1	0.0201	Has been documented in coastal gillnet fisheries and longline fisheries, but probably not high rates in the man fisheries in the NwS (purse seine and pelagic trawl), should be 1
	Marine_Mammals	2	0.0225	
	Foodweb	2	0.13	
Contaminants	Habitats	1	0.0039	Exclude from wire diagram. < 3 % of max value.
	Benthos	1	0.0039	Exclude from wire diagram. < 3 % of max value.
	Productivity	0	0	
	Zooplankton	0	0	
	Fish	2, change to 1	0.024269	The major pelagic fish stocks have considerably lower levels of contaminants than marine mammals, should be 1
	Seabirds	2	0.264269	Levels close to known thresholds for effects found in cormorant eggs, justifying 2 (so no change)
	Marine_Mammals	2	0.264269	
	Foodweb	2, change to 1	0.0239	Downgrading from 2 to 1 as a magnitude smaller impact sum compared to seabirds and marine mammals which are both also link-2 categories. Levels in fish are lower.
Noise	Habitats	1	0.017134	Leave out of wire diagram, as this assessment seems questionable.
	Benthos	2	0.023834	Leave out of wire diagram, as this assessment seems questionable.
	Productivity	0	0	
	Zooplankton	1	0.008355	Leave out of wire diagram as impact is low compared with other class 1
	Fish	2	0.108039	
	Seabirds	1	0.006276	Leave out of wire diagram as impact is low compared with other class 1
	Marine_Mammals	2	0.108615	
	Foodweb	1	0.007134	Leave out of wire diagram as impact is low compared with other class 1
Abrasion	Habitats	2	0.0972	
	Benthos	2	0.0972	

	Productivity	0	0
	Zooplankton	0	0
	Fish	0	0
	Seabirds	0	0
	Marine_Mammals	0	0
	Foodweb	0	0
Litter	Habitats	1	0.000924
	Benthos	2	0.030624
	Productivity	1	0.000924
	Zooplankton	1	0.000924
	Fish	2	0.030624
	Seabirds	1	0.007224
	Marine_Mammals	1	0.008412
	Foodweb	1	0.000924

Table 15. Adjustment log for the EO Sector-Pressure-Linkage framework from meeting March 15th, 2021. Meeting was attended by Per Arneberg, Gro van der Meeren, Metter Skern-Mauritzen and Anna H. Olafsdottir.

Adjustment of noise:	
Vessel noise:	-Occasional, not persistent; on the grounds that there is not vessel noise in all areas at all times. -Local (< 50%) for vessel noise, not wide (>50%). -Reduce Degree of Impact from Chronic to Low for all other components than marine mammals and fish; no effect on productivity (here understood as primary productivity). -Seismic; around 3 months of the year; widespread and occasional; no effect on productivity.
Fishing noise:	-Not well represented by the framework; intensive impact over few months in at smaller locations; but the strongest impact of all due to removal of substantial biomasses that impact both the fish stocks and foodwebs across their distribution area. -Change from Local and Occasional to Wide and Persistent impact on foodweb and fish.
Adjustment pollution:	
	-Marine mammals, chronic, high TL organisms likely accumulating high levels of POPs and possibly other contaminants. -Seabirds, chronic, high TL organisms likely accumulating high levels of POPs and possibly other contaminants. -Fish, Low, as the dominating stocks, the pelagic fish, have modest levels of pollutants, higher levels are seen in some demersal fish (halibut), but overall "low" should be the right category here. -Foodwebs, low, reflecting possible impacts on the groups above. -Zooplankton, no effects, low TL organisms. -Primary production, no effects, low TL organisms. -Habitats, no effects, e.g. coral reefs low TL and little accumulation; -Benthos, no effects, largely same TL as pelagic fish where low levels of pollutants are seen.

References

Grefsrud, E., Karlsen, Ø., Kvamme, B.O., Glover, K., Husa, V., Kupka Hansen, P., Grøsvik, B.E., Samuelsen, O., Sandlund, N., Stien, L.H., Svåsand, T. 2021. Rapport fra havforskningen Risikorapport norsk fiskeoppdrett 2021-8 ISSN: 1893-4536.

ICES. 2019. Working Group on Ecosystem Assessment of Western European Shelf Seas (WGEAWESS). ICES Scientific Reports. 1:64. 75 pp. http://doi.org/10.17895/ices.pub.5604

Pedreschi, D., Bouch, P., Moriarty, M., Nixon, E., Knights, A.M., Reid, D.A. 2019. Integrated ecosystem analysis in Irish waters; Providing the context for ecosystem-based fisheries management. Fisheries Research, 209, 218-229.

Supplementary Information.

Assessment table with ODEMM scoring and comments on the assessment from the workshop are available at WGINOR sharepoint:

1) Results of workshop February 1st, 2021:"Linkage Framework TEMPLATE_Stage 1 WGINOR WK Combined.xlsx"

2) Final results after ODEMM scoring adjustments at meetings in March 2021: "Pressure Assessment TEMPLATE Stage 2 Norwegian Sea v3_adjusted_after_WK.xlsx"

3) Conversion of ODEMM final results into ICES EO wire diagram table: "EO wire table summarized.xlsx".