WORKING GROUP ON THE INTEGRATED ASSESSMENTS OF THE NORWEGIAN SEA (WGINOR; outputs from 2021 meeting)

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

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

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Editors

Per Arneberg • Anna H. Ólafsdóttir

Authors

Johanna Aarflot • Tycho Anker-Nilsen • Sigurvin Bjarnason • Knut Yngve Børsheim • Cecilie Broms Lucie Buttey • Sólvá K. Eliasen • Anne Kirstine Frie • Eydna Homrum • Jan Arge Jacobsen • Mimi E. Lam Lísa Libungan • Xiaozi Liu • Gro van der Meeren • Kjell Arne Mork • Erik Askov Mousing • Leif Nøttestad Guðmundur Óskarsson • Hildur Pétursdóttir • Benjamin Planque • Warsha Singh • Øystein Skagseth Aril Slotte • Petur Steingrund • Espen Strand • Szymon Surma • Kjell Rong Utne • Antje Voelker

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Contents

Annex 3: Norwegian Sea ecosystem status summary 2021

This document gives a short summary of the current state and recent change of different compo-nents of the Norwegian Sea ecosystem while also briefly discussing possible causes of change. It was issued for the first time in 2021 (2020 meeting) and is planned to be updated annually. The ecosystem status summary is intended for a wide audience, including scientists, teachers, stu-dents, decision-makers, and the public interested in the Norwegian Sea ecosystem and marine environmental issues in general. It is prepared by the ICES working group on integrated ecosys-tem assessment for the Norwegian Sea (WGINOR). It is a summary of the scientific information prepared by the group and does not constitute ICES advice.

**Please note that this annex has its own reference list to make the text easily accessible for a non-scientist audience.

Highlights

- The recent 3-4 years trend of colder and fresher Atlantic inflow into the Norwegian Sea has ceased; however, the extent of Arctic Water is still increasing.
- Annual primary production was higher and spring blooms lasted longer for the period 2013-2020 compared to earlier years of time series which begins in 2003. Possible cause is increased inflow of cold and fresh Arctic water.
- Zooplankton biomass declined from around mid-2000´s and has since remained at a lower level.
- The biomasses of Norwegian spring-spawning herring increased in the last year, follow-ing the recruitment of a strong year class. Mackerel and blue whiting biomasses contin-ued to decline as in recent years. Recruitment of blue whiting is estimated to be higher in 2020 and 2021 than during the three previous years.
- Pelagically feeding seabirds breeding along the Norwegian coast have declined substan-tially since the start of monitoring in 1980, and common guillemot is at high risk of ex-tinction as a breeding species in the area.
- Information on marine mammals is not updated in this summary.

Graphical summary

	Topic	Overall trend	Situation in 2021	Certainty	Possible implications
	Ocean climate	General warm and saline conditions prevailed from the early 2000s until 2015-2016. The recent 2017-2019 trend of colder and fresher Atlantic inflow into the Norwegian Sea has ceased. However, the extent of Arctic Water is still increasing.	The recent 3-4 years trend of colder and fresher Atlantic Inflow into the Norwegian Sea has ceased. The extent of Arctic Water continues to increase.	Highly certain: dedicated monitoring with good spatial coverage exists.	The recent increase of Arctic Water may lead to increased new production due to relative high winter nutrient concentration.
	Primary production	Annual primary production was on average 30% higher and length of spring bloom on average 17 days longer for the period 2013-2020 compared to 2003-2012. Start of spring bloom varied from April 25 to June 13 with no temporal trend.	Comparable to the 7 preceding years	Highly certain: the phytoplankton estimates are based on satellite data covering the whole productive season with high geographic resolution.	Increased primary production may have led to increased food resources for herbivores 2013-2020.
	Zooplankton biomass	The spring biomass of mesozooplankton was at a higher level from 1995 to mid-2000s and has been at a lower level afterwards. Summer biomass shows an increasing trend during the last 10 years, except for the last year(s).	Biomass in 2021 was at the same level or decreasing compared to the last years. Summer biomass showed the larger decrease.	Moderately certain: plankton is patchily distributed, which leads to uncertain estimates.	Reduced zooplankton biomass may have caused reduced food resources for planktivorous feeders, including pelagic fish in the recent decade.
	Zooplankton spatial distribution	The spring distribution of zooplankton has changed from higher biomasses in Arctic water in the west to become evenly distributed in the Norwegian Sea.	In 2021 the zooplankton was evenly distributed both in spring and summer, but with some confined high-concentration areas.	Moderately certain: The spatial distribution reflects and is affected by the timing of the survey and the timing of the zooplankton seasonal development.	Changes in the spatial distribution of plankton can affect the spatial distribution of planktivorous fish.

	Topic	Overall trend	Situation in 2020	Certainty	Possible implications
	Pelagic fish biomass	The spawning biomass of Norwegian spring-spawning herring increased in the last year after a decade of decline. Spawning biomass of mackerel and blue whiting continue declining as in recent years.	Herring spawning biomass increased by 12% whereas mackerel spawning biomass declined by 11% and blue whiting by 17% compared to previous year. Fishing remains above scientific advice in all stocks.	Highly certain for herring and blue whiting, moderately certain for mackerel: estimates are based on quantitative stock assessments.	Changes in pelagic fish biomass have direct implications for fisheries opportunities.
	Pelagic fish spatial distribution	In the mid-2000´s mackerel distribution began expanding westward, into Icelandic and Greenlandic waters but has retracted since 2015 resulting in majority of the mackerel stock feeding in the Norwegian Sea.	No mackerel in Greenlandic waters and low levels in the south-eastern part of Icelandic waters in 2021, as observed in 2020.	Highly certain: based on ecosystem surveys in the Nordic Seas in spring (May) and summer (July)	Changes in pelagic fish spatial distribution have 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 bird colonies are at risk of extinction, and some have already disappeared.
	Marine mammals	Information not updated for 2021			

Climate

Current status and recent changes

Variation in ocean climate is important for the state of the 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].

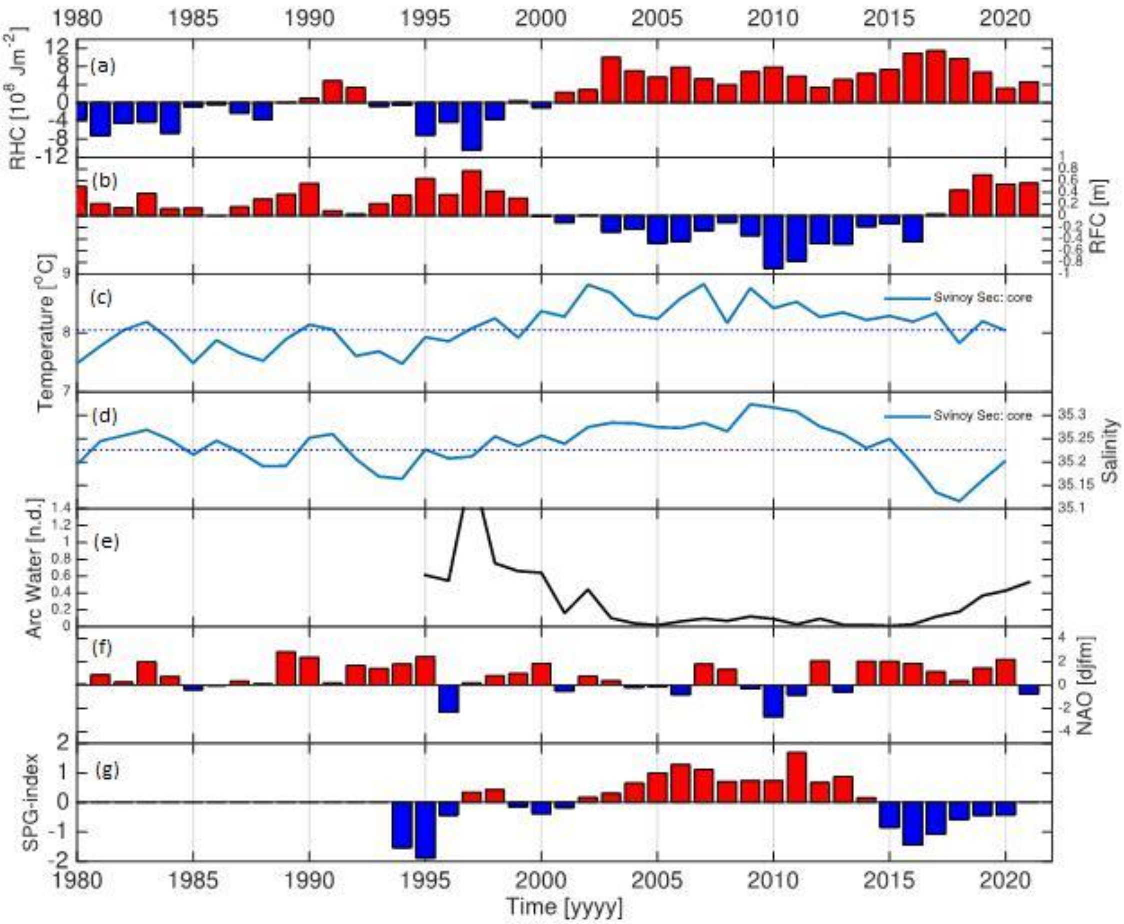


Figure 1. A subset of climate indicators for the Norwegian Sea: a) Relative heat content (RHC) and b) Relative Freshwater Content (RFC); Svinøy section Atlantic Water core c) temperature and d) salinity; e) Arctic Water amount in the Norwe-gian Sea, f) The North Atlantic Oscillation (NAO) winter index, and g) the Sub-polar Gyre (SPG) index (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 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 with only a minor decrease in heat content. The inflowing Atlantic water, which is monitored in the Svinøy section (at about 63°N) 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 in a low state since about 2003, has shown a consistent increase since 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 sub-polar gyre is located south of the Norwegian Sea, centered in Labrador Sea and Irminger Sea. 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 in-creased amounts of cold and fresh water from the western part of the North Atlantic eastward into the Iceland Basin and the Rockall plateau diluting the warm and saline water of the North Atlantic Current south of the Greenland-Scotland ridge. This causes 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 sub-polar gyre tends to be strengthened, and inflowing Atlantic water thus becoming colder and fresher. At the same time, ocean to air heat loss in the Norwegian Sea 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 sub-polar 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) and a major freshening of the inflowing Atlantic Water. Note that the NAO-index changed to nega-tive value in 2021. The overall freshening is also influenced by eastward expansion of Arctic Water into the Norwegian Sea. There are indications that the influence of the East Icelandic Cur-rent, that brings Arctic Water from the Iceland Sea to the southern Norwegian Basin, has in-creased in recent years.

Phytoplankton

Current status and recent changes

The primary production rates are calculated based on variables (e.g. colour) measured by the MODIS satellite[3] and represent the production available to other organisms in the ecosystem.

The annual primary production estimates from the last eight years of the satellite observation period (2003-2020) were higher compared to earlier years by approximately 30% (Figure 2). In addition, the length of the spring bloom increased on average by 17 days (data not shown). Longer spring blooms are associated with longer grazing period and consequently higher input of organic matter and energy into the pelagic food web[4].

The start of the spring bloom varied between April 25 and June 13 in the whole period, and there was no obvious relation between annual primary production and the start day of the spring bloom.

Possible reasons for recent changes

Increased flow of fresh Arctic water into Nordic Seas has increased stability of surface layer stratification[6]. More stable stratification may be the main reason for the higher productivity observed from 2013 onward. The production rates from the later part of the period suggest a more favour-able situation for herbivores compared to earlier years. It should be noted that the time interval covered by the satellite data is too short to distinguish long time trends from natural variation[5].

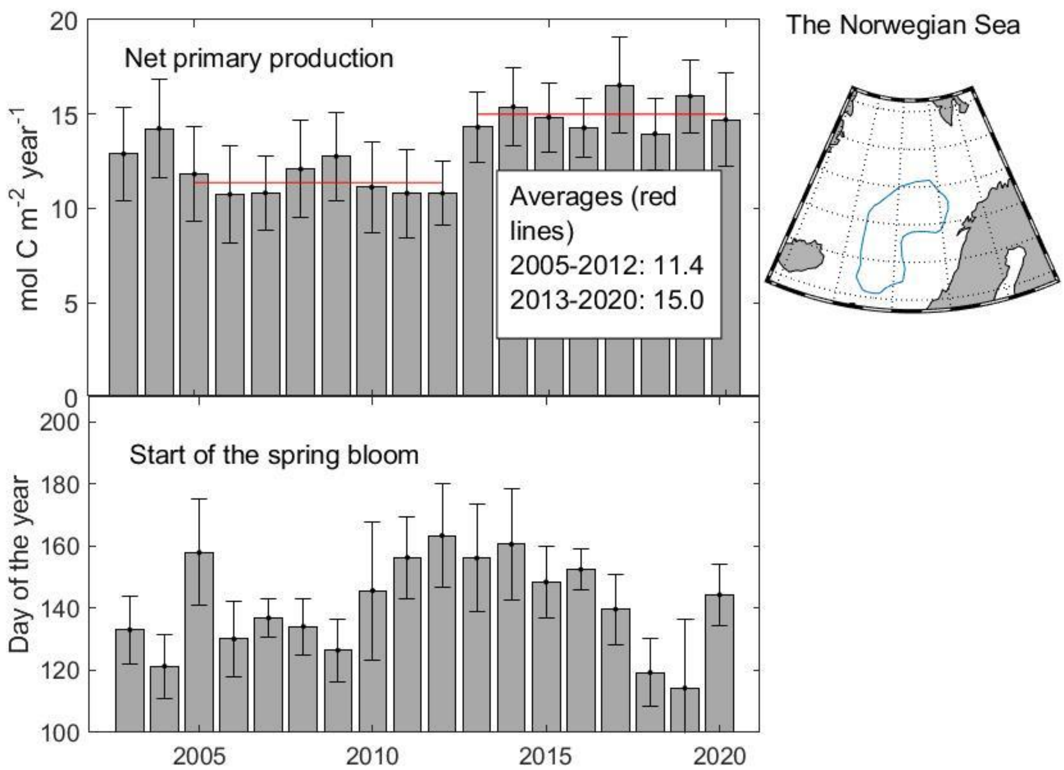


Figure 2. Estimated net yearly primary production (upper panel) and date for the start of the spring bloom (lower panel) in the Norwegian Sea. The inlet on the top-right shows the geographical region over which satellite data is compiled (blue polygon).

Zooplankton

Current status

The zooplankton biomass indices in all sub-areas in the Norwegian Sea in spring (May) were at the same level in 2021 as the year before, except for a small decrease in the northern Norwegian Sea including the Lofoten Basin. In summer (July and August), however, a decrease was observed in all areas and particularly in the Jan Mayen front and southern Norwegian Sea including the Lofoten Basin. Comparing the 2021-value between areas, the biomass indices were at similar levels in all sub-areas both in spring and summer.

Recent changes

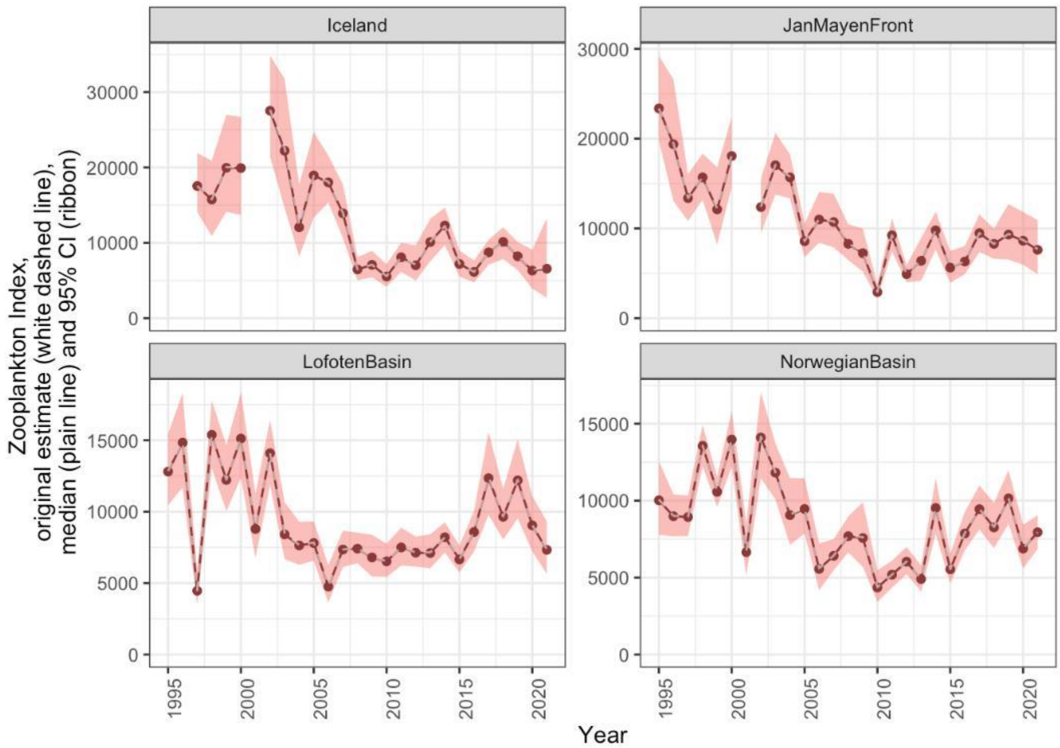
There have been two main changes in spring zooplankton biomass during the last three decades:
1) The long-term biomass level has decreased in all sub-areas, and 2) the previously higher zooplankton level in Arctic water northeast of Iceland has been reduced to the same level as in the Atlantic water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

For the period 1995 to mid-2000s the plankton indices in spring were relatively high, with fluctuations between years (Figure 3a). Since around mid-2000 the indices decreased and have since been at lower levels. The largest decline has taken place in Arctic water east of Iceland, where the reduction has been approximately 58 % from the "high-biomass" period to the "low-bio-mass" 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 11 years) and showing a tendency of 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 sec-tion) 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.

a)



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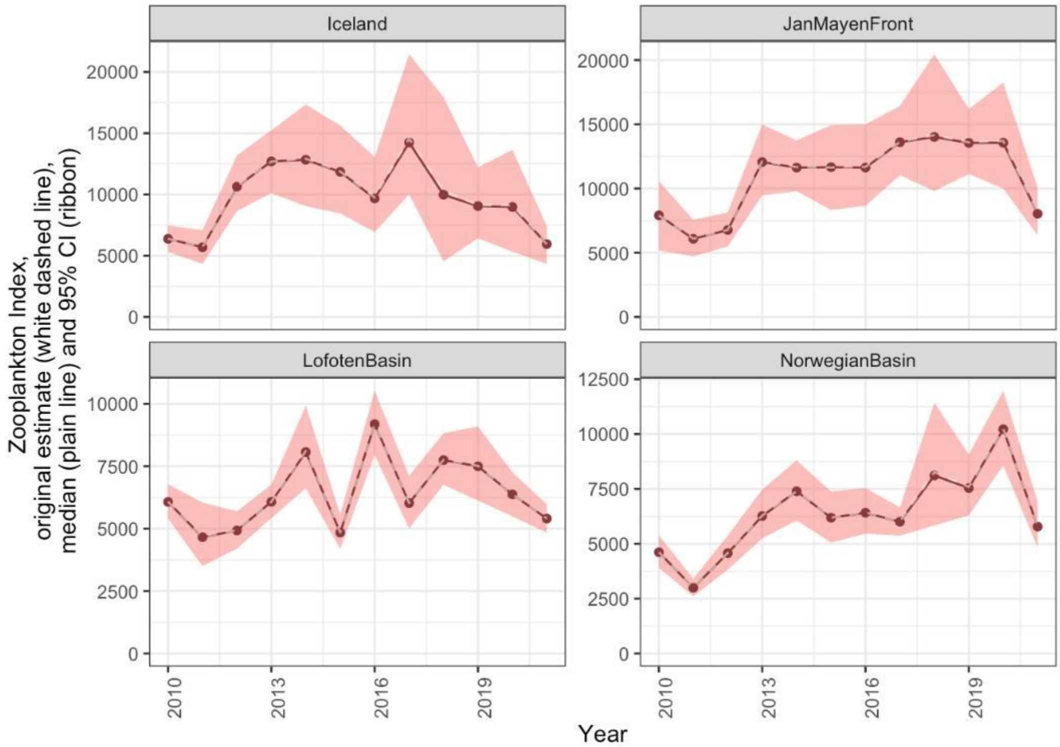

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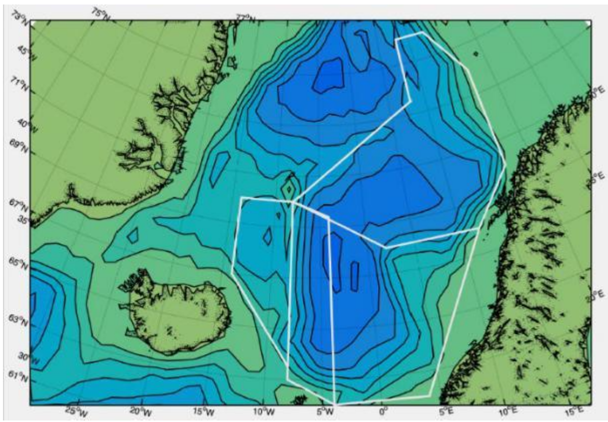


Figure 3. Indices of zooplankton biomasses (mg dry weight m^{-2}) in the upper 200 m of the water column in the Norwegian Sea and adjacent waters, a) in May during the time period 1995-2021, b) in July/August during the time period 2010-2021. The total area has been divided into 4 sub-areas, shown in panel c); the area east of Iceland (upper left), the Jan Mayen Arctic front (upper right), the Northern Norwegian Sea including the Lofoten Basin (lower left), and Southern Norwegian Sea including the Norwegian Sea Basin (lower right).

Pelagic Fish

Current status

Three fish stocks dominate the pelagic ecosystem of the Norwegian Sea: Norwegian spring-spawning herring (NSS, *Clupea harengus*), Northeast Atlantic (NEA) mackerel (*Scomber scombrus*), and blue whiting (*Micromesistius poutassou*). In 2021, estimated spawning stock biomass (SSB) was similar for all three stocks, ranging from 3.4 to 3.8 million tonnes. Combined SSB for all three stocks was 10.7 million tonnes [10](Figure 4).

Combined catch of the three stocks was 3.2 million tonnes in 2020, of which approximately 1.5 million tonnes was blue whiting, 1 million tonnes was mackerel, and 0.7 million tonnes was her-ring. 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 [10]. Mackerel exploitation is within limits for maximum sustainable yield, however the up-per boundary of the 95% confidence interval for fishing mortality is higher than maximum sus-tainable yield fishing mortality [10]. Stock status, for all three stocks, is good since SSB is above all biological reference points related to the risk of impaired reproductive capacity. However, her-ring SSB is very close to biological reference limits, as the 95 % SSB confidence limits include the reference limits [10].

Recent changes

The 2021 stock assessment results show an estimated 12% increase in herring SSB in 2021 com-pared to 2020, after a decade on continuous decline with an overall estimated decline of 52% [10]. Mackerel SSB continue declining in 2021 and has declined by an estimated 37% from peak stock size in 2014-2015 [10]. Blue whiting SSB also declined in 2021 compared to previous years and was estimated to be 43% lower than at the last peak size in 2017 [10].

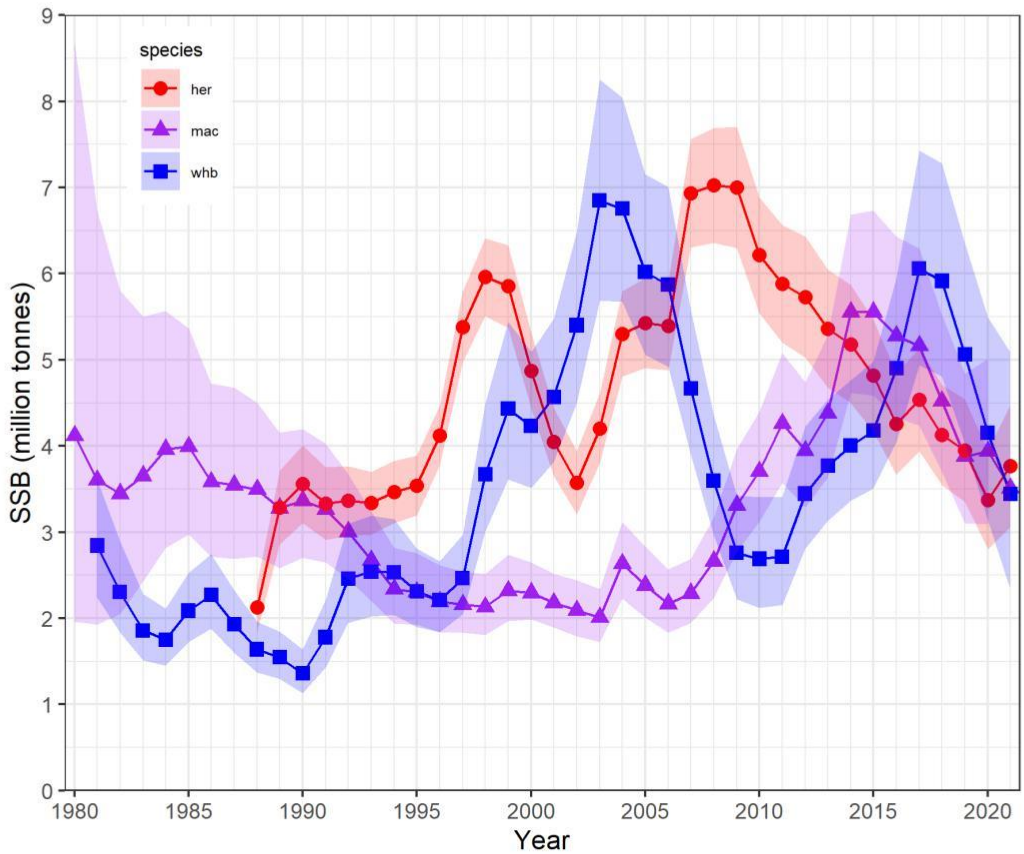


Figure 4. Estimated spawning stock biomass (lines) including 95% confidence intervals (shaded areas) for Norwegian spring-spawning herring (red filled circles), mackerel (purple filled triangles) and blue whiting (blue filled rectangles) from 1980 to 2021 [10].

Mackerel distribution in the Nordic Seas in summer 2021 was similar to observed distribution in summer 2020 and the western boundary of the distribution was limited to the east coast of Ice-land [11]. The distribution of blue whiting in 2021 was similar to the most recent years [12]. The dis-tribution area of herring in May was similar to the most recent period. The large 2016 year-class is now largely distributed throughout the geographical distribution range of the mature herring stock [13]. In July, however, the herring had shifted farther east and north; particularly five-year-old herring was distributed north-easterly [11].

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 in between (Figure 5). 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 (*i.e.*, in 2023). Fishing above advised level has accelerated the stock decline during a period of low recruitment. Since 2013, when sharing arrangements in fisheries were no longer agreed upon, annual commercial catch has on average been 31% higher than the advised total allowable catch (TAC). The increase in SBB in 2021 is due to increase in maturity of the large 2016 year-class from 10% mature at age 4 in 2020 to 60% at age 5 in 2020, and a small upward revision of this year-class [10].

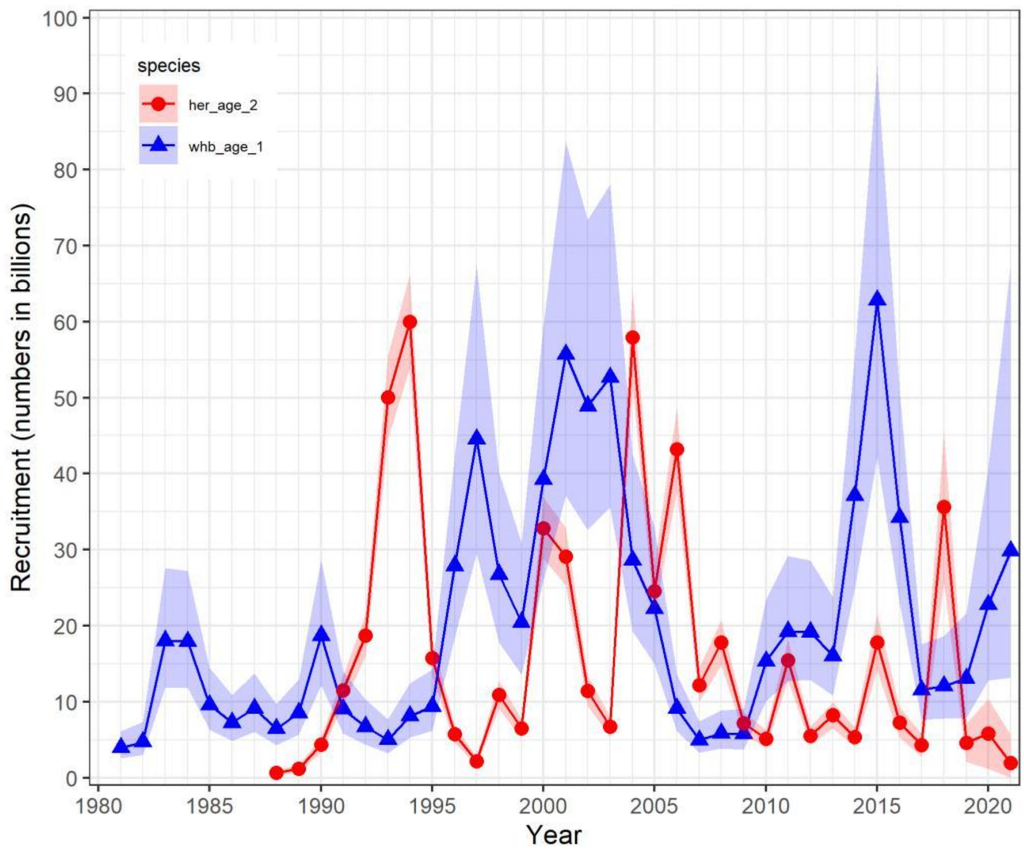


Figure 5. Estimated year-class size at recruitment for Norwegian spring-spawning herring (age 2; red filled circle) and blue whiting (age 1; blue filled triangle) from 1981 to 2021 [10].

The 2021 assessment of the mackerel stock included an upward revision of SSB and a downward revision of fishing mortality which reduced the perception of stock decline [10]. Changes in assess-ment perception of the stock is due to changes in relative weights of data sources in the assess-ment model. Estimates of mackerel recruitment at age 0 are highly uncertain and are thus not presented here. Mackerel year-class strength appears to be established when mackerel enter the fishery at age 2-3 years [10].

Since mackerel abundance peaked in 2015, the annual commercial catches have on average been 37% higher than the scientific advise [10]. Fishing above advised TAC repeatedly over years con-tributes to the observed decline in spawning stock size.

Blue whiting's sharp decline in SSB since 2017 is caused by excessive fishing, with catches exceeding the advised TAC by 25% since 2017, in combination with low recruitment in 2017-2019. However, improved recruitment in 2020 and 2021 are estimated to be higher than the three previous years, and these recruits will mature and contribute to the SSB already in 2022.

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 stock also has the capacity to recover quickly when recruitment is high as stock fluctuations in early 2000's and late 2010´s show.

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 a third, zooplankton abundance has remained within the range observed during period of macke-rel presence, and the western area remains warm enough for mackerel presence (> 8-9 °C [10]).

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.

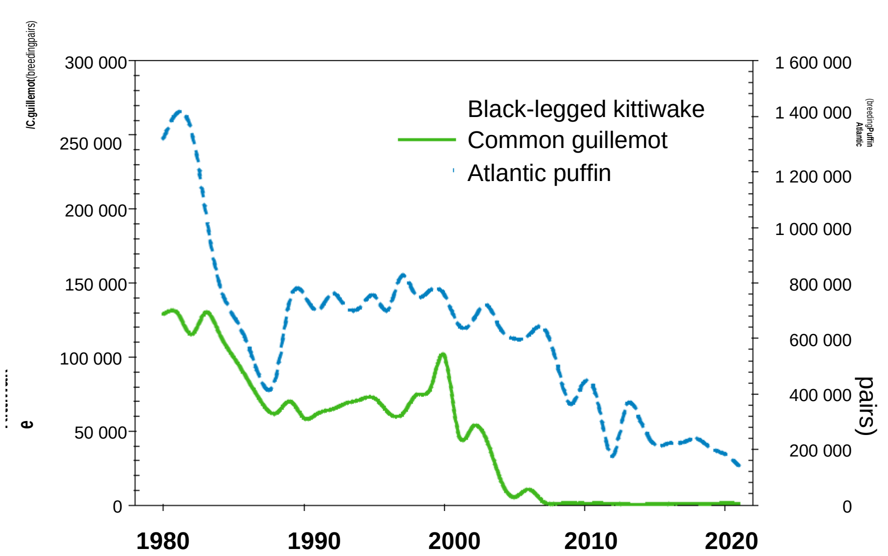
For the three pelagic species, time-series of their population development in the eastern Norwegian Sea (Figure 5a) were derived from their estimated breeding numbers in 2013[14] and annual monitoring of trends in selected breeding colonies (Runde (62.4°N), Sklinna (65.2°N), Røst (67.5°N) and Anda (69.1°N, 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 puf-fins and < 1000 pairs of common guillemots. Monitoring started in 2011, and has been done for common guillemot only, showing a declining trend.

The breeding population of kittiwakes in the eastern Norwegian Sea has declined by 81% since monitoring started in 1980. Its outlook is grim, with several large colonies already gone extinct and many more risking extinction within a few decades. In the same area and period, the breed-ing population of puffins has declined by 78% 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 b and c) 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 81% since the first counts in the mid-1980s. In contrast, shag populations in both colonies monitored in-creased from the mid-1980s to around 2005 but have decreased markedly thereafter.

a)



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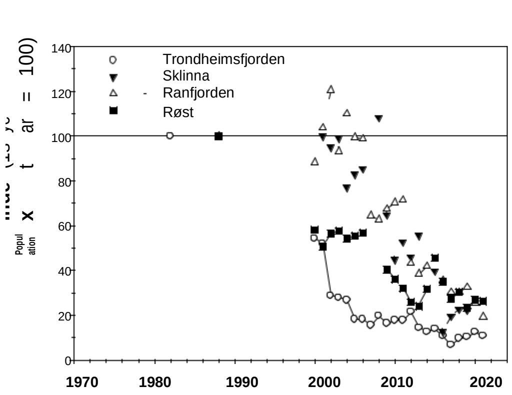

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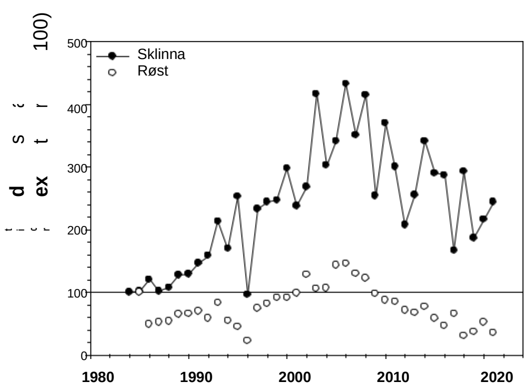

Figure 5. Population trends for seabirds breeding in the Norwegian part of the eastern Norwegian Sea since 1980, divided by (a) pelagic feeding species black- legged kittiwake (red line), common guillemot (green line) and Atlantic puffin (blue line) (upper left), (b) coastal benthic feeding common eider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

Possible reasons for recent changes

The largest changes in seabird numbers in the eastern Norwegian Sea are linked to ocean climate variability[15,16] and most likely mediated through substantial changes in prey abundance and availability with dire consequences for reproductive success and recruitment[17-22]. To some degree, this has also affected survival rates[23-25], which in addition can occasionally be severely hit by extreme weather events[26-28]. 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[21,29,30] and increased predation from white-tailed eagles[31,32], as well as contaminants (e.g., Bårdsen et al 2018[33]) and human disturbance[34]. The magnitude of seabird bycatch in some of Norway's most important fisheries has also been quantified in a series of recent studies[35,36].

Marine mammals

Information on marine mammals is not updated in this year's summary.

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Annex 4: Work on time series

On ecosystem components including climate indices

At the 2020 WGINOR meeting, the group initiated a discussion on which time series should be included in the work. A follow-up meeting was held on 18 February and the discussions contin-ued at the 2021 annual meeting. The output is the following:

The time series are going to be used to address to address the following issues:

1. Assess the overall state of key activities, pressures and components of the ecosystem (in-cluding climate)
2. Assess recent change of these key activities, pressures and components.
3. Assess unexpected changes in activities, pressures and ecosystem
4. As input to ecosystem assessment models
5. Providing input for direct management advice

Candidate time series for assessing the overall state of components of the ecosystem including climate are given in table A1. The list is not exhaustive and may include also time series on bio-mass of mesopelagic fauna as well as pelagic fish growth indexes. Also, this should be supple-mented with time series on human activities and pressures as outlined in input from the Mission Atlantic project.

Table A1. Candidate time series for assessing the overall state of components of the ecosystem, including climate

Theme	Ecosystem component	Time series
Climate	Heat content	Heat content in Atlantic water masses Temperature in Svinøy section
	Freshwater content	Freshwater content index
	Sub-polar gyre	SPG index
	Atmospheric conditions	NAO index
	Arctic water	Arctic water index
Phytoplankton	All species	Total new production
		Timing of spring bloom
Zooplankton	Mesozooplankton biomass	Mesozooplankton biomass
	Krill biomass	
Pelagic fish	Herring	Herring SSB
	Blue whiting	Blue whiting SSB
	Mackerel	Mackerel SSB
Seabirds	Atlantic puffin	Atlantic puffin breeding population
	Common guillemot	Common guillemot breeding popu-lation

	Black-legged kittiwake	Black-legged kittiwake breeding population
Marine mammals	Minke whale	
	Seals (which species?), sugges-tion to add hooded seals and harp seals	
	Other?	

Candidate time series for issue (2) (recent change) should include the series used to assess overall state for key components, activities and pressures described above as well as those used to assess unexpected changes below.

Time series for assessing unexpected changes should be for ecosystem components, activities and pressures that can change rapidly. Seabird breeding population is an example of a type of series that is not relevant here, as the species are long-lived and population sizes change slowly. Seabird recruitment estimates, on the other hand, are good candidates, as they can change mark-edly from year to year, also for long lived species. Candidate time series for ecosystem compo-nents are shown in table A2 (not an exhaustive list). This should be supplemented with time series on human activities and pressures as outlined in input from the Mission Atlantic project.

Table A2. Candidate time series for assessing the unexpected change in components of the ecosystem, including climate

Theme	Ecosystem component	Time series
Climate	heat loss?	Any time series reflecting this? NAO
Phytoplankton	All species	Any relevant here? Both of the ones above? We need something sensi-tive that is also of ecosystem signif-icance. Would be nice to have a time series on species composition
Zooplankton	Mesozooplankton biomass	Does not seem to change fast
	Krill biomass	
Pelagic fish	Herring	Herring recruitment
	Blue whiting	Blue whiting recruitment
	Mackerel	Mackerel recruitment
Seabirds	Atlantic puffin	Atlantic puffin recruitment
	Common guillemot	Common guillemot recruitment
	Black-legged kittiwake	Black-legged kittiwake recruitment
Marine mammals	Seals	Pup production, for hooded and harp seals?

Candidate time series for issues (4) and (5) have not been drawn up yet.

The following notes were made about time series that needs to be revised:

- Herring weight-at-age and length-at-age currently for age 6 which is young for as fully recruited to spawning stock at age 7. Select older age. Need to find correct reference for time series and add 95% confidence intervals to mean calculations.
- Blue whiting weight-at-age and length-at-age currently for age 6 which is old as majority of fisheries fish age ~2-5yr. Need to find correct reference for time series and add 95% confidence intervals to mean calculations.

It was also noted that it should be considered to add time series for geographical distribution range of the 3 pelagic fish stocks in the Norwegian Sea from the pelagic survey IESNS and IESSNS. IESNS from 1995 and IESSNS 2007 and 2010 onward.

Other notes from the meetings include:

- Climate core series are needed that should not be missed and that can be updated every year. It should be possible to obtain these from the Working Group on Operational ocean-ographic products for fisheries and environment (WGOOFE).
- When data comes from other groups, data source must be identified so that it can be tracked to original source (see also the section on management of the time series).
- Discussion on new series to include should be done regularly.
- It should be considered whether data on krill biomass can be addressed through the Working Group of International Pelagic Surveys (WGIPS).
- For modelling purposes, data on size fractions for mesozooplankton and on amphipods are needed, but this is fragmented and available only recently.
- For marine mammals there are uncorrected (i.e., not corrected for diving time) data on sperm whales, but not separate estimates for the Norwegian Sea. Data with good quality on minke whales, hooded seals and harp seals are available. It is suggested not to include coastal species if they do not occur beyond the coastal region (e.g., grey seals and harbour seals should not be included).

On human activities, based on input from the MISSION ATLANTIC project

MISSION ATLANTIC (MA) takes a fully holistic and integrative approach to assess the state of the whole Atlantic: no pressure or ecosystem component is excluded. This is performed by op-erationalizing Integrated Ecosystem Assessment at regional scale in the Atlantic Ocean and providing a synthesis at basin scale. One of the MA case studies corresponds to the Norwegian Sea offshore ecoregion and several time series have been gathered to describe the main human activities affecting the area.

Fishing activity is described by using series of total catch value and first-hand price for the main pelagic species (Herring, mackerel and blue whiting), the main demersal species (Cod and Had-dock) as well as Atlantic redfish. This information is made available by the Norwegian direc-torate of fisheries from 1995 to 2020. Catch data from the Norwegian Sea ecoregion are currently being compiled and will be use in the future as well as MSC certifications as in indicator of the respectability of each fishery. In addition, common minke whale **hunting** is described by the annual total catches (number of individuals). To describe the **Non-renewable exploration and extraction** we used data on the Gas and Oil production as well as information about the extent of the seismic prospection. This information is provided by the Norwegian petroleum directorate from 1970 until actuality, however it is aggregated for all the Norwegian territory. Series to de-scribe **shipping** have been made available at havbase.no and are available from 2010 to the ac-tuality. Finally, the a**quaculture** sector has been included for the risk represented by longdistance transported nutrients and contaminants. To follow the evolution of this sector the Norwegian directorate of Fisheries provide time series about the number of active Licenses.

Documentation and evaluation

The ICES Working Group on Common Ecological Reference Points (WGCERP) was established in 2019 and met in 2019 and 2021. The aim of WGCERP is to review and evaluated ecosystem indicators and reference points to support IEAs. In 2019 WGCERP reviewed a large number of ecosystem indicators and reference points used in different institutional frameworks (EU-MSFD, OSPAR, HELCOM, Norwegian management). In 2021 the group focused on developing concep-tual representations of how ecological indicators and reference points are linked to ecosystem dynamics and the management of human activities. WGCERP is developing a questionnaire-based framework to support this. Key attributes of indicators and reference points that are ad-dressed by this questionnaire include:

1. link of the indicator/RP to dedicated management actions
2. drivers of change of the indicator
3. link of the indicator/RP to other management actions
4. revision of the RP in the face of new data/observations
5. uncertainty estimates if the indicator/RP
6. possibility for projection/forecast of the indicator
7. existence of an operating/observation model for the ecosystem-indicator
8. monitoring and update of the indicator value

These attributes are proposed as a support to evaluate/prioritise the time-series used in WGINOR.

Management of time series

A framework based on GitHub will be used to manage the WGINOR time series. Before the annual meeting in 2022, meetings with WGINOR members will be held to work with this. Licences must be set up for every data provider and format for the data identified. Both these issues will be discussed with the ICES data centre. To begin with, the framework will be tested for three examples time series on herring, zooplankton and abiotic factors, respectively. Relevant members of WGINOR will contribute to this (Lísa Libungan, Sigurvin Bjarnason, Cecilie Broms and Øystein Skagseth). The issue will be brought up for presentation and discussion at the 2022 annual meeting.

Annex 5: Methods for IEA

WKINTRA

Three ICES Workshops on integrated trend analysis to support integrated ecosystem assessments (WKINTRA) have been conducted in 2018, 2019 and 2021. The aim of these series of work-shop is to develop good practices in the application of integrated trend analyses (ITA) and inter-pretation of their results to support IEA. So far, WKINTRA has reviewed ITA methods currently in use by IEA groups and developed a simulation-based approach to evaluate ITA methods. WKINTRA provided 7 main recommendations towards IEA groups, which are relevant to the work of WGINOR. These are:

1. clear specification of the objective when applying ITA methods
2. increased transparency and traceability of the methods used
3. explicit consideration of input data uncertainties
4. methods for detecting extreme events (such as heatwaves)
5. harmonisation in the reporting of ITA outputs
6. generalisation of the evaluation of ITA method performance
7. peer-reviewing of ITA methods across IEA groups

Panel-based assessment of ecosystem condition (PAEC)

The panel-based assessment of ecosystem condition (PAEC) is an evidence-based approach to assess ecosystem condition. The assessment is carried out by an expert panel with broad expertise in the ecosystems to be assessed and is inspired by approaches used in international assessments such as IPCC and IPBES. The assessment follows a developed protocol (Jepsen et al., 2020). For the ecosystem to be assessed, a list of **indicators** of change in ecosystem condition in response to anthropogenic drivers is developed. The indicators fall within seven main **ecosystem charac-teristics**: *primary production, biomass distribution among trophic levels, functional groups within trophic levels, functionally important species, biological diversity, landscape ecological patterns, and abi-otic factors*. The expected change in indicators in response to anthropogenic drivers are termed **phenomena**, and their selection is based on published literature, including reference to the con-fidence of a change being observed in response to anthropogenic drivers and the mechanism leading to a deterioration in ecosystem state. Datasets to quantify each indicator are identified and collated and the quality of each dataset is assessed in terms of its spatial and temporal ap-propriateness.

In the first assessment step, the **validity** (VP) of each phenomenon is scored and used to infer confidence in the causal relationship between changes in the indicator and anthropogenic drivers. The next step is an evaluation of the biological and statistical significance of the evidence for the occurrence of each phenomenon, termed **evidence** (EP) of the phenomenon. The third step is a consolidated assessment of the ecological state based on the associated indicators and phe-nomena, first for each ecosystem characteristic, and subsequently for the ecosystem as a whole. The assessment is based on the validity, the quality of the evidence, and the data quality for each phenomenon. This provides a qualitative assessment of deviation from the reference condition of "no deviation", "limited deviation" or "substantial deviation". The assessments are each sup-ported by narrative accounts.

A pilot assessment has been carried out for the Arctic part of the Barents Sea (Jepsen et al., 2019), and operational assessments are now done for this ecosystem, the Sub-Arctic part of the Barents Sea, the North Sea and the pelagic ecosystem in the Norwegian Sea.

Annex 6: Results from flagged observation analyses

The method for flagged observation analyses is described in the report with output from the annual WGINOR meeting in 2020 (ICES, 2021). The main outline of the method is illustrated in figure A.7.1. Principles for communication from flagged observation analyses are shown in figure A.7.2. The main objective with the flagged observation analyses is to identify observations that deviate substantially from expected trends and therefore warrant closer scrutiny and/or spe-cial attention in communication with stakeholders and other users of WGINOR results. These will be seen as located outside the forecast bands, and it is the observations from the three last years that is assessed. Below, results from flagged observation analyses are shown for 51 time series gathered by WGINOR (figure A.7.3). Assessments were made both for forecast bands based on 80% prediction intervals and 95% prediction intervals (see figure A.7.2). There were no observations outside the 95% predictions intervals for any of the 51 time series, meaning that none of the observations for the last three years fall outside the expectations for these years drawn up by the trend analyses. Thus, no observations were flagged for special attention in the assessment or for communication with stakeholders using this method.

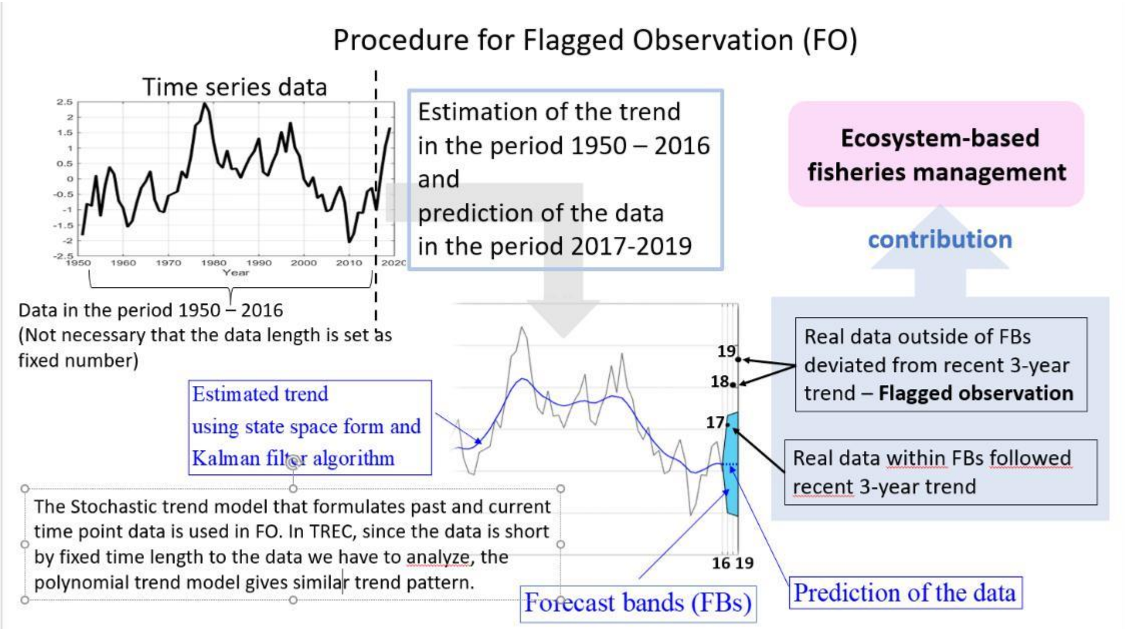


Figure A.7.1. General outline of the method for flagged observation analyses, see (ICES, 2021) for details.

Communication for flagged observation (FO) analysis

Predicted values help to image possible future and forecast band of the predicted value gives a range of values the random variable could take with relatively high probability. For example, a 95% prediction interval contains a range of values which should include the actual future value with probability 95%.

Therefore, the 95% and 80% prediction intervals for the predicted values are plotted to know how much the real observation in predicted years is associated with expected range. If the observation locates within narrow band, the data is interpreted to follow the trend presenting tendency from the past more.

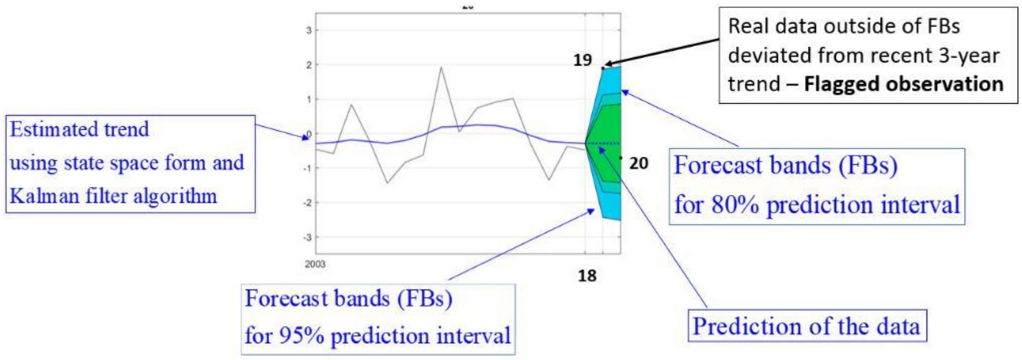
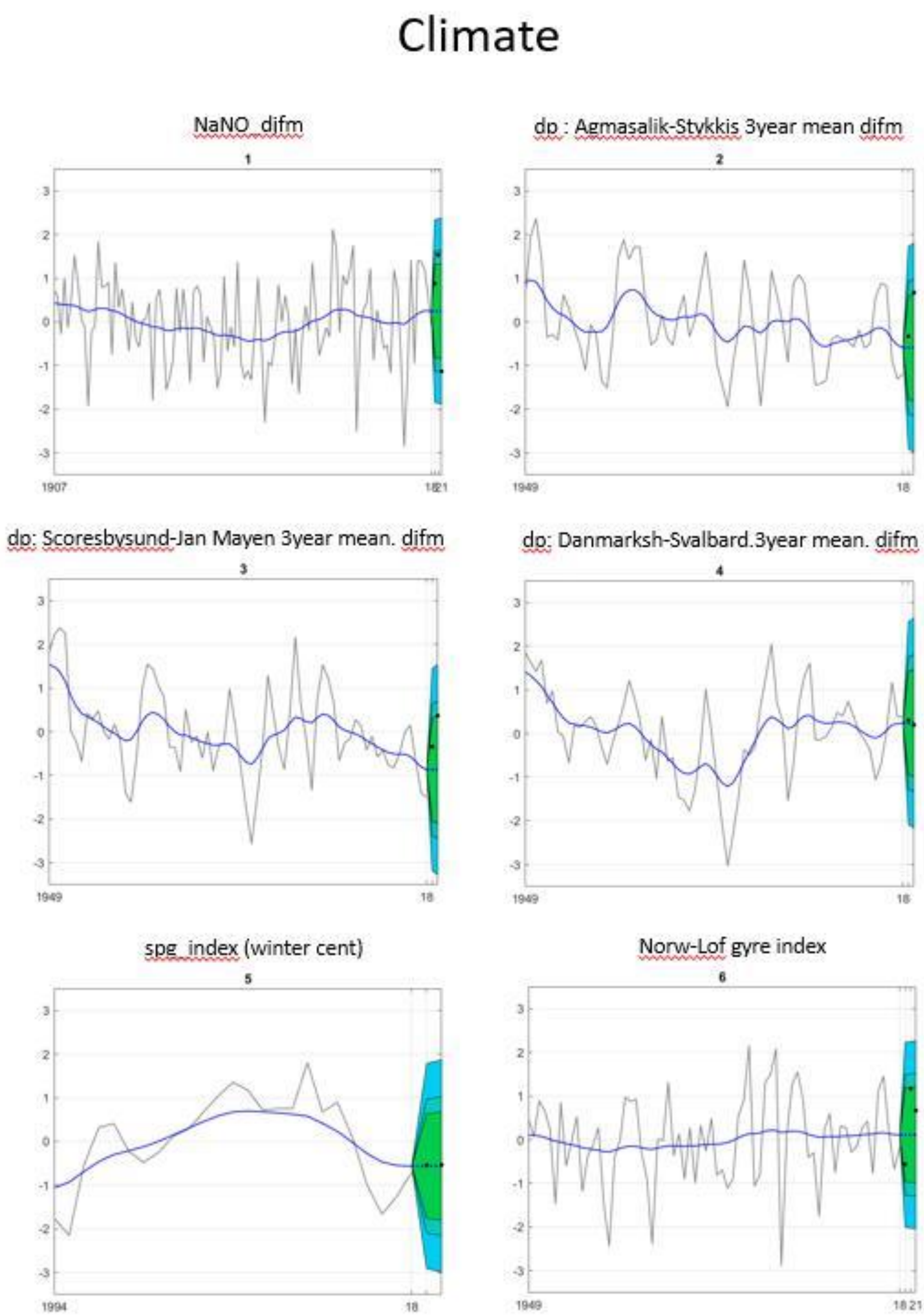


Figure A.7.2. Principles for communication from flagged observation analyses.



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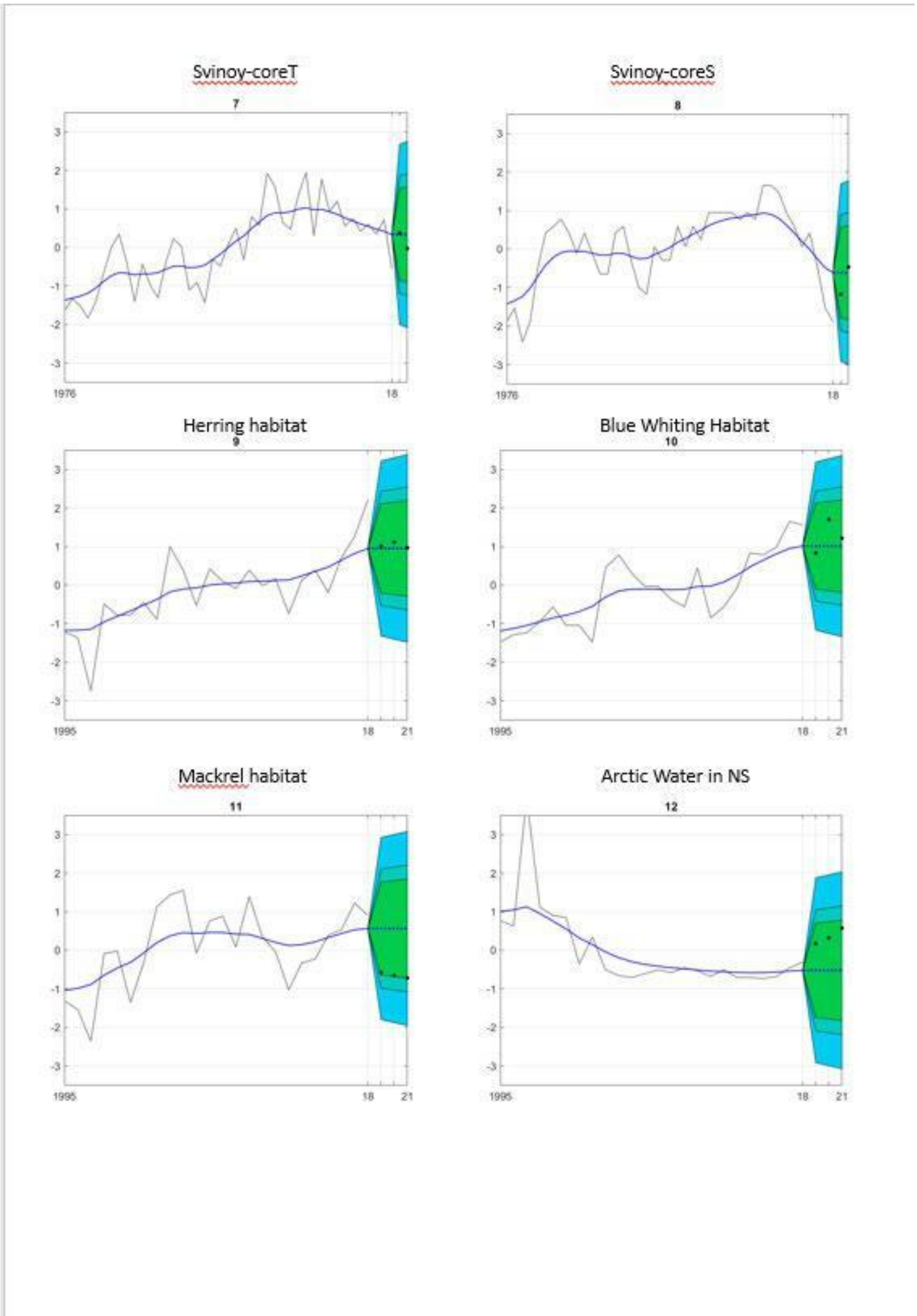

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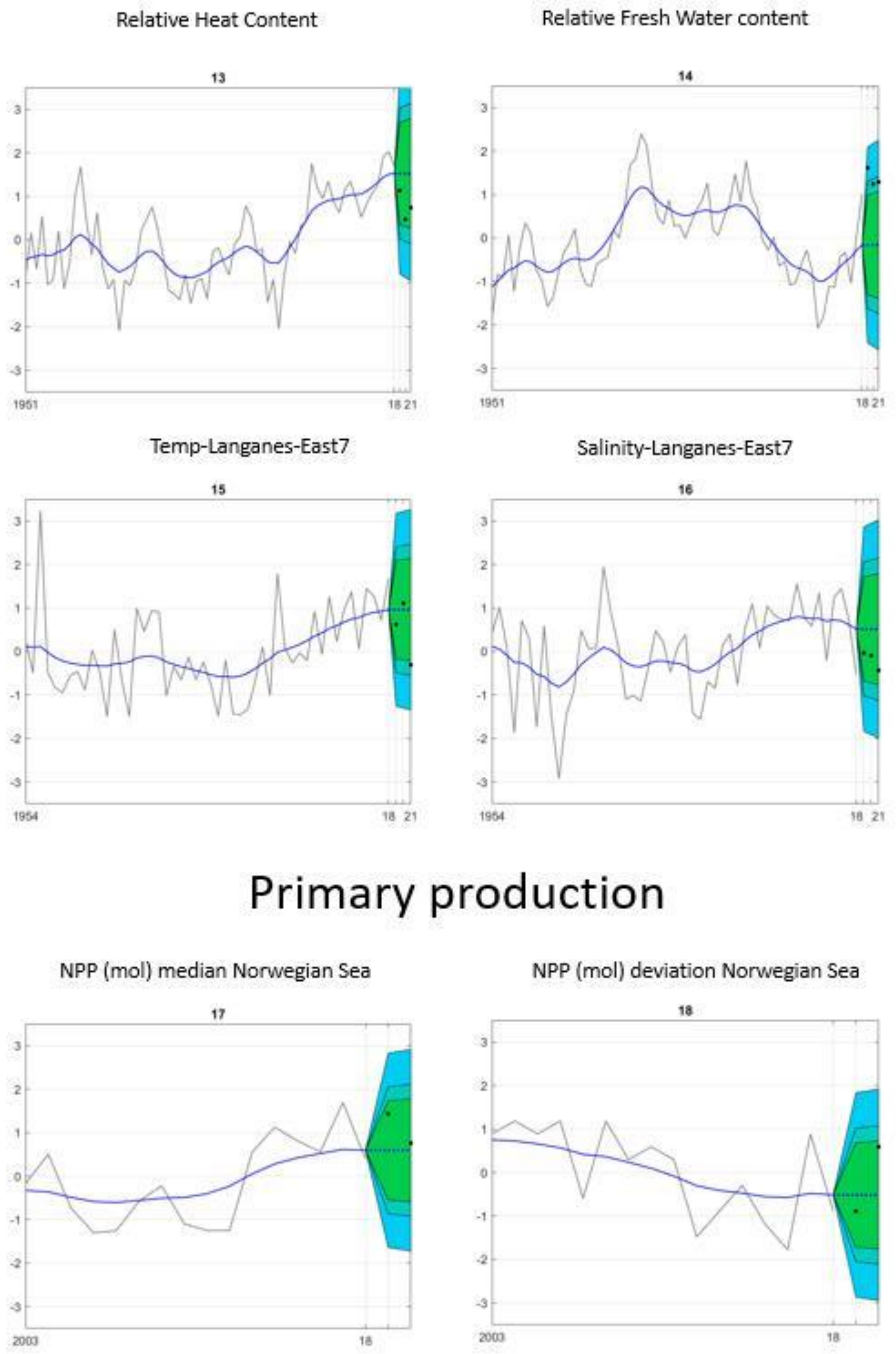

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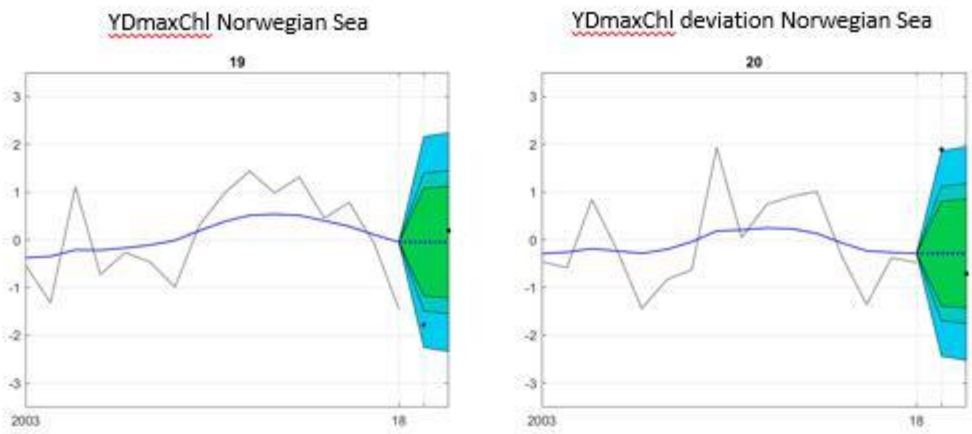
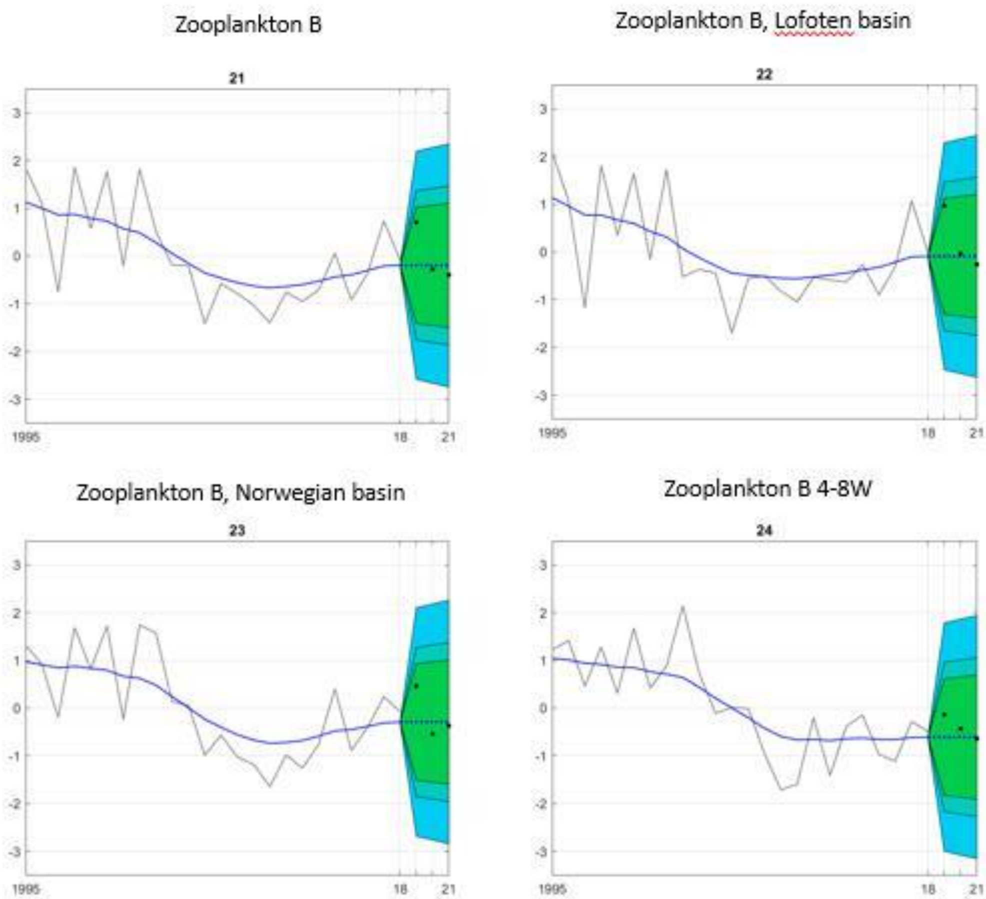


Secondary production



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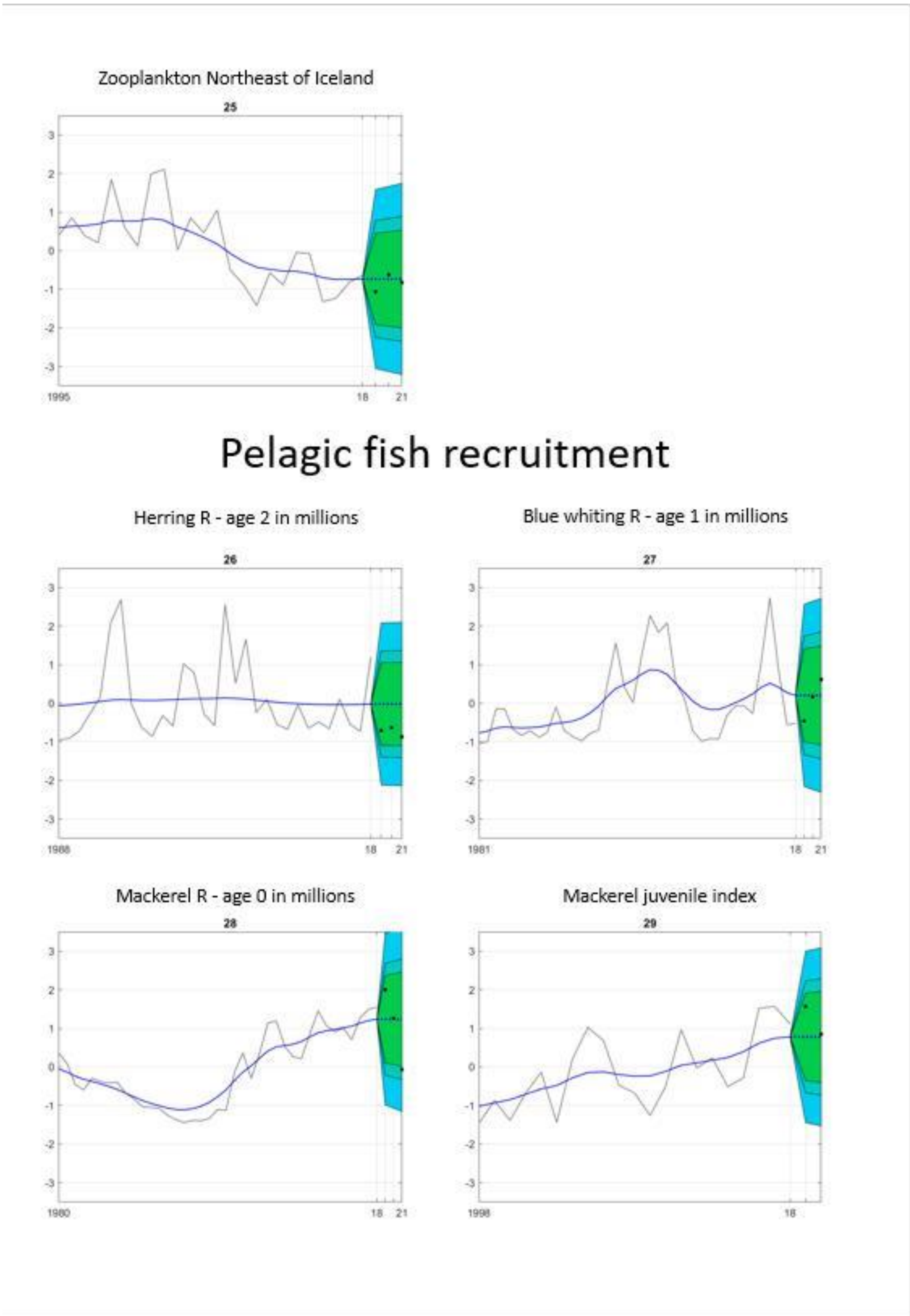

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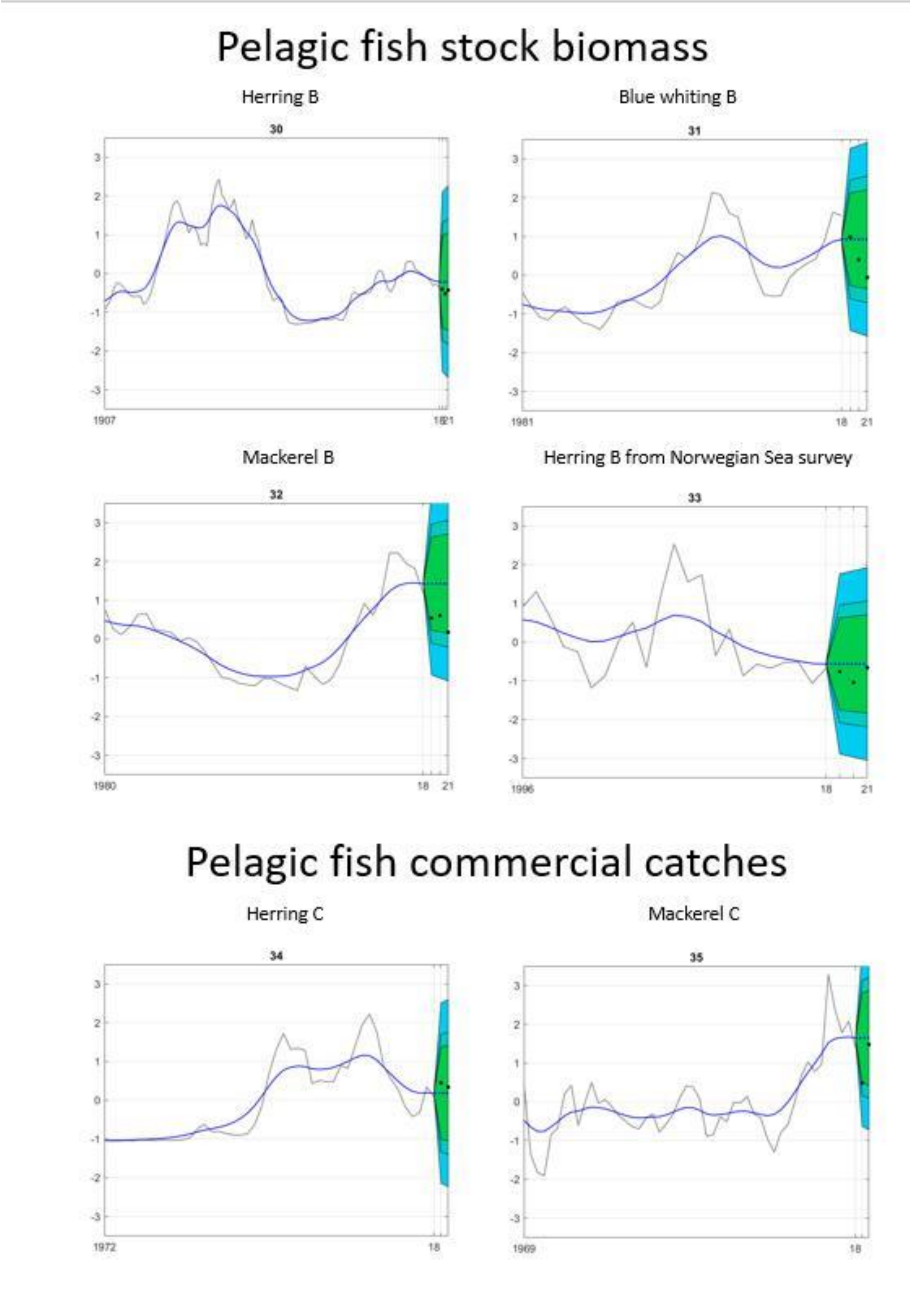

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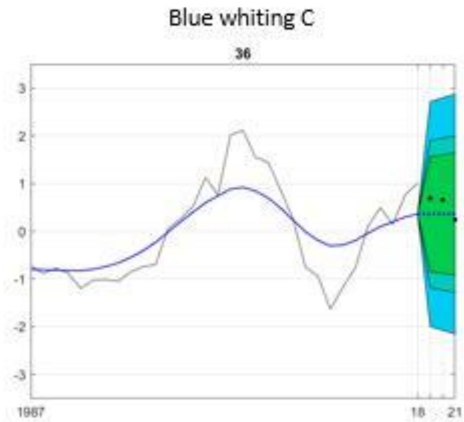
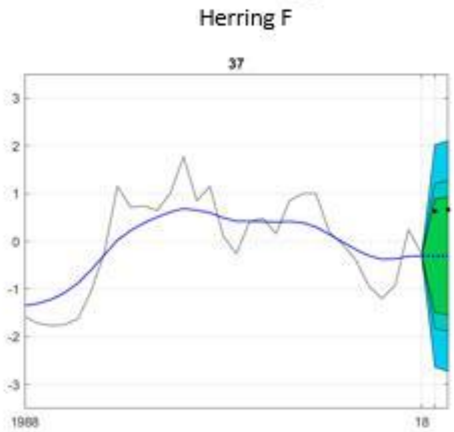
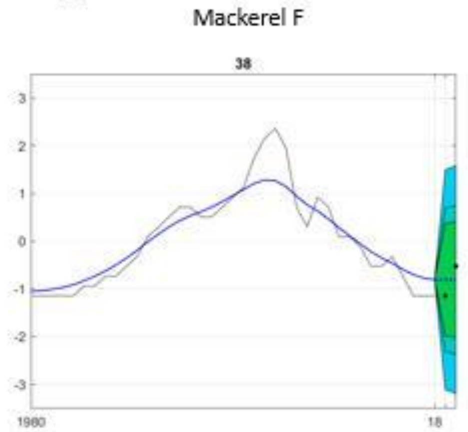
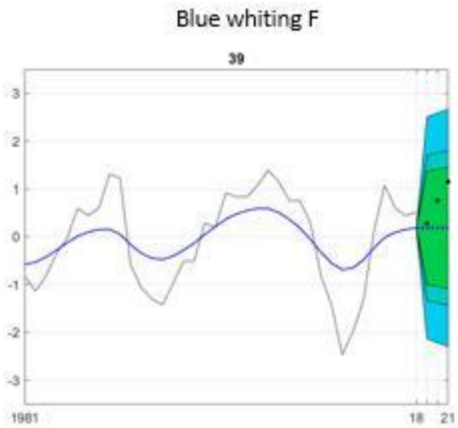


Pelagic fish fishing mortality







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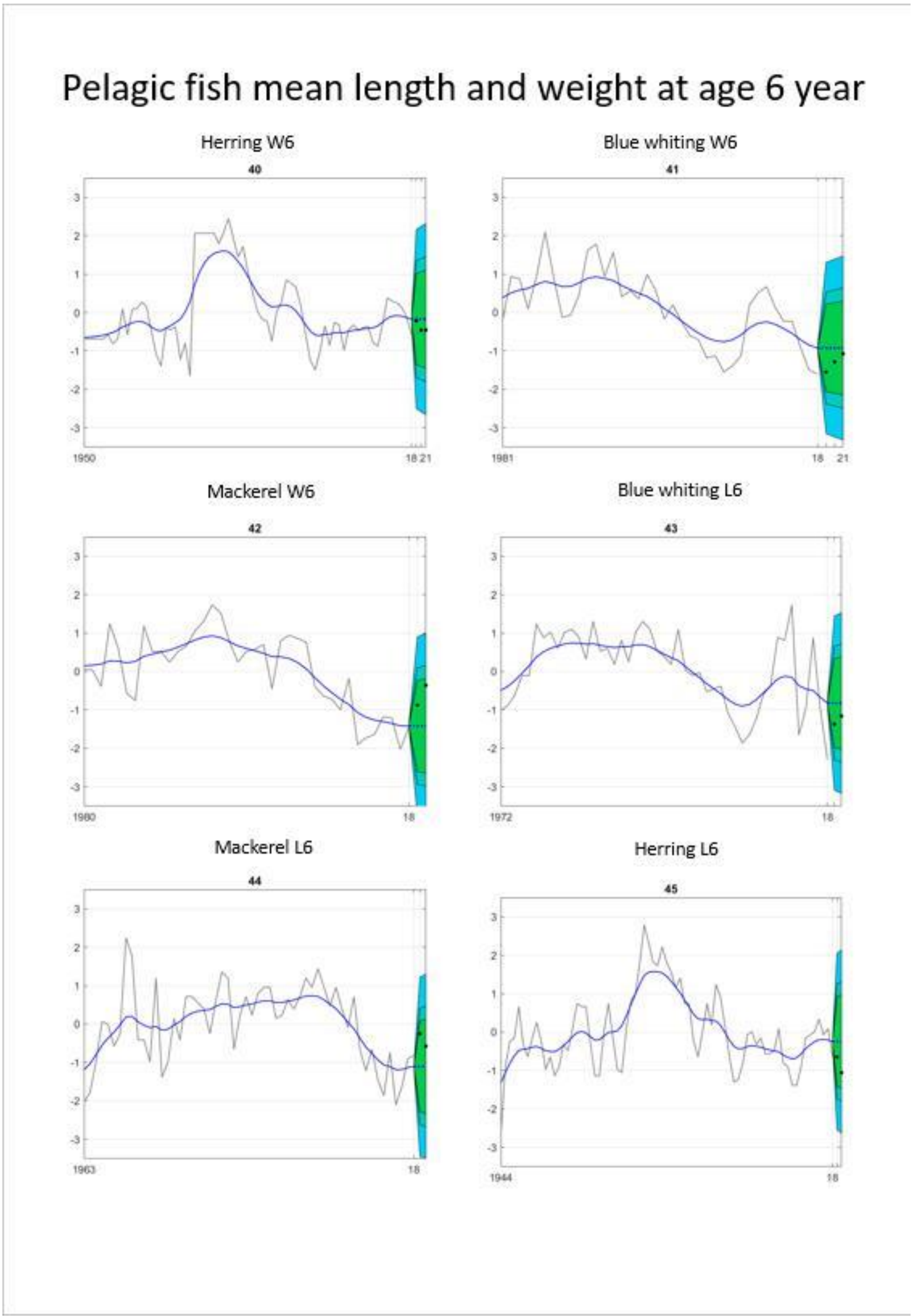

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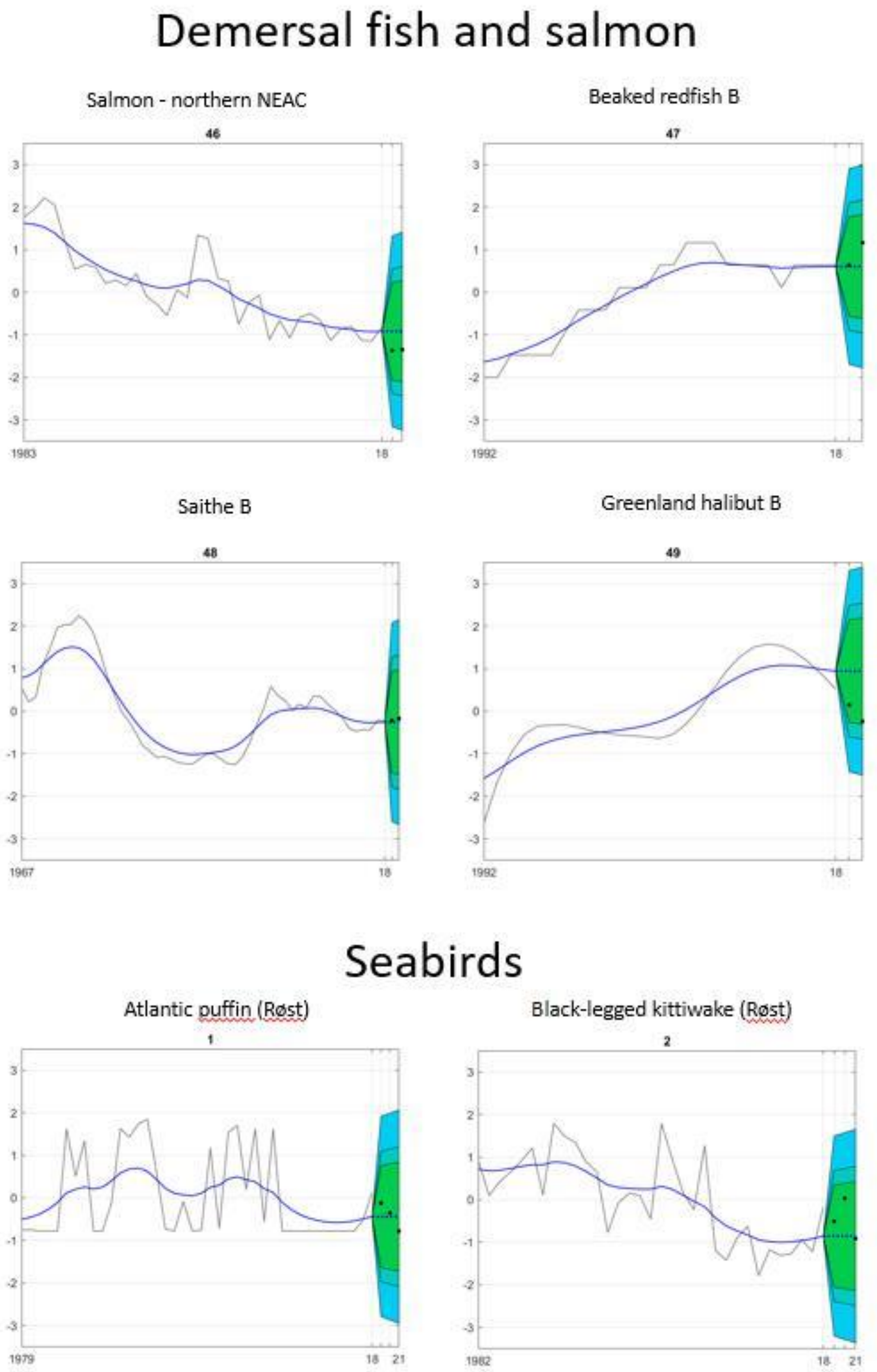

Figure A.7.3. Results from flagged observation analyses of 51 time series on climate, primary production, secondary production, pelagic fish recruitment, biomass, catches in fisheries, fishing mortality and mean length and weight at age 6 years, demersal fish and salmon and seabirds. Grey line runs between observation before last three years, blue line indicates estimated trend using state space form and Kalman filter algorithm, forecast bands for 80% and 95% prediction intervals indicated with green and blue shading, respectively. Observations for three last years shown as black dots.