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

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Contents

i Executive summary

The Working Group on Integrated Ecosystem Assessments for the Norwegian Sea (WGINOR) executes and develops an integrated ecosystem assessment (IEA) for the Norwegian Sea ecoregion. This report summarizes the working group's progress on annual updates to the IEA and time series, development of an ocean climate forecast, a food-web based assessment of the pelagic ecosystem, evaluation of single and multispecies harvest control rules for pelagic fish, revisions of the Ecosystem Overview completed in 2021, and establishment of dialogue with pelagic fisheries stakeholders and managers in Norway, Faroe Islands, and Iceland. The Norwegian Sea Ecosystem Overview revision included updates to the pressures and their importance, and a re-evaluation of the sector-pressure-component pathways. Other outputs included: (1) a 10-page ecosystem state summary for a non-scientific audience was produced (Annex 3), (2) a framework for identifying extreme values in the time series for in-depth analysis was developed, and (3) a study on multispecies harvest control rules scenarios and another on impact of value- and ecosystem-based management scenarios on Norwegian Spring-spawning herring showed impact of management decisions on the ecosystem. Dialogue was also successfully initiated with pelagic fisheries stakeholders and managers in Iceland.

Research on ocean climate impacts on ecosystem productivity indicated Arctic water masses facilitate greater abundance of nutrients and zooplankton compared to Atlantic waters. Preliminary results suggest oceanographic conditions are influenced by many processes operating at different time-scales complicating the development of ocean climate forecast products. Model reconstruction of trophic interactions in the pelagic ecosystem suggests limited competitions between dominant pelagic fish stocks. Comparison of diet estimation methods reveals occurrence-based methods give similar results to weight-based methods but are more robust and cost efficient. Furthermore, sampling fewer specimens at more stations reduces diet variance.

WGINOR priorities for the next term is to continue development of robust IEAs to support development of ecosystem-based management and ecosystem-based fisheries management in the Norwegian Sea.

ii Expert group information

Expert group name	Working Group on Integrated Assessments of 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 (47 participants)
	22-26 November 2021, Hafnarfjörður, Iceland (38 participants, 7 in person and 31 online)

1 Progress on the terms of reference

ToR a

The work with this ToR consists of two parts, one on performing integrated ecosystem assessment and another on identifying warning things for management.

Integrated ecosystem assessment

Interim integrated assessments have been performed through updating and providing a summary report on key time series for physical environment, primary production, plankton, pelagic fish, seabirds and marine mammals (ICES, 2020; ICES, 2021). In 2020, an ecosystem state summary called "Norwegian Sea ecosystem status summary" was developed. This is described in detail in the report from the 2020 meeting (ICES, 2021). The summary is short (around 10 pages) and provides information of the status for climate, primary production, zooplankton, pelagic fish, seabirds, and marine mammals. The summary will be updated annually, and can, if required, be used to update sections of the Norwegian Sea ecosystem overview yearly. The summary for 2021 is given in annex 3. WGINOR recommends that ACOM and the Ecosystem Observation Steering Group (EOSG) consider how this can be done (Annex 4).

Time series on ecosystem components, including climate indices, and on human pressures are central in the work with integrated ecosystem assessments. Several lines of work have been applied to various aspects of the time series. This includes work on which time series to include, evaluation and documentation of the time series as well as management of the time series. Work on time series to include has been done intersessional in 2021, starting with an online meeting 18 February where different types of purposes for use of time series were identified and discussed. This was followed up at the 2021 annual meeting, resulting in a list of the following 5 purposes for use of the time series:

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

The group has also discussed which time series that may be useful for each of these purposes. The output from these discussions is given in annex 5. Another line of work on time series has been done through the project Mission Atlantic, where several times series on human pressures in the Norwegian Sea have been identified. These will be considered for inclusion on the list of time series routinely updated and used by WGINOR. Details on this are given in annex 5.

The ICES Working Group on Common Ecological Reference Points (WGCERP) has developed a framework for documenting and evaluating time series used in integrated ecosystem assessments. The framework was presented at the annual 2021 WGINOR meeting, and WGINOR will consider how to implement it in the work of the group. Details on this are given in annex 5.

A framework for management of the time series using GitHub was discussed at the annual 2021 meeting. This will be developed in 2022 with the aim of implementing it as soon as possible in the group's work. Details on this are given in annex 5.

Methods that can be used in integrated ecosystem assessments were presented and discussed at the annual 2021 meeting. These originate from the three ICES Workshops on integrated trend analysis to support integrated ecosystem assessments (WKINTRA) (ICES, 2018; ICES, 2019a) and a panel-based assessment of ecosystem condition (PAEC) (Jepsen et al., 2020). The group will continue to discuss how these frameworks can be used in the integrated assessments for the Norwegian Sea. Details on the frameworks and their possible applications discussed for WGINOR are given in annex 6.

Framework for identifying warning signals for management

Under this part of the ToR, a framework has been developed for identifying observations that warrant closer analyses, assessment and/or attention when communicating with managers stakeholders and others. This is termed flagged observation analyses. The framework is described in the report from the 2020 annual meeting, where results from analyses of updated time series are given (ICES, 2021). Analyses were also done for the 2021 meeting. Results from these are presented in Annex 7.

ToR b

Progress on this ToR has followed several lines. One is within the project "Sustainable multispecies harvest from the Norwegian Sea and adjacent ecosystems" at the Institute of Marine Research, Norway and another in a study where harvest control rules have been tested for Norwegian and US systems using end-to-end ecosystem models. The output from these are described in the report from the annual meeting in 2020 (ICES, 2021). The intention was to continue the work in the SIS harvesting project in 2021, but this has not happened due to the COVID-19 pandemic. Progress is now restored, and work will be done on this ToR throughout 2022 and 2023.

A third line of work was presented at the 2021 annual meeting. Using end-to-end models, alternative value- and ecosystem-based management scenarios for Norwegian spring-spawning (NSS) herring that prioritized different stakeholders´ and citizens´ values have been simulated. The societal implications of these scenarios alongside the fate of commercially important fish species, such as herring and cod, and the ecosystem trophodynamics were explored. More details on the study are given in the section on science highlights (ch. 2).

ToR c

Background

Norwegian Sea ocean climate and its temporal variability is influenced by properties and relative fraction of Atlantic or Arctic source waters flowing into the area (Helland-Hansen and Nansen, 1909). Changing temperature condition have a direct impact on both metabolic rate and geographical distribution of many species and facilitate ecosystem changes (Skjoldal, 2004). Further ecosystem impact is caused by different nutrient (Rey, 2012) and zooplankton (Wiborg, 1954) composition between source water masses. Due to the large inertia of the ocean, Norwegian Sea ocean climate can be predicted a few years in advance by combining present observational state upstream in the North Atlantic with knowledge of how anomalies propagate in relation to the general ocean circulation.

Research progress during term

Øystein Skagseth lead the research for ToR C. The work was funded by a project call "Sustainable multispecies harvest from the Norwegian Sea and adjacent ecosystems" at the Institute of Marine Research, Norway. The research progressed from a work plan presented at the 2019 meeting to a manuscript ready for submission presented at the 2021 meeting.

The 2019 work plan included two research projects:

1. To identify observed trends and anomalies upstream in the North Atlantic Current, Sub-polar 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 timescale. Use available hydrography, ocean state products, satellite sea surface height and sea surface temperature data, and atmospheric reanalysis.

2. Improve the understanding of how the environmental changes affect the ecosystem directly and indirectly. This will involve both changes in temperature and salinity (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.

Skagseth provided an update on research progress at the annual meeting with a presentation followed by plenary discussion. For details about progress in earlier years see reports from the 2019 (ICES, 2020) and 2020 meetings (ICES, 2021). During the 2021 meeting, Skagseth presented the results for the two research projects, see abstract below.

For project (1) data analysis has advanced but is not completed. Preliminary results show that local atmospheric variations noticeably impact ocean climate in the Norwegian Sea. Temporal scale of atmospheric variations is measured in weeks which limits forecast timescale for ocean climate. Furthermore, the Norwegian Sea Atlantic slope current is impacted by inflow of Atlantic waters with a few years forecast window. Oceanographic conditions of the Norwegian Sea interior are influenced by fraction of Atlantic and Arctic water masses but involve many oceanographic processes operating at different timescales which complicates predictions. Future analytical work will test predictability skills of upstream ocean climate indicators on conditions in the Norwegian Sea and compare predictions to stochastic noise, *i.e.* local forcing. This work is planned to continue during the next WGINOR term.

Project (2) has advanced to a stage of having a manuscript ready to be submitted in December 2021. The main conclusion is that ocean climate in the Norwegian Sea from 1995 to 2020 can be split into three periods. From 1995 to 2005, the Norwegian Sea was dominated by "Arctic" water masses with high abundance of nutrients and zooplankton. From 2006 to 2016, was a period dominated by "Atlantic condition" with low nutrient and zooplankton abundance. From 2017 to 2019, conditions were dominated by "Arctic" water masses with unusually warm temperature and relative increase in zooplankton and unknown effects of nutrient abundance. The project will be completed once the manuscript is published.

Abstract of presentation by Øystein Skagseth (Institute of Marin Research, Norway) in 2021.

The ocean climate of the Norwegian Basin is largely set by the relative amount of Atlantic Water in the eastern and Arctic Water in the western part. Here we utilized hydrographic data from repeated sections together with annually gridded survey data of the upper 1000m to resolve the main hydrographic changes over the period 1995-2019. Based on integrated heat -and freshwater content we divide into three periods. From 1995-2005 we denote as "Arctic" period is characterized by a relative fresh and cold Atlantic Water overlaying Arctic Intermediate Water that basically span the whole Norwegian Basin. Differently, during the period 2006-2016 the Atlantic

Water is warmer and more saline, and the layer of Arctic Intermediate Water is greatly reduced. During the recent years, 2017-2019, there has been an extreme freshening of the Atlantic Waters, the layer of Arctic Intermediate Water has not recovered, but instead a layer of warmer but relative fresh Arctic Water have expanded. Based on spatial hydrographic maps, together with variability in abundance of the Arctic zooplankton species *Calanus hyperboreus*, the sources of these changes are likely from the Greenland – and Iceland Seas. We note that the overall abundance of zooplankton is significantly higher in the Norwegian Basin in periods of relative high amount of "Arctic" Water indicating an ecosystem effect. Furthermore, we show that both nitrate and silicate winter (pre-bloom) concentrations are significantly higher in the Arctic Water compared to Atlantic Water, and that there is a reduction in nutrients from the "Arctic" period 1995-2005 compared to the "Atlantic" period 2006-2016. Since these nutrients can be interpreted as the potential for new production, changes in the influx of western subarctic waters are expected to have a bottom-up effect on the Norwegian Sea. Hence this study indicates that rather than the temperature of the Atlantic Waters, the amount of Arctic Waters and their concentration of large and nutrients zooplankton species as well as nutrients is more important for the ecosystem functioning. Predictability from the Sub-polar North Atlantic through eastern continental margin of the Norwegian Sea is well documented. Further work will focus predictability of the more ecosystem important extent of Arctic Water in the Norwegian Basin.

ToR d

The work under this ToR has followed two lines, one on quantification of trophic interactions using food web-based models and another on developing a framework for diet estimation from stomach samples.

Quantification of trophic interactions in the Norwegian Sea pelagic food-web over multiple decades

In 2020, WGINOR members were invited to a workshop to jointly build a food-web model relevant for small pelagic fish and their zooplankton prey in the Norwegian Sea. The work was followed up by the building of a numerical model using the RCaN modelling framework. The RCaN food-web assessment model is based on inverse modelling and is designed to handle input observations and knowledge that are uncertain. We analyse if the reconstructed food-web dynamics are supportive of top-down or bottom-up controls on zooplankton and small pelagic fish and of competition for resources between the three small pelagic species. Despite high uncertainties in the reconstructed dynamics, the model results highlight that interannual variations in the biomass of herring, mackerel and blue whiting can primarily be explained by changes in consumption rather than by predation or fishing. Variations in the biomass of copepods and krill were also linked to variations in consumption, while the past dynamics of amphipods can be explained by both consumption and predation. The study provides a comprehensive reconstruction of trophic interactions in the pelagic ecosystem of the Norwegian Sea. The results show little support for the hypothesised competition for resources between the three small pelagic species, despite their overlapping diets. We conclude that it is unlikely that the assessment and management of these commercial stocks during the last 30 years would have benefited from explicit incorporation of trophic interactions.

Diet estimation framework

Assessing diet composition have important applications in both ecological research and fisheries management. However, the classical approach of visual inspection and subsequent weighing of individual prey groups (weight-based approach: %W) is costly and time consuming. Recent studies have suggested that an occurrence-based approach (%F) requiring only a list of taxa is more robust than %W while retaining essentially the same amount of information and requiring less laboratory work. In a study, WGINOR members have compared estimates and quantified the uncertainty in diet composition, diet width and dietary overlap of major prey groups using both %W and %F for the three dominating pelagic fish in the Norwegian Sea: NSS herring, Northeast Atlantic (NEA) mackerel and blue whiting. The diet composition data originated from 36 trawl surveys with a total 14,462 sampled fish. Overall, a high level of agreement for the estimates between the two approaches were found. However, for herring and mackerel, using %F led to a higher relative importance of Amphipoda vs. Copelata, whereas for blue whiting, Calanoida became more important, compared to %W. The increased importance of Calanoida using %F for blue whiting led to a higher degree of dietary overlap between blue whiting and the two other species. We found that increasing the number of sampled stations led to higher confidence in the estimates, whereas the number of fish sampled per station had little impact. Overall, the confidence intervals were narrower using %F compared to %W allowing for better detection of inter-annual change using %F vs. %W.

ToR e

The ToR's aim is to initiate a dialogue between WGINOR members and stakeholders and managers, in pelagic fisheries in the Norwegian Sea, by hosting a stakeholder meeting during the annual meeting in each country. This would be the first meeting of WGINOR members and stakeholders. During the 3-year term, WGINOR only hosted one stakeholder meeting which was in Iceland. During the annual WGINOR meeting in Norway in 2019, it was decided to delay the stakeholder meeting to the next term as Institute of Marine Research had shortly before hosted a stakeholder meeting in Norway. The WGINOR 2020 annual meeting was scheduled to be hosted in the Faroe Islands and to include a meeting with stakeholders and managers in the Faroes. The meeting was moved online due to the COVD-19 pandemic. The Faroese WGINOR members considered it unproductive to have the first stakeholder online and it was decided to delay the meeting to the next term (ICES 2021).

During the 2021 annual meeting, WGINOR hosted a stakeholder meeting with pelagic fisheries stakeholders and managers in Iceland. The meeting was intended to be a hybrid meeting giving Icelandic stakeholders the option to attend the meeting in person. Due to a sharp spike in COVID-19 infections in Iceland in the week leading up to the meeting it was moved online with a few days' notice. The 1.5-hour long meeting was in the morning of November 24th and was attended by five stakeholders, three managers and 16 WGINOR members.

The meeting's aim was to introduce WGINOR work to stakeholders and to facilitate a dialog between stakeholders, managers and WGINOR members. At the meeting, basic concepts of integrated ecosystem assessment and the major WGINOR products relevant to stakeholders and managers, the Norwegian Sea Ecoregion Ecosystem Overview and the Norwegian Sea Ecosystem Status Summary, were introduced with time for questions after each introductory presentation, see agenda below.

The panel discussion was blighted by limited participation of managers and stakeholders. The managers asked some questions and made a few comments, and stakeholders made a comment. It is possible that the online venue, unfamiliarity with WGINOR work and members, low number of stakeholders and managers relevant to WGINOR members, and English as the meeting language created a non-inclusive environment. It is vital to create a more inclusive meeting environment at the next stakeholder meeting to facilitate active engagement of attendants in discussions. It is recommended that the next meeting will be in person, uses Icelandic as the meeting language, reduces the number of WGINOR members relative to stakeholders, and to hold separated meetings with managers and with stakeholders. In addition, hosting stakeholder meetings with participants from all three countries present should be considered.

Both managers and stakeholders commented that they were neither aware of WGINOR nor its products relevant to stakeholders and managers prior to receiving the meeting invite. They considered WGINOR products, the Norwegian Sea Ecoregion Ecosystem Overview and the Norwegian Sea Ecosystem Status Summary, interesting and something they will discuss further within their ministry and association. They consider this initiation of a dialogue a positive step and hope it will continue and evolve further in the coming years.

Managers also commented that WGINOR products provide ecosystem information which is relevant background information for single-stock management decisions for the major pelagic fish stocks. They asked for availability of similar information for Icelandic waters which are located west of the Norwegian Sea ecoregion. There exist no ICES working group for integrated ecosystem assessment for the Icelandic EEZ, but the Marine and Freshwater Research Institute, in Iceland, produces an Ecosystem Overview for Icelandic waters in collaboration with ICES. Furthermore, WGINOR research is relevant to Icelandic waters as various ecosystem components in the Norwegians Sea impact conditions in Icelandic waters. The major research surveys providing information for the Norwegian Sea also research Icelandic waters, International Ecosystem Spring Survey in Nordic Sea (IESNS) in May and International Ecosystem Summer Survey in Nordic Seas (IESSNS) in July. The same major pelagic fish stocks occupy both areas.

Managers voiced two concerns. First that WGINOR should consider hosting separated meetings with fisheries stakeholders and managers in the future as they have different interests in the IEA process. Managers are responsible for making management decisions based on advice from ICES in contrast to fishing companies interested in fishing opportunities. Another concern was that ICES would not communicate with managers on a regular basis during the IEA development. Working mostly in isolation and investing large amounts of time developing an IEA with a myriad of ecosystem interactions and options is of limited use for management. Managers are interested in a direct two-way dialogue with options to provide feedback on current IEA status and impact direction of future IEA development. Such two-way dialogue is more likely to result in IEA outputs which are useful to managers than scientist developing IEA in isolation.

Meeting agenda: ToRe, Dialogue with stakeholders and managers in Iceland.
November 24, 2021.

10:00-11:30 Dialogue with stakeholders from Iceland, based on presentation of WGINOR work, plans and results and input from stakeholders on their needs and priorities.

10:00 – 10:20. Welcome and Meeting participants introduction round.

10:20 – 10:30. Introduction to WGINOR work, integrated ecosystem assessment and role of stakeholders in the process. Presenter Warsha Singh.

10:30 – 10:50. Panel discussion about WGINOR work and stakeholder involvement.

10:50 – 11:00. Introduction to WGINOR products focused on stakeholders: the WGINOR 10-page Ecosystem Overview Summary, first published in 2020, and the ecosystem overview, an ICES advisory product. Presenter Anna H. Ólafsdóttir

11:00 – 11:20. Panel discussion about WGINOR products aimed for stakeholders.

11:20 – 11:30. Closing of meeting.

Stakeholders and managers invited to the stakeholder meeting, attendees in bold:

From Fisheries Iceland: Heiðrún Lind Marteinsdóttir, **Hrefna Karlsdóttir**, Kristján Þórarinsson, **Hildur Hauksdóttir**, and Viðar Engilbertsson.

From Marine Stewardship Council: **Gísla Gíslason**.

From the Ministry of Industries and Innovation: Áslaug Eir Hólmgeirsdóttir, **Kristján Freyr Helgason**, **Skúli Kristinn Skúlason**, and **Stefán Ásmundsson**.

Pelagic fishing industry, company name in bracket: Garðar Svavarsson (Brim), Þorsteinn Kristjánsson (Eskja), Gunnþór Ingvason og **Grétar Örn Sigfinnsson** (Síldarvinnslan), Friðrik Már Guðmundsson (Loðnuvinnslan), Aðalsteinn Ingólfsson (Skinney-Þinganes), **Sindri Viðarsson** (Vinnslustöðin), Stefán Friðriksson (Ísfélag Vestmannaeyja), Ingi Jóhann Guðmundsson (Gjögur), og Baldvin Þorsteinsson (Samherji).

ToR f

The first major revision on the Norwegian Sea ecoregion ecosystem overview (EO) began in 2018, was accepted by the ICES Advice Drafting Group to finalize draft Ecosystem Overviews (ADGECO) at a meeting on May 6th 2021 and published by ICES on 27th May 2021.

The first revision draft, submitted to ICES in fall 2019 with mostly text changes, was reviewed by ADGECO at their meeting held on 6th – 8th November 2019.

During the 2019 annual meeting, ADGECO feedback was discussed in plenary and it was decided to revise the pressures, listed by importance, from:

1. Selective extraction of species
2. Abrasion
3. Substrate loss and smothering
4. Introducing contaminating compounds
5. Nutrient and organic enrichment

to:

1. Selective extraction of species
2. Introducing contaminating compounds
3. Underwater noise
4. Abrasion

Meeting attendees did not evaluate sector-pressure-component pressure pathways (ICES, 2020). Some revisions on the EO text by WGINOR members were done by correspondence. The revised EO was rejected by the ADGECO at a meeting on 28th November 2020, due to lack of evaluation of sector-pressure-component pressure pathways.

During the 2020 WGINOR annual meeting, work continued revising the EO (ICES, 2021). In a plenary discussion it was decided to keep the four pressures, decided on in 2019. Meeting attendees felt incompetent to either qualitatively or quantitatively evaluate sector-pressure-component pressure pathways due to lack of methods to do so. It was concluded to use a simplified version of the Options for Delivering Ecosystem-based Marine Management (ODEMM) methodology (Pedreschi et al., 2019) to evaluate pathways, as outlined in the 2019 WGEAWESS report (ICES, 2019b). This was done during an online workshop, in February 2021, chaired by Mette Skern-Mauritzen and attended by 21 WGINOR members. The chair calculated the sums of impact risks from the ODEMM assessment which was used to guide a subjective scoring in the ICES EO tables. Workshop results showed an inflated sum of impact risk for the pressures contaminants, noise, and abrasion, compared to scientific knowledge of those pressures' impact on the ecosystem. High number of pathways inflated the impacts. Three more workshops were hosted online in March 2021, where WGINOR members downgraded inflated impact risks using scientific knowledge in a plenary discussion. Once work on adjusting the sector-pressure-component pressure pathways was completed, EO text revisions began. Various experts from WGINOR and IMR, Norway, provided text on "Pressures" in the revised EO, WGINOR provided text for "Climate Change Impact", the "Status of the Ecosystem" chapter was revised using text from the Norwegian Sea Ecosystem Status Summary, and the ICES secretariat provided updated figures and tables. The revised EO was submitted to ICES by 26th March 2021 and accepted at the ADGECO meeting on 6th May 2021. For details of the revision process see the report from the WGINOR 2020 meeting (ICES, 2021).

At the 2021 meeting, the Norwegian Sea Ecosystem Overview Summary was updated, and the updated version will be used to revise the State of the Ecosystem Chapter of the Norwegian Sea EO. The ICES secretariat will update the figures with time series of fishing mortality of the three pelagic species. The update must be evaluated and accepted by ADGECO in early 2022 before any changes are made to the EO.

2 Science highlights

Here are described science highlights from the 2021 meeting that were not submitted through the e-evaluation from the meeting (WGINOR E-evaluation_ 2021).

2.1 Spatial and temporal patterns of the Norwegian coastal cod catching fleets

Xiaozi Liu (University of Bergen, Norway).

Fishers make repeated choices with respect to where, when, and what to fish. While this trip information may be known for fishers and few experts, it has not been fully utilised for management purpose. Using sale slips data, we proposed a set of methods combining model-based classification of fishing strategies with regression models to study the spatial and temporal patterns of coastal cod- catching fleets in Norway. The data from year 2019 includes 761 vessels. Gaussian mixture model (GMM) identified eight species clusters where Northeast Arctic cod (NEAC, *Gadus morhua*) appears in four of the clusters. Trips featuring pure NEAC catches accounted for about one third of the total trips in 2019. The Herfindahl-Hirschman Index, which we use to measure diversity of fishing patterns, shows that one quarter of the vessels engaged in a specialised fishing strategy (1–2 main target clusters); the rest followed more mixed fishing strategies. Our fixed-effect regression model further reveals gear use, spatial, and temporal patterns that characterise each fishing strategy. The identified information on fishing strategies can help to improve the design of effective fisheries management policies.

2.2 Evidence of an ecological regime revealed from the unprecedented reduction in marine growth of Atlantic salmon

Øystein Skagseth (Institute of Marin Research, Norway).

No abstract available for presentation as manuscript in submission.

2.3 Inserting Values into Ecosystem-based Fisheries Management

Mimi E. Lam (University of Bergen, Norway), Szymon Surma (University of British Columbia, Canada), Holly A. Perryman and Tony J. Pitches

To overcome the societal challenges of implementing ecosystem-based fisheries management, we explored diverse value-based scenarios for the Norwegian spring-spawning herring fishery. We conducted dynamic ecosystem simulations with management strategy evaluation (MSE) to evaluate the trade-offs in performance amongst candidate fisheries management strategies, while considering the impacts of uncertainties and errors. We ran MSE simulations with two updated ecosystem models for the Norwegian and Barents Seas: Atlantis ‘NoBa’ and Ecopath with Ecosim (EwE) ‘NorBar’. Atlantis is a biogeochemical-based, end-to-end model that simulates physical, chemical, and biological oceanography, as well as ecology, while EwE is a whole-ecosystem, mass-balanced model that tracks energy flows among functional groups that can span all trophic levels. We simulated six alternative value- and ecosystem-based management scenarios for Norwegian spring-spawning (NSS) herring that prioritized different stakeholders´ and citizens´ values (in parentheses): 1. no herring fishing (conservation); 2. fishing herring for human consumption only (food security); 3. Lenfest Forage Fish Task Force recommendations (ecosystem services); 4. adopted ICES harvest-control rule (HCR) (political compromise); 5. industry-proposed HCR (socio-economic stability); and 6. fishing herring to collapse (short-term profit maximization). We explored the societal implications of these scenarios alongside the fate of commercially important fish species, such as herring and cod, and the ecosystem trophodynamics. Using multi-model inference, we compared the MSE-scenario model outputs to give a robust value- and ecosystem-based integrated assessment of the societal and ecological impacts and risks, and consequent policy trade-offs, of conflicting uses and potential regime shifts of marine resources in the Norwegian and Barents Seas.

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Annex 1: List of participants

Members which attended meeting in person are listed in bold. Other members attended meeting online. Stakeholders and managers only attended the stakeholder meeting session.

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Annex 2: Resolution for 2019-2021

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 food-web 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 food-web 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: Norwegian Sea ecosystem status summary 2021

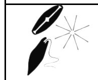
This document gives a short summary of the current state and recent change of different components of the Norwegian Sea ecosystem while also briefly discussing possible causes of change. It was issued for the first time in 2021 (2020 meeting) and is planned to be updated annually. The ecosystem status summary is intended for a wide audience, including scientists, teachers, students, 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 ecosystem 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, following the recruitment of a strong year class. Mackerel and blue whiting biomasses continued 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 substantially since the start of monitoring in 1980, and common guillemot is at high risk of extinction 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].

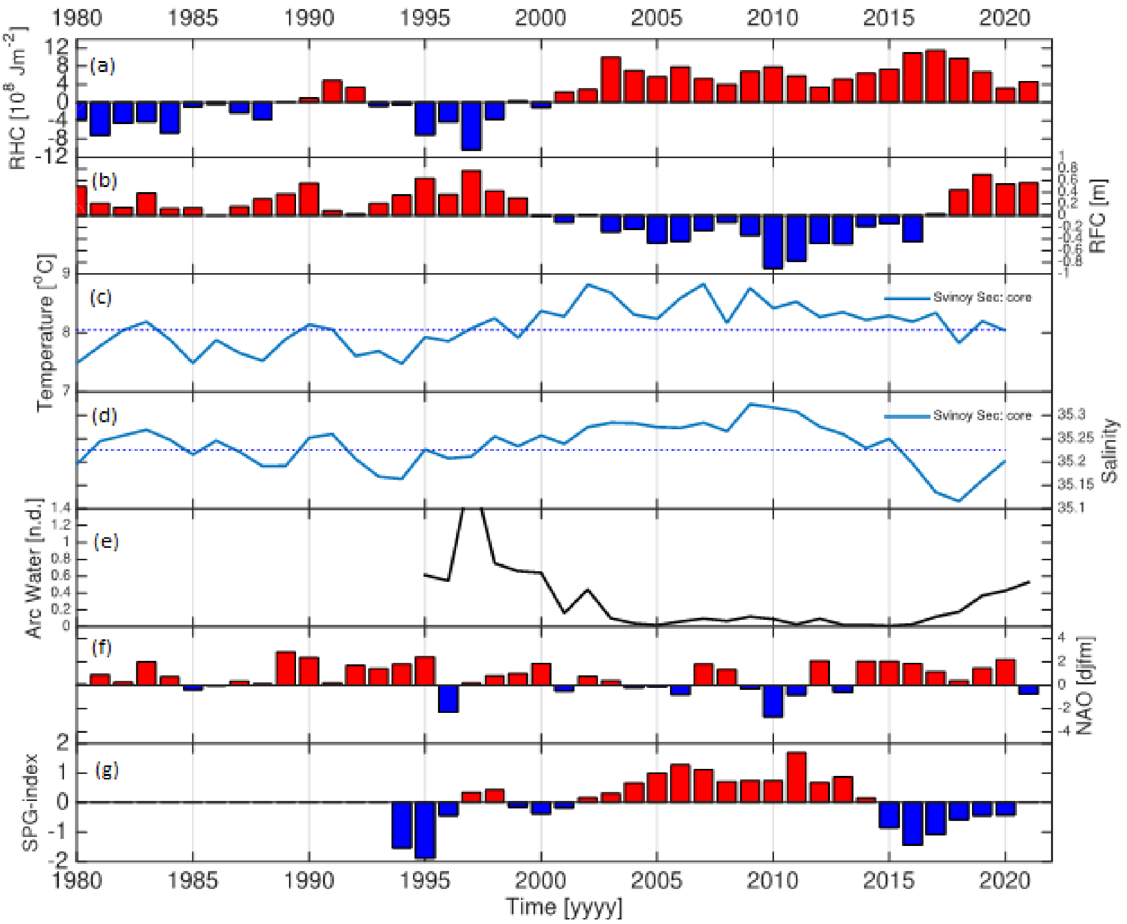


Figure 1. A subset of climate indicators for the Norwegian Sea: a) Relative heat content (RHC) and b) Relative Freshwater Content (RFC); Svinøy section Atlantic Water core c) temperature and d) salinity; e) Arctic Water amount in the Norwegian Sea, f) The North Atlantic Oscillation (NAO) winter index, 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 increased 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 negative 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 Current, that brings Arctic Water from the Iceland Sea to the southern Norwegian Basin, has increased 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 favourable 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].

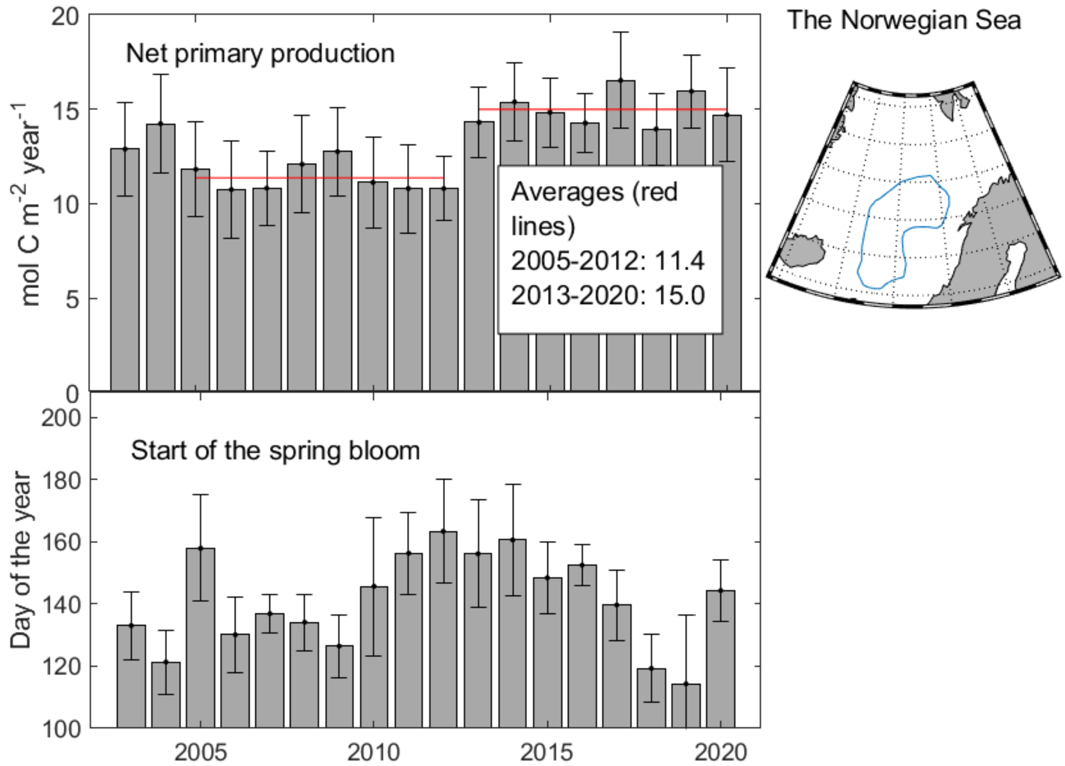


Figure 2. Estimated net yearly primary production (upper panel) and date for the start of the spring bloom (lower panel) in the Norwegian Sea. The inlet on the top-right shows the geographical region over which satellite data is compiled (blue polygon).

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

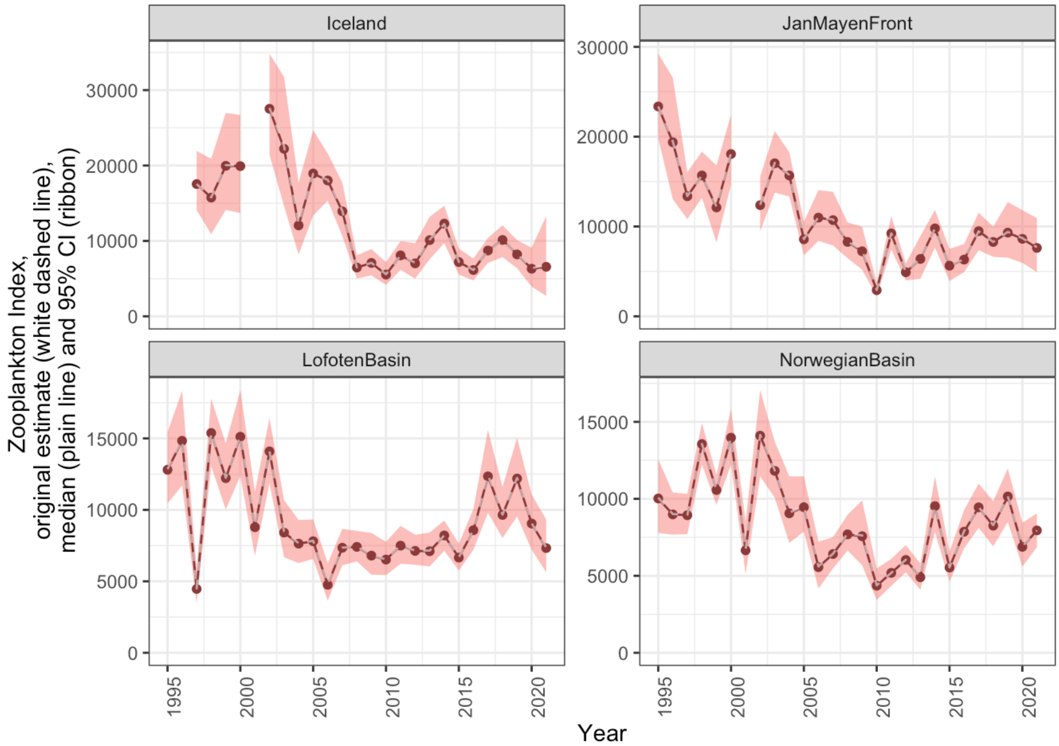
There have been two main changes in spring zooplankton biomass during the last three decades: 1) The long-term biomass level has decreased in all sub-areas, and 2) the previously higher zooplankton level in Arctic water northeast of Iceland has been reduced to the same level as in the Atlantic water 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-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 11 years) and showing a tendency of a slight increase over the entire area.

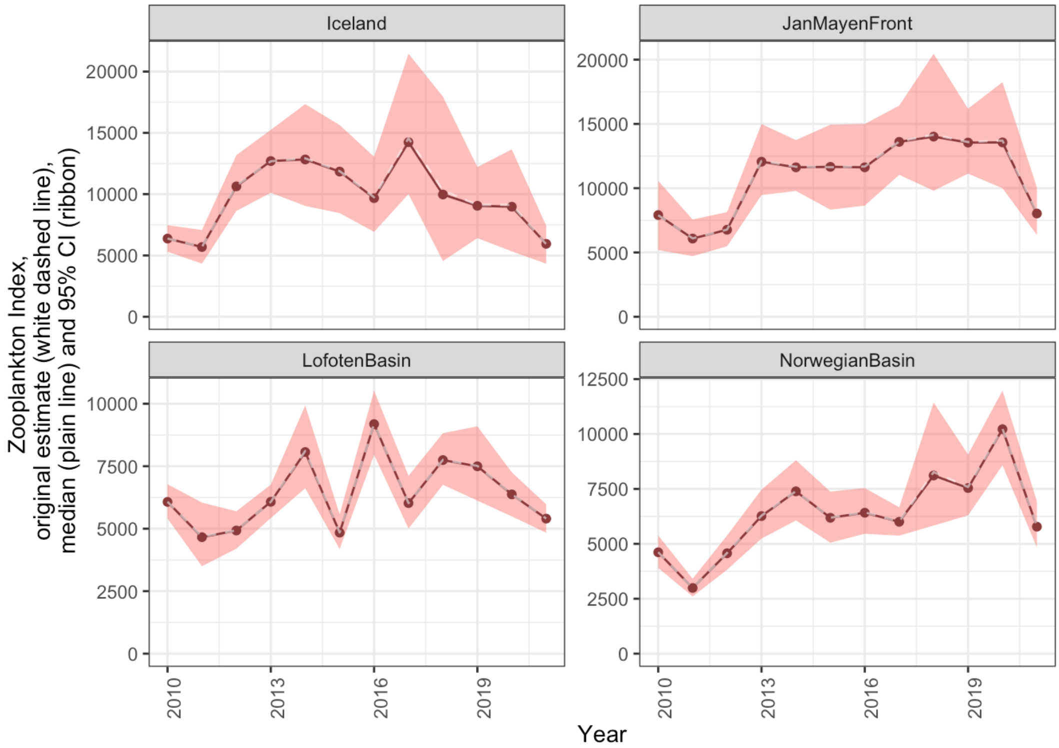
Possible reasons for recent changes

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 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.

a)



b)



c)

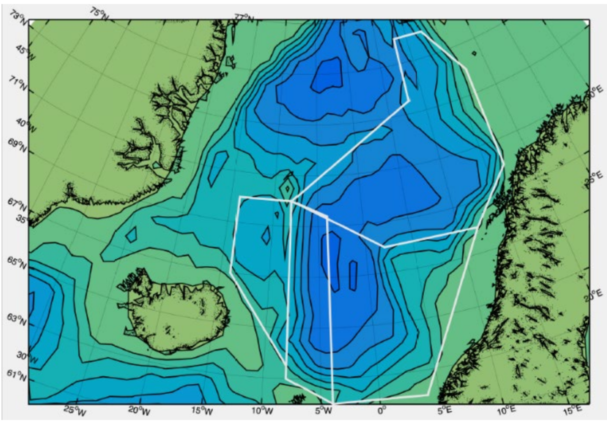


Figure 3. Indices of zooplankton biomasses (mg dry weight m^{-2}) in the upper 200 m of the water column in the Norwegian Sea and adjacent waters, a) in May during the time period 1995-2021, b) in July/August during the time period 2010-2021. The total area has been divided into 4 sub-areas, shown in 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 herring. 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 upper boundary of the 95% confidence interval for fishing mortality is higher than maximum sustainable 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, herring 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 compared 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].

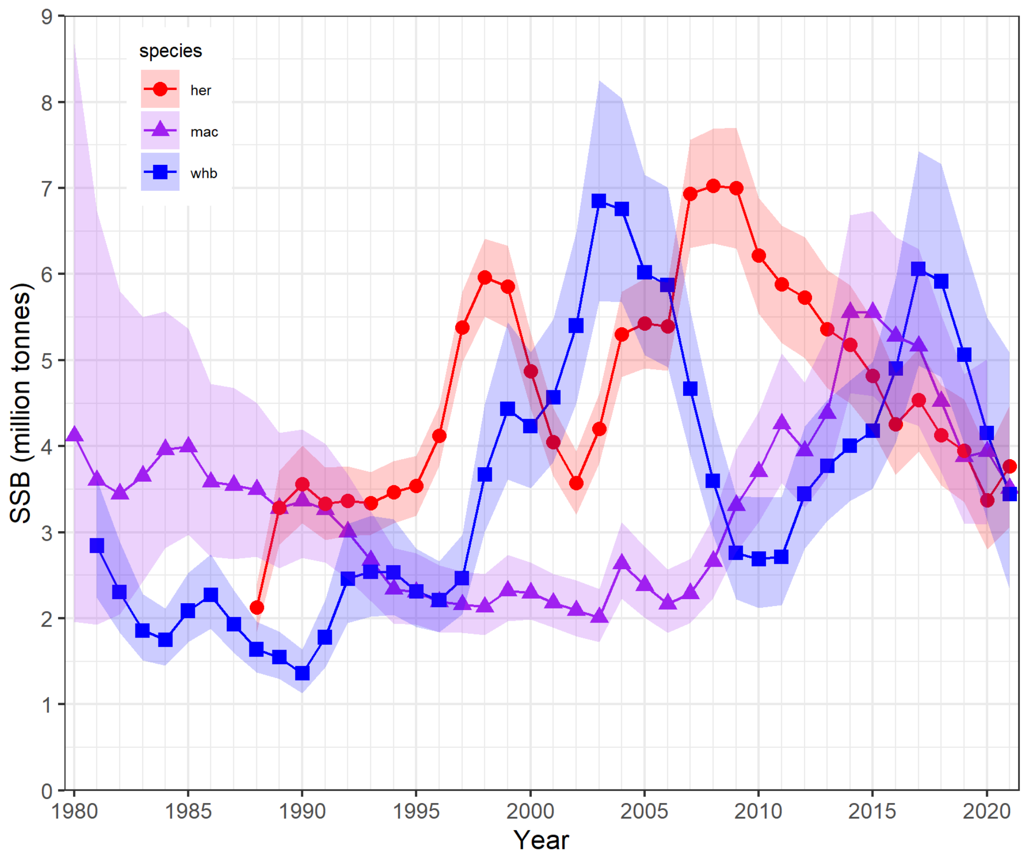


Figure 4. Estimated spawning stock biomass (lines) including 95% confidence intervals (shaded areas) for Norwegian spring-spawning herring (red filled circles), mackerel (purple filled triangles) and blue whiting (blue filled rectangles) from 1980 to 2021 [10].

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 Iceland [11]. The distribution of blue whiting in 2021 was similar to the most recent years [12]. The distribution 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].

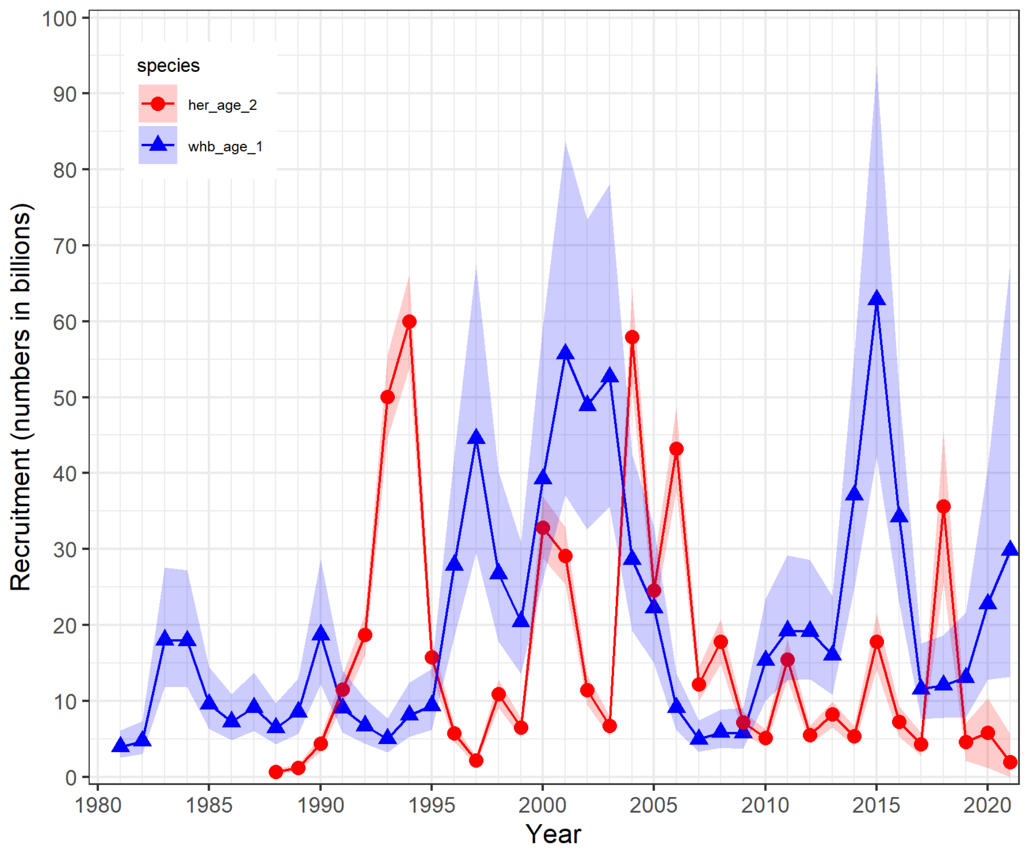


Figure 5. Estimated year-class size at recruitment for Norwegian spring-spawning herring (age 2; red filled circle) and blue whiting (age 1; blue filled triangle) from 1981 to 2021 [10].

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 assessment perception of the stock is due to changes in relative weights of data sources in the assessment 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 contributes 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 mackerel 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.

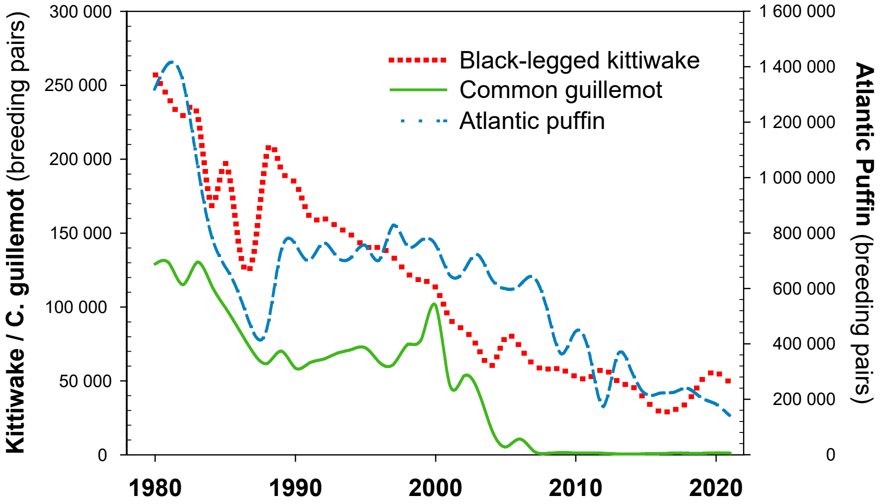
For the three pelagic species, time-series of their population development in the eastern Norwegian Sea (Figure 5a) were derived from their estimated breeding numbers in 2013[14] and annual monitoring of trends in selected breeding colonies (Runde (62.4°N), Sklinna (65.2°N), Røst (67.5°N) and Anda (69.1°N, 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 puffins 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 breeding 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.

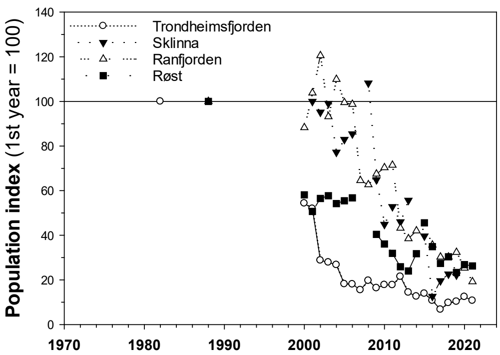
For the two coastal species, trends in breeding populations in the eastern Norwegian Sea (Figure 5 b and c) are monitored in selected areas along the mainland coast (Trondheimsfjorden (63.4°N, only eider), Sklinna (65.2°N), Ranfjorden (66.2°N, only eider), and Røst (67.5°N).

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 increased from the mid-1980s to around 2005 but have decreased markedly thereafter.

a)



b)



c)

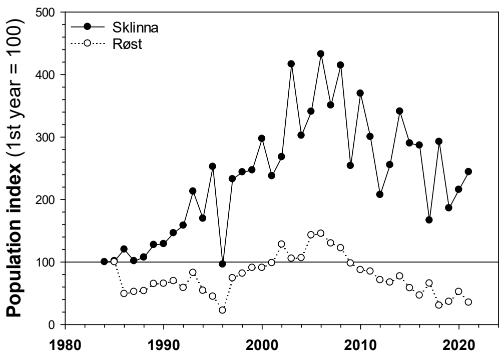


Figure 5. Population trends for seabirds breeding in the Norwegian part of the eastern Norwegian Sea since 1980, divided by (a) pelagic feeding species black-legged kittiwake (red line), common guillemot (green line) and Atlantic puffin (blue line) (upper left), (b) coastal benthic feeding common eider (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 continued 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 (including 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 biomass of mesopelagic fauna as well as pelagic fish growth indexes. Also, this should be supplemented 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 population

	Black-legged kittiwake	Black-legged kittiwake breeding population
Marine mammals	Minke whale	
	Seals (which species?), suggestion 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 markedly from year to year, also for long lived species. Candidate time series for ecosystem components 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 sensitive that is also of ecosystem significance. 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 oceanographic 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 operationalizing 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 Haddock) as well as Atlantic redfish. This information is made available by the Norwegian directorate 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 describe **shipping** have been made available at havbase.no and are available from 2010 to the actuality. 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 conceptual 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 addressed 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 workshop is to develop good practices in the application of integrated trend analyses (ITA) and interpretation 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 characteristics**: *primary production*, *biomass distribution among trophic levels*, *functional groups within trophic levels, functionally important species, biological diversity, landscape ecological patterns, and abiotic 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 confidence 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 appropriateness.

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 phenomena, 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 supported 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 special 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.

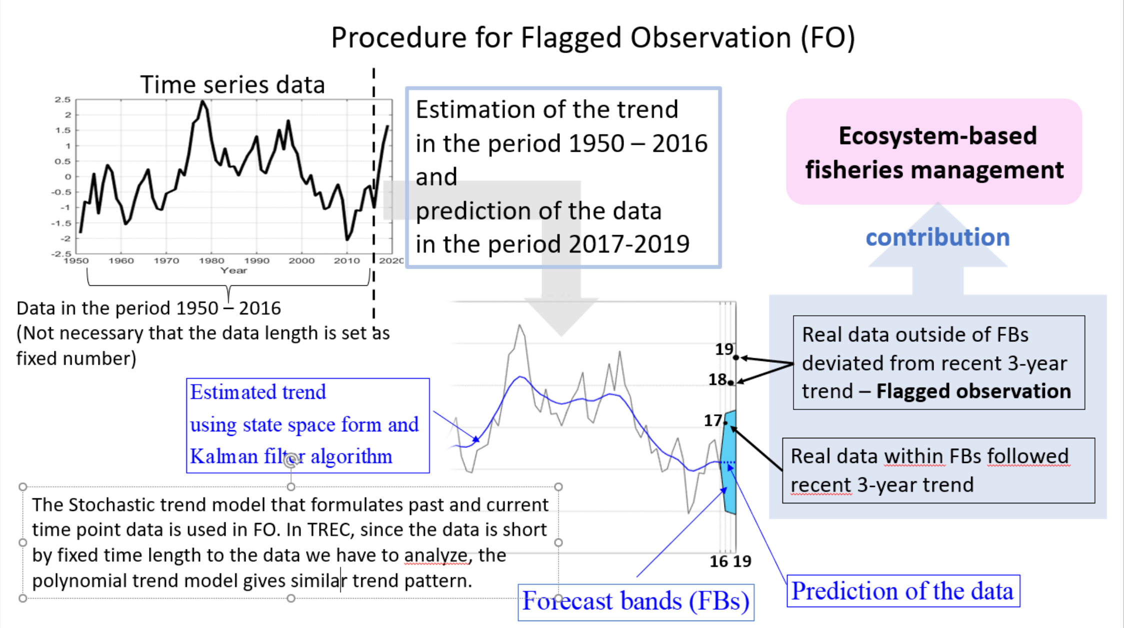


Figure A.7.1. General outline of the method for flagged observation analyses, see (ICES, 2021) for details.

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.

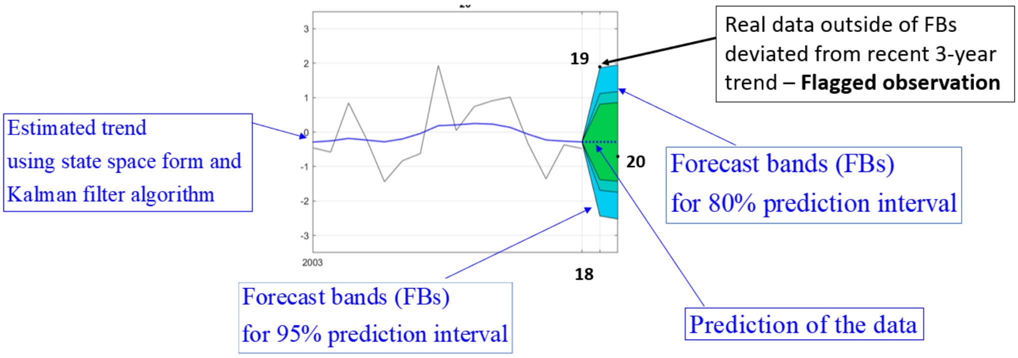


Figure A.7.2. Principles for communication from flagged observation analyses.

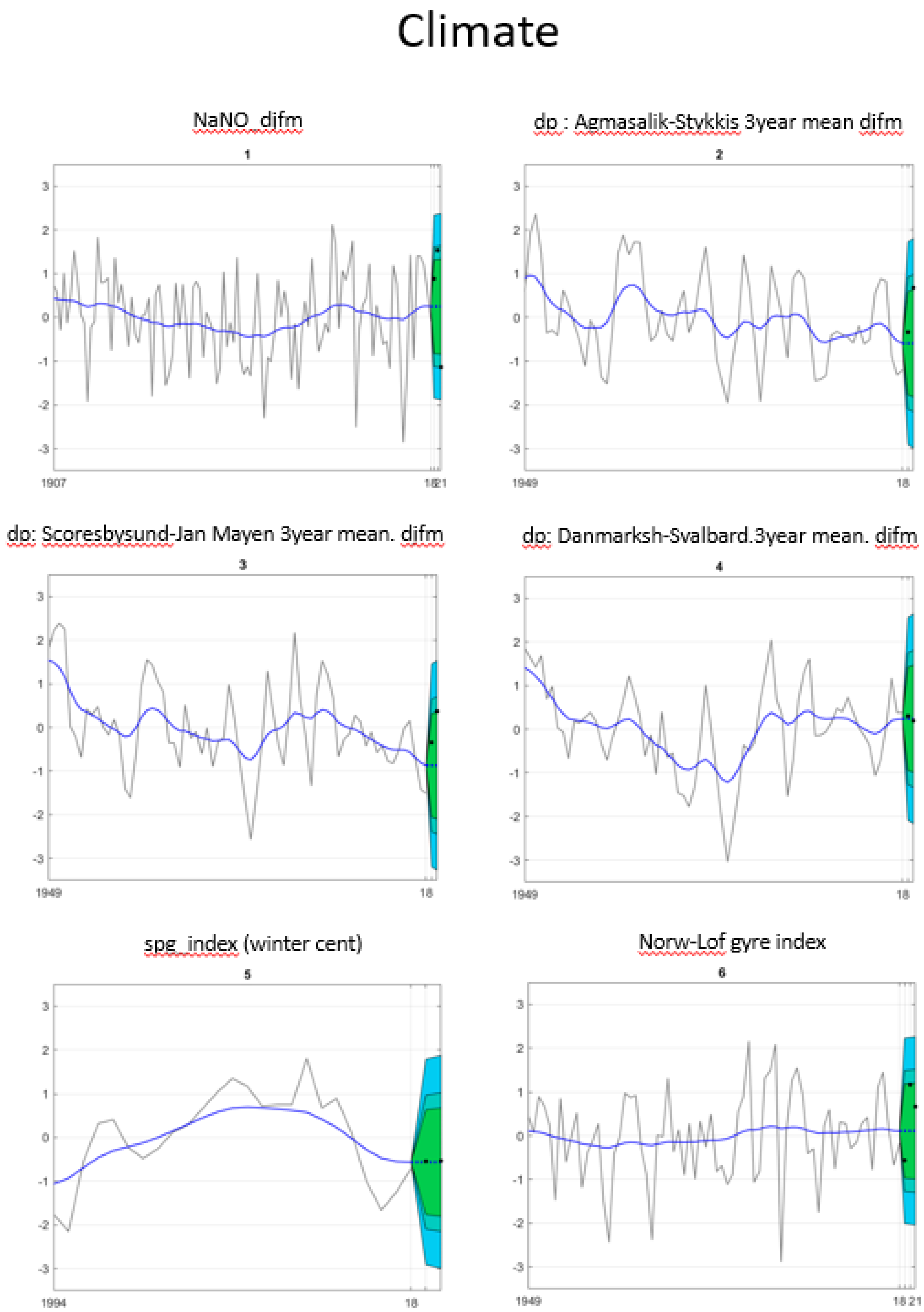
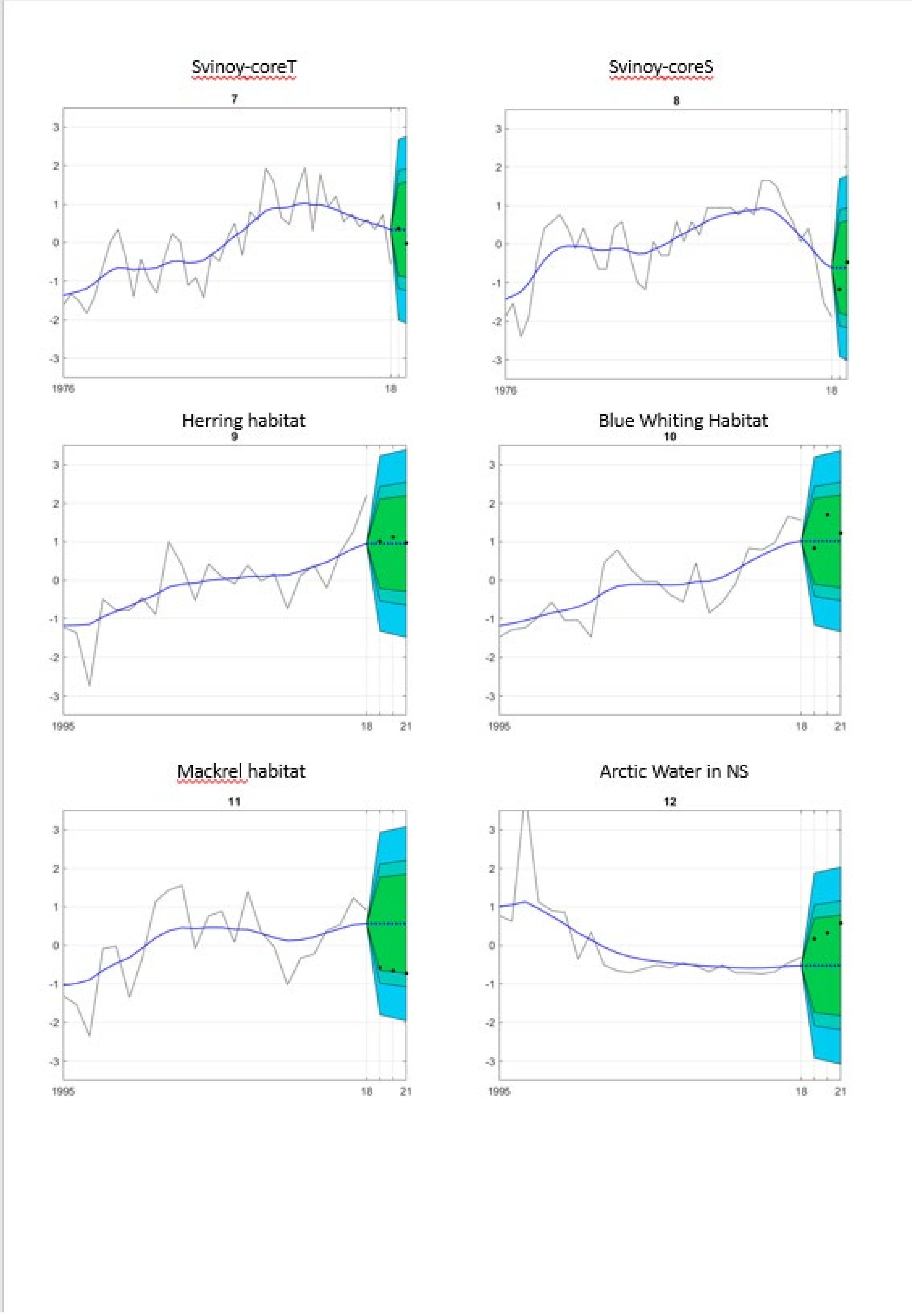


Figure A.7.3, continued on next pages



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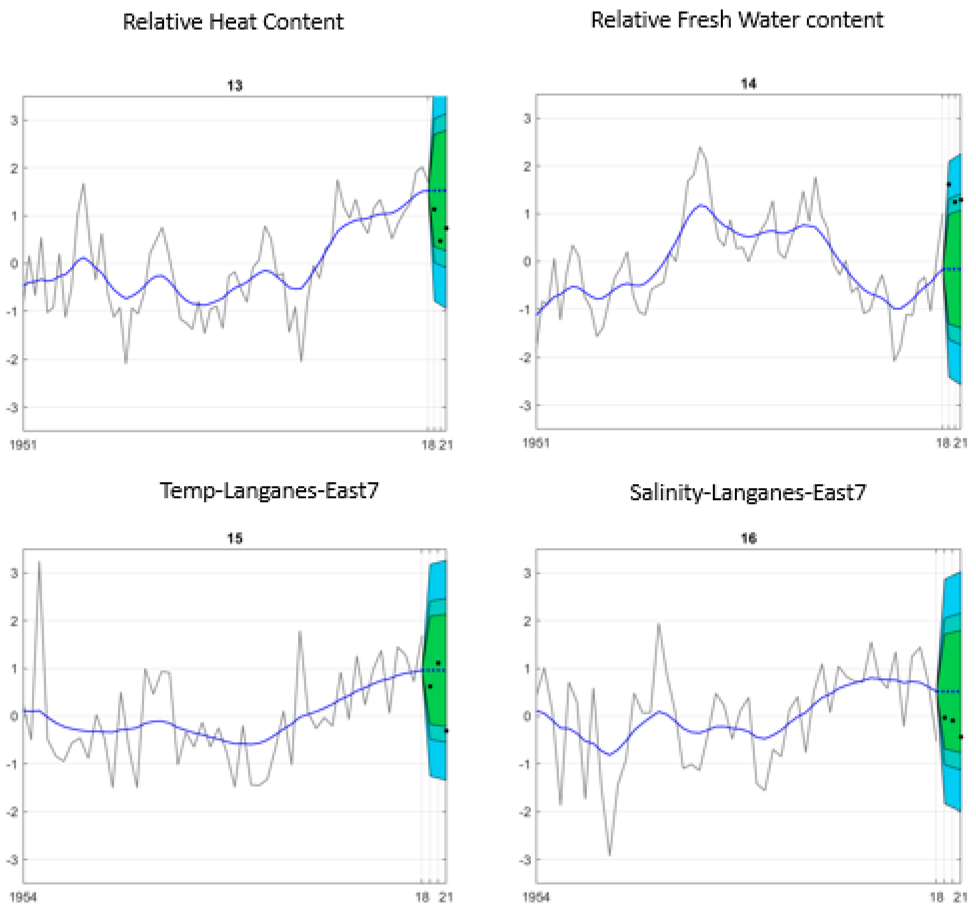
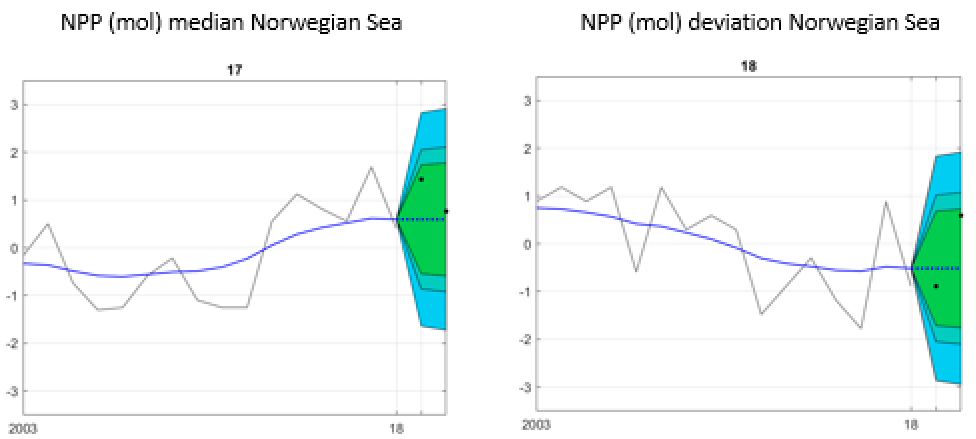


Primary production



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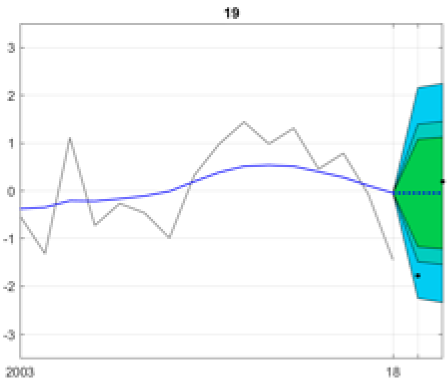
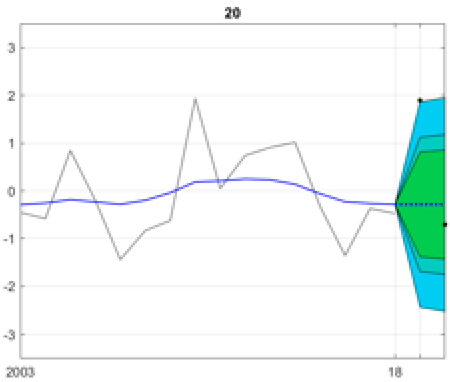
YDmaxChl Norwegian Sea

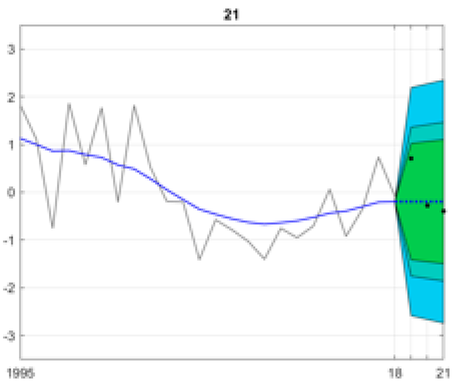


YDmaxChl deviation Norwegian Sea

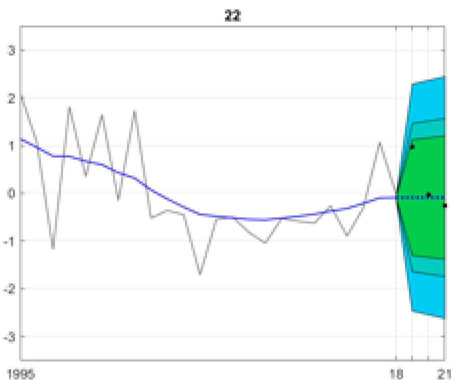


Secondary production

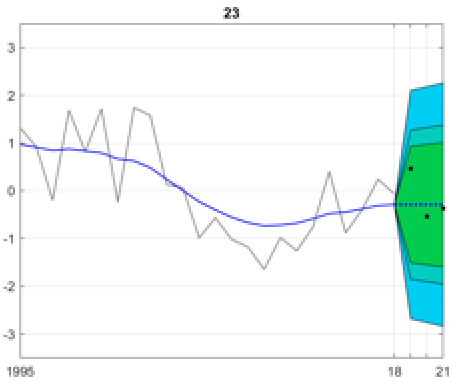
Zooplankton B



Zooplankton B, Lofoten basin



Zooplankton B, Norwegian basin



Zooplankton B 4-8W

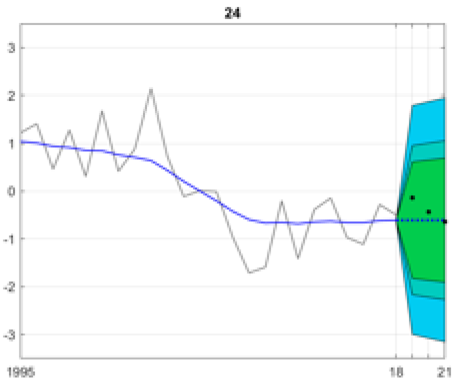
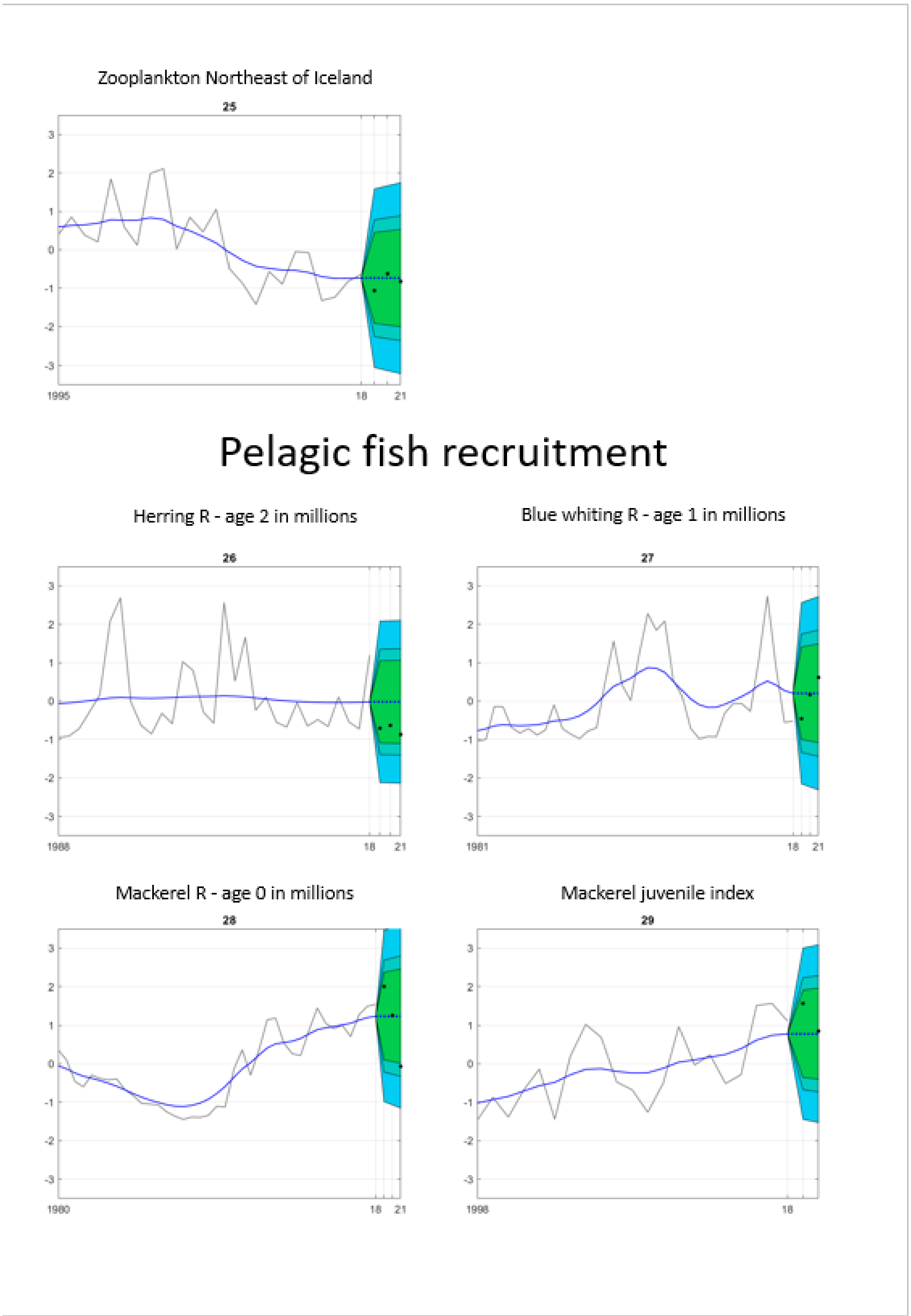


Figure A.7.3, continued on next pages



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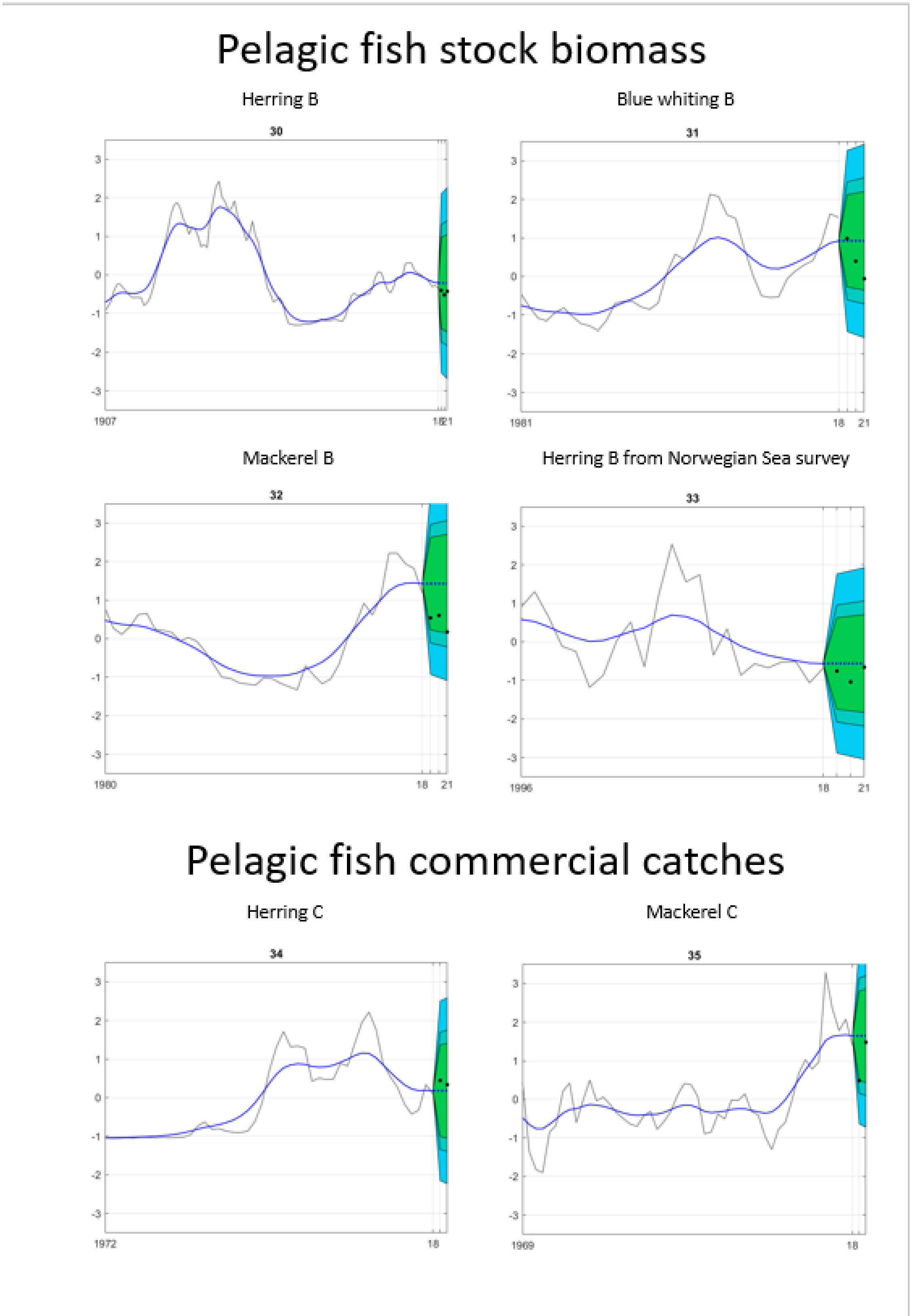

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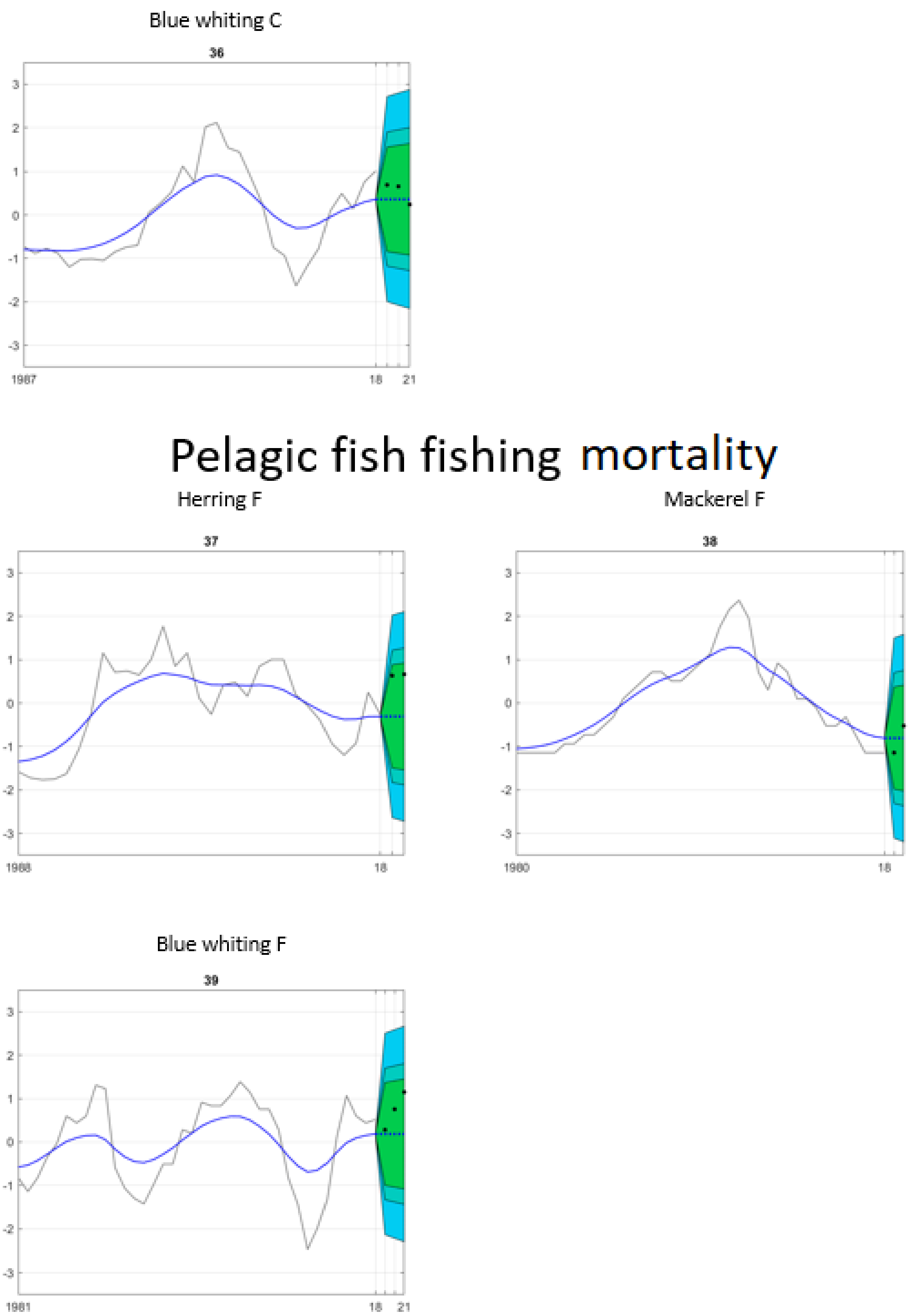

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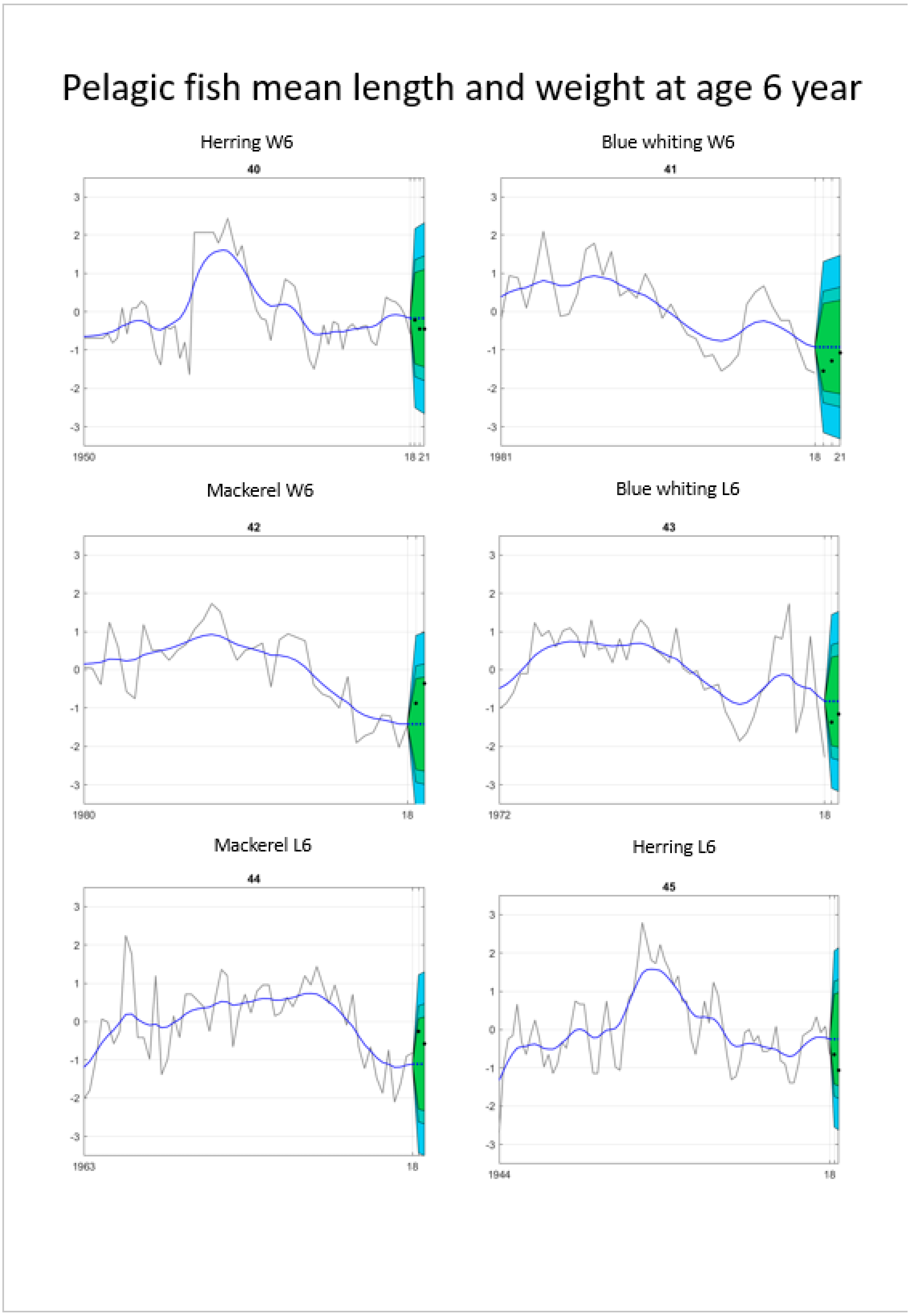

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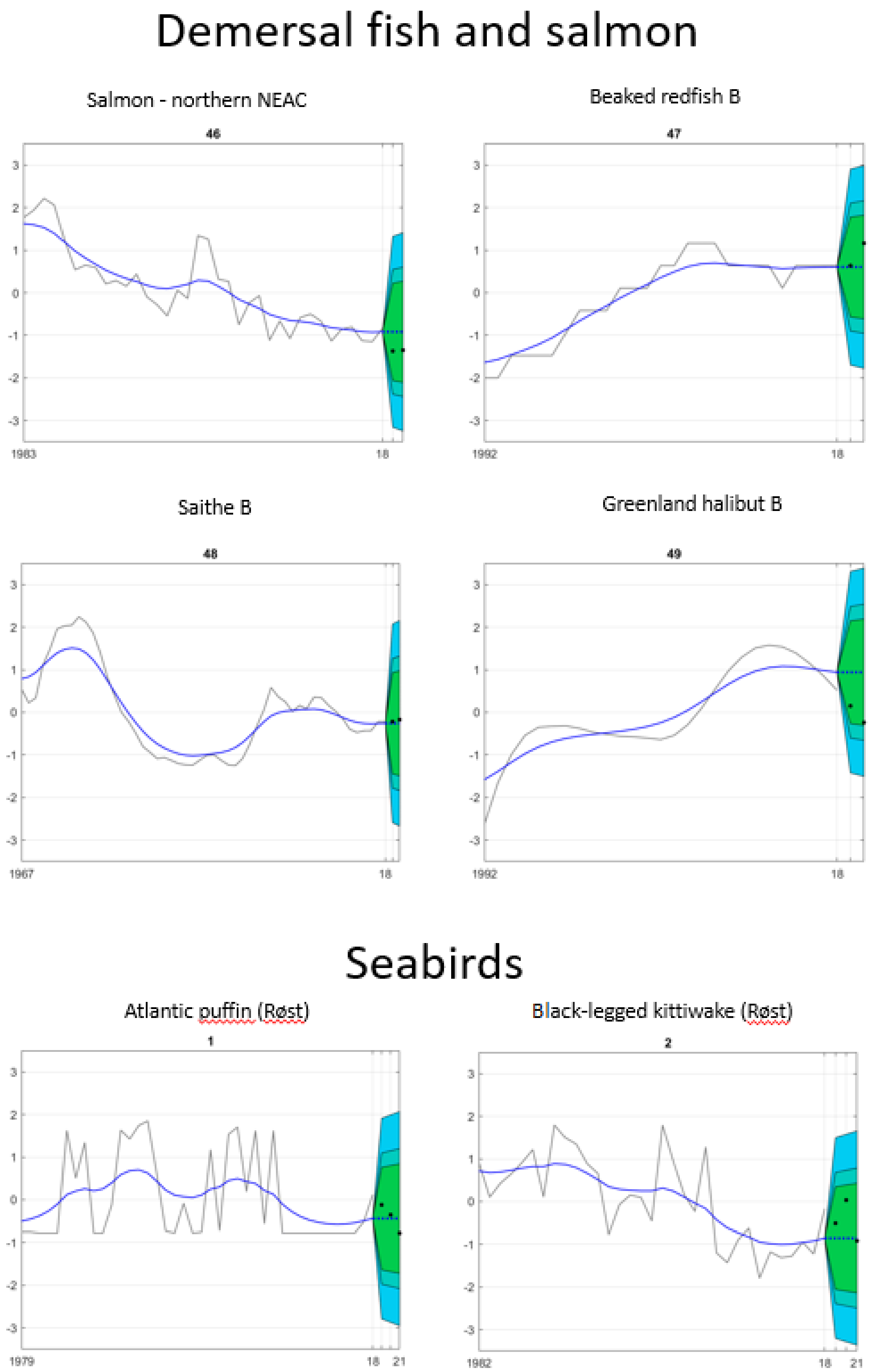

Figure A.7.3. Results from flagged observation analyses of 51 time series on climate, primary production, secondary production, pelagic fish recruitment, biomass, catches in fisheries, fishing mortality and mean length and weight at age 6 years, demersal fish and salmon and seabirds. Grey line runs between 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.