WORKING GROUP ON THE INTEGRATED ASSESSMENTS OF THE NORWEGIAN SEA (WGINOR; outputs from 2023 meeting)

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Contents

i Executive summary

The ICES Working Group on integrated assessments for the Norwegian Sea (WGINOR) synthesizes and evaluates information on physical, chemical, ecological, human, and environmental processes affecting the Norwegian Sea ecosystem. For this purpose, it gathers information, performs data analyses, and interacts with stakeholders. Based on these, WGINOR develops and produces an annual ecosystem status summary and assembles a knowledge base that supports the Norwegian Sea Ecosystem Overview.

In 2023, WGINOR updated the integrated ecosystem assessment of the Norwegian Sea and reports that 1) while the extent of Arctic Water is increasing, the heat content in the Norwegian Sea remains above the long-term average, 2) the annual primary production remains stable, but the seasonal timing of peak production is gradually shifting to a later date, 3) zooplankton spring biomass declined in the mid-2000s and since then there has been no clear trend but variations between years, 4) spawning-stock biomass of herring and mackerel continued to decline in 2023 whereas the blue whiting stock is increased due to historically high recruitment of two year classes, 5) breeding numbers for Atlantic puffin and black-legged kittiwake continue to decline at the Norwegian coast and common guillemot numbers remain low despite an increasing trend in the last decade, 6) distribution of baleen whales has gradually shifted towards Barents Sea and North Sea. Minke whale abundance is estimated to have increased considerably in the last years. Abundance indicators for main seal species suggest declining numbers or are highly uncertain.

WGINOR is gradually implementing standardized data analysis procedures. For the second time, some of these analyses are implemented in the ICES Transparent Assessment Framework (TAF). WGINOR is also developing a set of geographical polygons to report the results of regional analyses in a standardized manner. WGINOR began work of systematically reviewing and selecting indicators, from a compilation of time-series available to WGINOR, to be included in the integrated ecosystem assessment of the Norwegian Sea. In 2023, the indicators time-series for ocean climate and fish were reviewed.

In 2023, WGINOR discussed emerging issues related to underwater noise and deep-sea mining. WGINOR invited stakeholders from the Faroe Islands' organizations to further develop the dialogue between WGINOR scientists and the end-users of WGINOR work. Additional scientific highlights from the group include research on foodweb assessment modelling, regime shift detection methods, mackerel migration, and blue whiting early life stage survival.

ii Expert group information

Expert group name	Working Group on Integrated Assessments of the Norwegian Sea (WGINOR)
Expert group cycle	Multiannual fixed term
Year cycle started	2022
Reporting year in cycle	2/3
Chairs	Anna H. Ólafsdóttir, Iceland
	Benjamin Planque, Norway
Meeting venues and dates	14–17 November 2022, Sommarøy, Norway and online (28 participants)
	20–23 November 2023, Tórshavn, Faroe Islands and online (61 participants)

1 Introduction

The Working Group on the Integrated Assessments of the Norwegian Sea (WGINOR) met at Havstovan in Tórshavn, Faroe Island on the 20–23 November 2023 to review the progress made on all terms of reference. The meeting was held in a hybrid format with ~2/3 of the participants physically attending and ~1/3 online.

At the annual meeting, progress on all terms of reference (ToR) was presented and discussed. Additionally, there was a plenary discussion about diversity, equity, and inclusion (DEI) goals for WGINOR. The new ICES stakeholder guidelines (ICES, 2024b) were introduced in plenary and discussed. There was a plenary discussion about potential collaboration and even integration of the five ICES working groups for integrated ecosystem assessment in Nordic Seas. Three science highlights and two emerging issues for future revision of the ecosystem overview were presented and discussed. Finally, future funding opportunities for WGINORs research were discussed.

Two intersessional online meetings were organized during 2023. One meeting was to select time-series for oceanographic variables to include in the WGINOR dataset. The other meeting was to select time-series representing fish biology and ecology. Time-series included in the WGINOR dataset are used to preform integrated assessment of the pelagic ecosystem of the Norwegian Sea and to update ecosystem status summary report of trends and recent changes in the region.

The list of participants is provided in Annex 1 and the meeting agenda in Annex 3.

The terms of reference are as follows:

- ToR a: Perform integrated assessment of the pelagic ecosystem in the Norwegian Sea and develop a framework for identifying important signals for management.
- ToR b: Utilize multispecies and ecosystem models to evaluate effects of single and multispecies harvest control rules on fishing yield and ecosystem state of the pelagic ecosystem in the Norwegian Sea.
- ToR c: Continue development of forecast products (1–5 years) for ocean climate and initiate development of forecast products for other ecosystem components in the Norwegian Sea.
- ToR d: Continue improvement of workflow, transparency, and replicability.
- ToR e: Develop a two-way dialogue between WGINOR and relevant stakeholders and managers in Norway, Faroe Islands, and Iceland.
- ToR f: Compile information for future ecosystem overview revisions based on the ICES technical guidelines.
- ToR g: Annually review and revise the ecosystem status summary to report trends and recent changes.

2 Integrated assessment of the Norwegian Sea (ToR a)

The integrated assessment of the Norwegian Sea consists in the presentation of the current state and recent trends in several ecosystem components, including the physical ocean and atmosphere, primary producers, zooplankton communities, fish, marine mammals, and birds. For this purpose, a collection of indicator time-series are updated annually. The current knowledge of the Norwegian Sea ecosystem is presented and discussed among WGINOR group members at the annual meeting. In 2023, this took place during the first and last day of the meeting.

Since 2020, the result of these presentations/discussions is summarized in the form of an "Ecosystem Status Summary" (ESS). The general principles for the writing/updating of the ESS are presented in section 8 of this report and the ESS is presented in Annex 4.

The key message from the 2023 assessment is as follows:

- Extent of Arctic Water has increased from 2017. This has been accompanied by a freshening and cooling. Due to relatively low heat loss from the ocean to the atmosphere, the heat content in the Norwegian Sea remains above the long-term average.
- During the period 2003 to 2023 primary production has varied slightly from year-to-year and without noticeable trend. The timing of the peak of production has gradually shifted to a later date by 10 days per decade.
- Zooplankton spring biomass, measured since 1995, declined in the mid-2000s. Since then, there has been no clear trend but variations between years. The biomass has been low in some subareas the last few years.
- A decline in spawning biomass started around 2009 for Norwegian spring-spawning herring and around 2015 for mackerel. These declines continued in 2023. Blue whiting biomass increased by more than a third in 2023, driven by historically high recruitment of two year classes.
- Long-term decrease in breeding numbers for Atlantic puffin and black-legged kittiwake continues at the Norwegian coast. Common guillemot numbers are still low but have increased markedly over the last decade.
- Abundance indicators suggest declining population levels for hooded and grey seals, low levels for harbour seals, and highly uncertain for harp seals. Harbour porpoise bycatch levels estimated over the period 2006-2018 were unsustainable. The distribution of baleen whales has gradually shifted towards the Barents Sea and the North Sea. The abundance of minke whales in the region is estimated to have increased considerably in the last years.

3 Multispecies models to evaluate harvest control rules (ToR b)

An update on multispecies Management Strategy Evaluation for Norwegian Sea pelagic fish stocks

A Management Strategy Evaluation (MSE) has been previously developed to test single-species harvest control rules against likely consequential interactions between the Northeast Atlantic mackerel, blue whiting, and Norwegian spring-spawning herring stocks (ICES, 2023a). This presentation provides updates on both developments in the MSE framework and new results. The multispecies MSE framework was adapted from FORTRAN code underlying the models presented in Skagen *et al*. (2013). This code base was generalized and wrapped in a R packaged now named *simse* (**S**uper-**I**ndividual based **MSE**). One new result is the inclusion of competition effects via density-dependence in growth. Models incorporating both interspecific (total abundances of all three species, or subsets of two species) and intraspecific density effects were explored; for all species, models incorporating only intraspecific density effects produced the best predictions of historical trends in each stock's average weights-at-age. Precautionary fishing reference points (Fp05) were computed using models with these density-dependent effects, which produced equal (for herring) or higher (for mackerel and blue whiting) values compared to those currently used by management (ICES, 2022a). However, when finding the optimal target F that is input into each stock's HCR with TAC stability constraints incorporated in MSE simulations, optimal values were identical with those currently used by management (equal to Fp05). Additional updates were made to previous MSE simulations exploring mackerel predation effects on herring recruitment. The most notable is the development of a model that accounts for mackerel overlap with larval herring that is modulated by larval drift velocities (i.e. the effect of mackerel is weaker in years when herring may be transported more rapidly northward). Testing a set of plausible herring HCR's against this interaction model (assuming historical patterns in herring larvae starting locations and drift velocities) shown no herring HCR was precautionary. Overall, these results suggest existing single-species management for mackerel and blue whiting is "optimized" against effects of competition, while the herring HCR (specifically the control parameters) may not be robust to continuing mackerel predation in the long term.

4 Forecast products (ToR c)

Lateral oceanic connectivity and advective delays make Norwegian Sea water more predictable than the rest of the world oceans

The subpolar North Atlantic oceans are important for the global climate system, and for the global production of marine food. Poleward upper-ocean flows of warm and saline Atlantic waters, and southward returning cold and dense near-bottom waters (the Atlantic Meridional Overturning Circulation, AMOC) are highly important for the living conditions around the subpolar oceans, the rapidly changing Arctic Ocean, as well as for the circulation in the World Oceans. The strong, but variable, atmospheric jet stream controls the number, intensity, and pathways of storm systems across the subpolar Atlantic, which cool the surface ocean, lead to deep winter convection (1-2 km) and nutrient upwelling, in addition to adding vorticity to the ocean. This induces marked horizontal circulation cells like the Subpolar Gyre and the Norwegian Sea gyre, whose variable size and strength modulate the physical characteristics of the main AMOC flow branches, and their biogeochemical and biological content. Together with the northward flowing warm water, ideal conditions for primary production are established, which in turn enables the subpolar North Atlantic to accommodate its very rich ecosystems. The involvement of a deep water column and the considerable lateral oceanic connectivity and associated advective delays, both make these water more predictable than the rest of the world oceans. Key convective processes, and the upper ocean Arctic-to-Atlantic oceanic connectivity take place on Greenlandic waters, while Faroese waters represent the main gateway between the North Atlantic and the high Arctic. Furthermore, there is transatlantic connectivity. Waters from Greenland flow eastwards across the North Atlantic and influence properties of the Atlantic inflow in Faroese waters, and this signal returns westwards, and can be observed far north along the east Greenland slope - after a time-lag.

Major shifts in this complex system directly affect the livelihood and distribution of commercial fish stocks, seabird populations and marine mammals – also identified as biogeographic shifts. While such shifts have always been part of natural cycles, man-made influence could provoke the system into a hitherto unknown realm, potentially leading to irreversible tipping points. Central themes in the climate reports from the Intergovernmental Panel for Climate Change (IPCC) are a weakening of the AMOC and a reduction in total animal biomass, particularly in the waters southeast of the Faroes and the North Sea during the 21st century. It is, however, admitted that the climate model uncertainty is especially pronounced in the waters south of Greenland.

The unity of the Danish realm (Denmark, the Faroe Islands and Greenland) thus stands in a unique position to improve our ability to make predictions of the marine climate and ecosystems, both on short (< 5 years) and on climate projection (50–100 years) time-scales. And to implement monitoring and modelling activities which can improve management of our still rich marine resources. This is both an opportunity and an obligation to the international research community.

5 Workflow, transparency, and replicability (ToR d)

Continued improvement of workflow, transparency, and replicability of the scientific work that supports the IEA for the Norwegian Sea.

During the year many WGINOR members contributed to projects related to this ToR. Progress on the intersessional work was presented and discussed at the annual meeting and include:

- gradual shift towards the regular use of git and of the WGINOR GitHub repository to perform version control and to share data and code, and implementation the ICES Transparent Assessment Framework (TAF)
- development of standardized procedures for the selection of time-series of relevance to WGINOR,
- provision of standardized meta-data for WGINOR time-series,
- development of new time-series,
- compilation of mackerel abundance data,
- development and application of standardized time-series analyses and visualization tools (TREC, FO, ATAC),
- standardized documentation of the geographical polygons used by WGINOR in recent years and development of a set of geographical polygons that can be commonly used across ecosystem components.

5.1 GitHub and TAF

Data and code common to the WGINOR group is gradually made available through the group github repository (https://github.com/ices-eg/WGINOR). The analysis of net primary production (NPP) and the production of standard graphs using the ATAC method (Analysis of Trends and Recent Changes) that were implemented in the ICES-TAF framework in 2022, were updated in 2023. The "TAF_NPP" github directory also hosts the most updated version of the WGINOR polygons (https://github.com/ices-eg/WGINOR/blob/main/TAF_NPP/bootstrap/data/WGINORStrata.xlsx).

5.2 Selection of time-series

Two intersessional online meetings were held in September 2023 to select relevant time-series for WGINOR work for ecosystem components ocean climate and fish biology and ecology.

5.2.1 Ecosystem component: Ocean Climate

An online intersessional meeting was hosted online September 21, 2023. The meeting was chaired by Benjamin Planque. The meeting started with a brief introduction about the role of time-series indicators for IEAs and the existing frameworks that are used internationally for selecting relevant ocean indicators, in particular within the frame of GOOS, the Global Ocean Observing System and its Essential Ocean Variables. Some criteria considered for the selection of ocean climate time-series, and for documenting meta-data includes:

- *What data type: in situ, satellite, model, other?*
- *Is the time-series already available to WGINOR?*

- *Is it readily available, or could it be available from an external source? Resource link (doi, https)*
- *Is there available documentation about the source and processing of the data behind the time-series (e.g. using TAF)?*
- *Does the series correspond to a specific region within the Norwegian Sea? Does this correspond to a WGINOR polygon? If not, could it be made so?*
- *What is the temporal coverage? Can the time-series be updated annually?*
- *Who in the group is currently responsible for the time-series?*
- *How does the time-series relate to WGINOR Ecosystem State Summary and to the Norwegian Sea Ecosystem Overview?*
- *Are there uncertainties estimates associated with the time-series? If yes, are these provided to WGINOR? If no, could these be obtained?*
- *Is there a possibility to derive forecasts (1-4y), outlooks (5-20y) or projections (20+y) for this time-series?*
- *How does it relate to GOOS Essential Ocean Variables?*

The outcome of this discussion included:

- *Transition from three NAOI (North Atlantic Oscillation Index) to a single index: the NAOI from NCAR Pressure based (not PCA based), NCAR is referred to as source of data and documentation.*
- *Removal of the three pressure difference indices previously reported by WGINOR: Agmasalik-Stykkis, Scoresbysund-Jan Mayen, and Danmarksh-Svalbard.*
- *Transfer of the responsibility for documenting and updating the Subpolar Gyre indices (SPGs) to the* Working Group *on Oceanic Hydrography, within the framework of IROC (Ices Report on Ocean Climate).*
- *Need for further discussion on the interpretation of the Norwegian Sea-Lofoten gyre index. The time-series of this indicator is continued for the time being.*
- *Time-series of Svinøy section core temperature and salinity are maintained. These are EOVs and IROC will be referred to as the source of data and documentation.*
- *Time-series of relative heat content and freshwater content are maintained. IROC will be referred to as the source of data and documentation.*
- *Time-series of area for S>35 (km*^{2}*) and Arctic Water in the Norwegian Sea are maintained. This are prepared by and for WGINOR. The group has responsibility for fully documenting how these series are produced and eventually move the calculations into TAF or a TAF-like sysem.*
- *The time-series Temp-Langanes-East7 and Salinity-Langanes-East7 are maintained. These are EOVs. They are not currently part of the IROC time-series. WGINOR should seek for their inclusion in IROC and could then refer to IROC to as the source of data and documentation.*
- *Additional time-series related to ocean currents, sea surface temperature (SST), surface heat fluxes, or heatwaves could be considered by WGINOR in the future*
- *External data and indicator sources, such as Copernicus Marine Services should also be considered as a possible source of dataseries and documentation. Discussion are ongoing, supported by the EU-project NECCTON.*

5.2.2 Ecosystem component: Fish biology and ecology

An online intersessional meeting was hosted online September 20, 2023 (meeting minutes in Annex 7). The meeting was attended by nine WGINOR members and chaired by Anna H. Ólafsdóttir. The meeting began with a discussion about criteria for time-series selection. It was decided to select one time-series to describe a phenomenon, data needs to be accessible to WGINOR, the fish stock needs to be distributed over a significant part of the ecoregion, to use variables calculated at fish stock level, to include time-series uncertainties when possible, and if the time-series is produced by WGINOR the goal is to document the time-series compilation, code made accessible on GitHub, and provide open access to the data. For size-at-age variables it was decided to use the age when approximately 90% or more of a year class is mature.

Currently, time-series related to fish biology and ecology are mostly limited to three pelagic stocks (Norwegian spring-spawning herring, Northeast Atlantic mackerel, and Northeast Atlantic blue whiting) for several reasons. They have a wide-ranging distribution in the Norwegian Sea, at least during their summer feeding season, are keystone species in the foodweb of pelagic ecosystem, are commercially important, and are data rich compare to other fish species present in the ecoregion.

Time-series for abundance of saithe and Greenland halibut were removed from WGINOR IEA as their distribution is limited to a small part of the ecoregion. Time-series for abundance of redfish and salmon abundance time-series remain a part of the IEA as these stocks are distributed throughout the ecoregion.

For the pelagic fish stocks, it was decided to use herring age 2, mackerel age 2 and blue whiting age 1, derived from the annual stock assessment (ICES, 2024a), to present size of year-class at recruited to the fishing stock. For stock biomass, estimates of spawning-stock biomass from the assessment will be used. ICES landings will be used to represent amount of annual catch per species. For size-at-age, weight in the stock for the assessment will be used for herring age 6, mackerel age 3 and blue whiting age 4. All the time-series except catch include uncertainty estimates.

5.2.3 Future work on selection of time-series

At the annual meeting in November 2023, there was a plenary discussion about the next steps in time-series selection for WGINOR IEA. It was decided to select IEA time-series for four ecosystem components during the next work year by hosting online intersessional meetings with WGINOR members and relevant scientists from outside WGINOR. The four ecosystem components are:

a) Top predators – marine mammals. Currently no time-series are included in WGINOR IEA. Intersessional meeting to be chaired by Anne Kirstine Frie and Hiroko Solvang
b) Human activities. Currently no time-series are included in WGINOR IEA. Intersessional meeting to be chaired by Lucie Buttay.
c) Biogeochemistry. Currently no time-series are included in WGINOR IEA. Intersessional meeting to be chaired by Per Arneberg.
d) Primary production. Intersessional meeting to be chaired by Benjamin Planque.

5.3 Meta-data for time-series

Improvement of metadata information for time-series, used by WGINOR for IEA, began at the annual meeting and the aim is to finalize the work by correspondence before the annual meeting 2024. The new format for WGINOR time-series includes 2 data-table. The first table called *MetaData* contains the information relevant to the description of individual time-series. The second table named TimeSeries contains the actual values of each time-series. The two tables are related via the key-variable *ShortName.*

The current mete-data descriptions include:

- *Series category: climate, primary production, secondary production, seabirds, mammals*
- *ShortName (no special characters, no space)*
- *Variable name*

- *Unit*
- *data type: in situ, satellite, model, other*
- *Ressource link, doi…*
- *Source*
- *Description*
- *comment (This column will be removed. All this information is covered in other columns)*
- *Series in TAF: yes no*
- *Regional extent: Station, transect, polygon, depth layer, other?*
- *Temporal coverage*
- *Contact person*
- *E-mail*
- *Series used in the ecosystem status summary, and/or for the ecosystem overview?*
- *Are there uncertainties estimates associated with the time-series? If yes, are these provided to WGINOR? If no, could these be obtained?*
- *Is there a possibility to derive forecasts (1-4y), outlooks (5-20y) or projections (20+y) for this time-series?*
- *How does it relate to GOOS Essential Ocean Variables (http://www.goosocean.org/eov)?*
- *Could this be requested to (provided by) an external source such as Copernicus Marine Services*

5.4 New time-series

Multiple time-series were considered as candidate for inclusion in WGINOR work and were discussed at the meeting. These include new time-series related to ocean climate (section 5.2.1), to spatial distribution of pelagic fish (section 7.3), to foodwebs (section 7.4), to total fishing pressure (section 7.5), and other human activities and related pressures (section 7.6).

5.5 Standard time-series analyses and visualizations

In recent years, WGINOR has developed methods to standardize the statistical analysis and visualization of multiple time-series. This was done through the development of TREC (trend estimation and classification, Solvang and Planque, 2020; Solvang and Ohishi, 2023), FO (Flagged observations) and ATAC (Analysis of Trends And recent Changes, https://github.com/ices-eg/WGINOR/tree/main/TAF_ATAC). The statistical approaches and implementations vary between methods, but the goals are similar, that is to analyse past changes in time-series in a systematic manner, with a focus on the multidecadal trends and on recent years' variations. Advantages of using standardize methods include: to ease interpretation by WGINOR group members, to build group capacity in statistical interpretation, to improve the comparison and communication of results across different ecosystem components. Examples of analysis using both methods are illustrated in figure 5.1. The methods' description and the analyses of the entire set of WGINOR time-series are presented in Annex 5 (ATAC) and Annex 6 (TREC and FO).

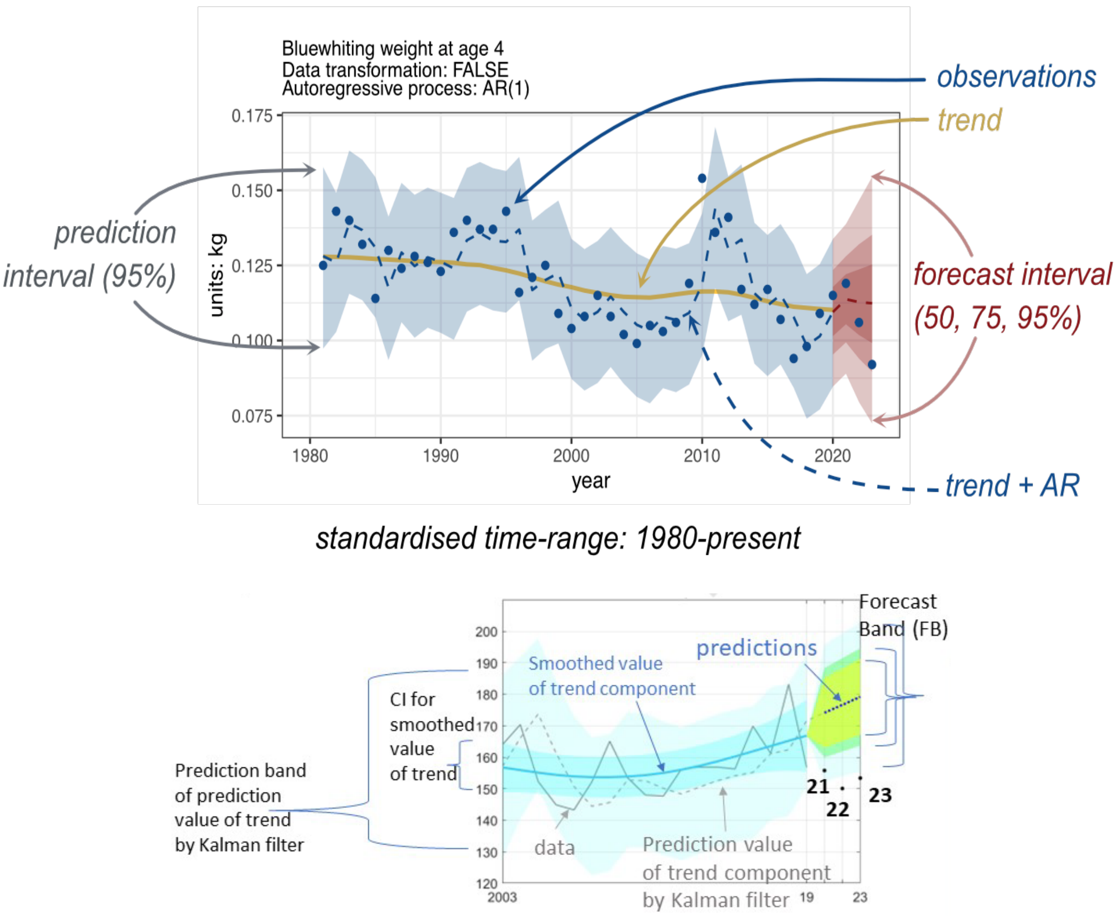

Figure 5.1 An example of ATAC (top) and TREC-FO (bottom) results highlighting the different graphical elements used for the interpretation of temporal changes.

5.6 WGINOR polygons

In 2022, the set of geographical polygons used by the members of WGINOR in the past was compiled and a first draft of *common* polygons was established. This set is called the *WGINOR polygons*. In 2023, this set was circulated between Norway, Iceland and the Faroes and was further refined. The file containing the polygon definitions is available from the WIGNOR GitHUb (https://github.com/ices-eg/WGINOR/blob/main/TAF_NPP/bootstrap/data/WGINOR-Strata.xlsx). The revised polygons were discussed during the 2023 meeting and some further refinements will be conducted in 2024. These include:

- splitting of the subpolar midwater polygon (SPMW) in two parts, one in the North and one in the south (light blue line in figure 5.2)
- exclusion of the Faroe shelf from the SPMW polygon,
- adjusting the southwest border of the SPMW to follow the Reykjanes ridge,
- adding of two new polygons towards Greenland (white delineations in Figure 5.2).

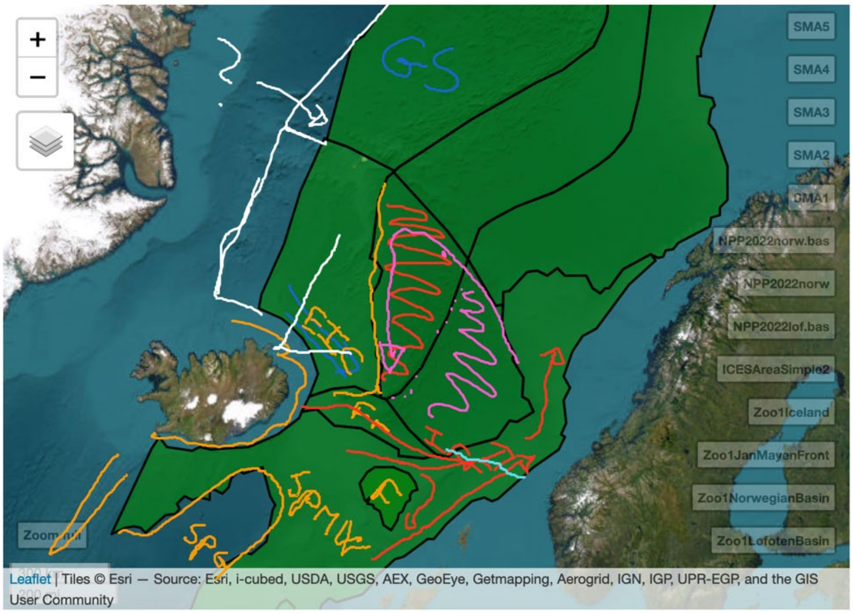

Figure 5.2 Geographical distribution of the WGINOR polygons. The colored drawings were added during the annual meeting discussion on polygon definition.

5.7 Mackerel abundance data

Creating a dataset with mackerel swept-area abundance data from IESSNS is necessary for computations of time-series describing mackerel distribution. IESSNS raw trawl catch weight by species for all stations exists in the PGNAPES database, closed access database hosted at Havstovan in Faroe Islands. The raw PGNAPES output includes several invalid trawl stations, for each year, which cannot be identified from information recorded in the database. In depth knowledge from IESSNS participants is needed to separate invalid stations from valid ones. Anna H. Ólafsdóttir and Sólvá K. Eliasen, IESSNS participants for years, have now compiled a mackerel abundance data from IESSNS which only includes valid trawl station and has swept-area abundance calculated from the raw catch weight.

The work included creating an R code that details invalids stations and deletes them from data. Calculations of mackerel abundance from mackerel catch weight are also included. At the annual meeting, an error in the mackerel abundance data were discovered, its source identified, and code corrected.

Future work includes more thorough error checking of mackerel abundance data and the R code, add a direct connection to the PGNAPES database to the code, and make the code available open source (WGINOR GitHub).

6 Dialogue with stakeholders (ToR e)

First open dialogue of WGINOR with stakeholders in the Faroe Islands

WGINOR ToR e focuses on developing a dialogue with stakeholders in the country where the annual meeting is hosted each year. In 2023 the meeting was hosted in Faroe Islands. WGINOR members from Faroe Islands organized a half day stakeholder meeting for Faroese stakeholders (meeting minutes in section 6.1). This was the first time WGINOR hosted a stakeholder session in the Faroe Islands. The meeting aimed at introducing WGINOR research and scientific output to stakeholders. Invitations to attend the meeting were sent to 21 entities which included ministries, governmental agencies, academic institutes, fishing industry associations, private companies, and nongovernmental organizations. The meeting was attended by fifteen stakeholders representing ten entities (Table 6.1). Stakeholders were given the opportunity to ask questions during dedicated periods, between the scientific presentations. The meeting host put great effort into engaging stakeholders in a discussion after each presentation. Most of the meeting was conducted in Faroese.

Table 6.1 List of entities invited to attend the stakeholder meeting with information on how many persons attended from each entity.

Entity	Invited	Attendance
Ministry of Fisheries	x	3
Ministry of Foreign affairs, Industry and Trade	x	0
MRCC	x	0
Faroese Environment Agency	x	0
Statistics Faroe Islands	x	0
University of the Faroe Islands	x	1
Faroese Geological Survey	x	0
NGO's	2 invited	0
Faroese Pelagic Association	x	1
Shipowner's Association	x	1
Pelagic companies/Shipowners	x	5, representing 4 companies
Other companies	5 invited	4, representing 2 companies

6.1 Meeting minutes from the stakeholder meeting

Stakeholder meeting. Held at Havstovan (Faroe Marine Research Institute) 22 November 2023, 13:30–16:00

Invitations were sent out to 21 entities, of which some are umbrella organizations/associations one month prior to the meeting and a reminder was sent the week prior to the meeting. Together with the invitation, "Norwegian Sea Ecosystem Overview" and the "Ecosystem Status Summary" (ESS) were also attached. The ESS was also available in printed format at the meeting.

21 persons, representing 13 entities responded and said that they wanted to come. In the end 15 persons, representing 10 entities came.

The meeting

13.30-14.40 First session:

- Marita Rasmussen (Director at Havstovan) says welcome
- Eydna í Homrum introduces the group
- Anna Ólafsdóttir gives a presentation about WGINOR
- Sólvá Eliasen gives a presentation about phyto- and zooplankton
- Hjálmar Hátún gives a presentation about oceanography
  - Two questions: Anna Ólafsdóttir asks about western expansion of mackerel and East Icelandic Current.

14.40 Coffee break – ESS copies available to participants

15.15-15.45 Second session

- Jan Arge Jacobsen presents about pelagic species (herring, blue whiting and mackerel)

15.45-16 Questions and discussion

To Jan: Representative for Fishowner's Associacion asks about "Historial assessments compared to current assessment: Are similar issues seen in herring and blue whiting as in mackerel?" – No. Talk for a while about the mackerel stock assessment and the issues it has.

Eydna: asks the audience about feedback on the ESS. Seems that nobody has read. Therefore: we hope to get feedback for next meeting.

Eydna: Ecosystem based management – what do people think? We're far from it. If not well done, it is a disaster. It's necessary to start somewhere in order to reach the high goals.

Anna: asks which concerns the stakeholders have regarding the future. Pelagic company: the herring fishing season has been shortened over the last 6 years with a week pr year. This is worrying. It is also worrisome that the herring stock is predicted to go below Blim. Sjókovin: It is worrying that herring and mackerel stocks are both going down. If the coastal states reach an agreement, our quotas will be much reduced, perhaps with 50%. Sjókovin wishes that the Faroes would fish more sustainable. This would increase chances for not going below e.g. Blim and in addition we would get other benefits as well.

6.2 Update on the ICES Stakeholder engagement initiative

In October 2022, the ICES Stakeholder Engagement Strategy (ICES, 2024b) was approved by the ICES Council and the Workshop on Implementation of Stakeholder Engagement Strategy (WKSTIMP) was established to develop guidelines for this strategy. The WKSTIMP report defines a suit of actions to make the ICES Strategy work. If implemented successfully, a diverse and representative pool of competent, reliable, and committed stakeholders will engage with ICES. All stakeholders will be able to contribute effectively based on a clear understanding of the process and what is expected from them. ICES will become a natural place for stakeholders to engage and collaborate, delivering better science and advice by integrating essential knowledge and providing arenas for meaningful dialogues. And, the engagement process will be fully traceable, and its monitoring and evaluation outcomes inform decision-making and organizational learning (Figure 6.1).

The ICES Stakeholder Engagement Strategy was not used for guidance when planning the stakeholder session presented in the current report as WGINOR chairs were yet not aware of the release of the strategy. The strategy will be included for guidance for planning future stakeholder engagement.

Figure 6.1 ICES Stakeholder Engagement Strategy Principles. Source ICES Stakeholder Engagement Strategy

7 Information relevant to Ecosystem Overview (ToR f)

Relevant emerging issues and new ecosystem indicators

Following the dialogue with stakeholders in 2022 (section 6 in ICES, 2023b) two topics in relation to emerging issues were selected for presentation: underwater noise and deep-sea mining. These are of potential relevance to the next Ecosystem Overview. Paul Wensveen and Gabrielle Dublet-Adli were invited to present the current status of the Norwegian Sea regarding these two emerging issues, and to discuss about their possible implication. Further plenary discussions pointed to a potential emerging issue related to whale-fish-fishing interactions, e.g. impacts of whales preying on fish, importance of the whale pump, emerging new stock assessment for whales. These is identified as a specific topic for discussion in future WGINOR meetings. There were no additional emerging issues identified during the stakeholder dialogue at the 2023 meeting.

Indicators of relevance to future ecosystem overviews include indicators of fish spatial distribution, indicators of foodweb structure, indicators of regional fishing pressure, and other indicators of human activities. These were presented and discussed in plenary.

7.1 Emerging issue: Underwater noise

Paulus J. Wensveen

Underwater noise generated by human activities in the oceans is an emerging topic of concern. This presentation provided a brief introduction to the physics of sound underwater, sound sources and their characteristics, importance of sound for marine wildlife, and potential impacts of anthropogenic noise. Research on communication masking in baleen whales and behavioral responses of beaked whales to naval sonar was highlighted. We discussed joint monitoring programs in the EU including their recent efforts to create basin-wide noise maps, and the need for such project in the Norwegian Sea area.

7.2 Emerging issue: Deep-sea mining

Gabrielle Dublet-Aldi

Interest for deep-sea minerals is growing with the demand on critical elements and with the need for supply independence. It is not clear if deep-sea mining will become an important activity in the near future, due to uncertainties on ore values, technological challenges to access and treat the ores occurring in extreme environments, lack of legislation in place and public resistance. However, Norway is one of the countries, with Cook Islands, Japan, and maybe China, driving deep-sea exploration towards extraction in national waters. Deep-sea mining is thus an emerging issue potentially affecting more or less locally the seabed (life and support removal, compaction, burial, shift of feeding communities, etc) and the water column (turbidity, sound, temperature, organic matter, metal concentrations, etc). Deep-sea mining activities may also affect global geochemical processes (e.g. C cycling), connectivity and behavior of living populations, political relationships, and other anthropic sea activities. Due to lack of knowledge, the foreseen effects are not easily measurable or quantifiable, and the political requirement of sustainability in management of deep-sea exploitation will inevitably be entailed by evaluative uncertainties (e.g. regarding the definition of environmental goals, survey and monitoring criteria and thresholds, and the effectiveness of mitigation strategies). Research activities are currently addressing important challenges, for example technological development (e.g. Green Platform project by

ADEPTH minerals), exploration (e.g. MINDeSEA) and to some extent, environmental baselines and management questions (e.g. Hitchin *et al.*, 2023) while the international seabed authority is pressed by exploration initiatives (e.g. Nauru / The Metal Company in 2021) to develop regulations (Singh, 2021) and Norway already produced a law in 2019 regulating the process for exploration and extraction in national deep waters. (Lov om mineralvirksomhet på kontinentalsokkelen (havbunnsmineralloven) - Lovdata.)

7.3 Spatial indicators for pelagic fish distribution

Currently no time-series describing spatial distribution of the three pelagic stocks, in the Norwegian Sea, is included in the WGINOR time-series collection. The Global Ocean Observation System guidelines for observing fish abundance and distribution (https://www.goosocean.org/index.php?option=com_oe&task=viewDocumentRecord&docID=17510) state that measurement of fish distribution is an essential part of ecosystem monitoring.

At the intersessional meeting, 20 September, it was decided that WGINOR would begin analytical work to produce time-series describing spatial distribution of pelagic fish stock in the Norwegian Sea. Two annual international research survey measure abundance and distribution of the three pelagic species in the Norwegian Sea, conducted in May and July. However, the standard output from the surveys does not include time-series measuring spatial distribution of the three stocks. It was decided that WGINOR members would begin analytical work on compiling time-series describing spatial distribution of mackerel in Nordic Seas in July (ICES IESSNS survey) with the goal of presenting preliminary results at the annual meeting in November. The analytical approach will be developed by Hiroko Solvang. Anna H. Ólafsdóttir and Sólvá K. Eliasen are responsible for compiling time-series of mackerel abundance per trawl station from the IESSNS, from 2010 to current, from raw IESSNS survey data extracted from the PGNAPES database, located at Havstovan in Faroe Islands.

At the annual meeting, Hiroko Solvang presented results from calculations of mackerel center of gravity in Nordic Seas in July from 2010–2023. The results showed error in the raw mackerel abundance data and large impact of few extreme catches on center of gravity. During a plenary discussion, error in raw input data were identified, options for analytical methods to minimize impact of extreme catches were discussed and suggested to use more than one time-series to measure annual changes in mackerel distribution. The next steps are to correct the raw input data (see section 5.3), to find the best statistical method to minimize the impact of few extreme catches on spatial calculations, and to calculate time-series measuring geographical size of mackerel distribution area, maximum northward distribution in the Norwegian Sea, and maximum westward distribution in Nordic Seas.

7.4 Foodweb indicators

A foodweb assessment model was developed for the purpose of quantifying foodweb dynamics in the Norwegian and Barents Seas (see section 10.1). The outputs from this model provide complements to the outputs from stock assessment models that focus primarily on biomass or numbers within isolated populations. In contrast to stock assessment, foodweb assessment models focus primarily on interactions between species (or species groups) and provide reconstructed dynamics of trophic fluxes (consumption and predation). The indices derived from the foodweb assessment are model-based (the trophic exchanges are modelled) and data-constrained (the reconstructions should match observations and knowledge). With reconstructions available for a simple foodweb that includes the major fish species and groups (including mackerel, herring, blue whiting in the Norwegian Sea), it is possible to derive time-series of simple indices such as consumption-over-biomass and predation-over-biomass (see Figure 7.1). The model outputs are also amenable to more thorough analyses using for example Ecological Network Analysis (ENA, Ulanowicz, 2004). Combining foodweb assessment modelling with foodweb indicators will contribute to understanding the structure of marine foodwebs and how they respond when perturbed, which are fundamental prerequisite of Ecosytem Based Management. This is a key area for research within ICES and this work will be presented and discussed at the ICES workshop on the operational use of Food Web indicators and information (WKFoodWeb) in February 2024.

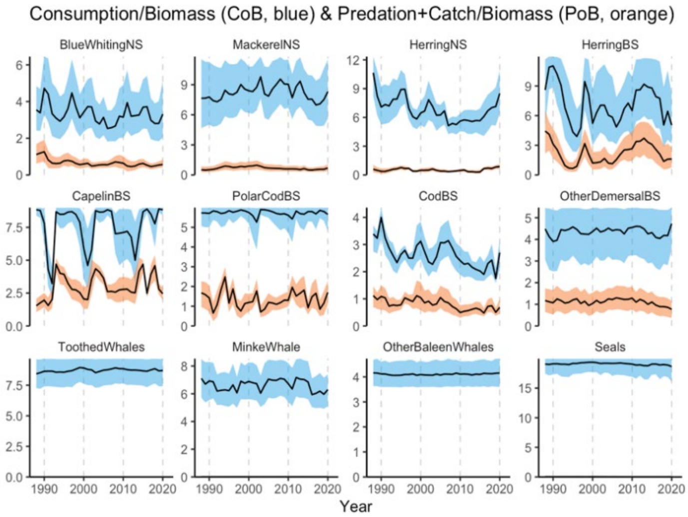

Figure 7.1 Modelled time-series of consumption-over-biomass (blue) and predation&catch-over-biomass (orange) for the 12 species included in the foodweb assessment model. The black lines show the median estimates and the colored ribbons provide uncertainty estimates (95% intervals).

7.5 Ecosystem Fishing Index

One challenge for Integrated Ecosystem Assessments (IEA) is to identify indicators of ecosystem status that are informative, robust and can be transferable into management actions. In the Norwegian Sea ecoregion, fishing represents the most important pressure on the ecosystem. Most individual fish stocks in the region are described as well managed. However, the impacts of fishing extend beyond individual fish populations. The combined effects of fishing on all targeted and non-targeted populations can affect ecosystem functioning and the related activities and services. Recently, some indicators of fishing pressure at an ecosystem level have been proposed (Link and Watson, 2019). Two of those indicators have been applied and tested for the ICES IIa area: the Ryther index and the Fogarty index. The Ryther index, corresponds to the annual total catch per square kilometer. During the period 2006–2021, the Ryther index was above the threshold of ~ 1 tonne.km^{-2}.year^{-1}, proposed by previous studies to characterize overfishing (Figure 7.2). This could indicate that the system is highly productive, that the species fished in the ICES IIa regions use a much wider area, or that the Norwegian Sea is experiencing ecosystem overfishing. Here we highlight the potential of the Ryther index, to document how the fishing pressure change in time in the area. Although some additional work would be needed to propose a threshold of overfishing, the Ryther index is based on widely available and reliable catch data (*i.e.* ICES official catches) that are updated annually. The Fogarty index was also explored. This index is the ratio of total catches to the productivity of the ecosystem. Because of the high level of uncertainty associated with absolute estimates of primary production, and because of the assumptions required to calculate the Fogarty index (e.g. harvesting factor and trophic transfer efficiency), there remains some concerns about the usefulness of the Fogarty index in the context of the Norwegian Sea ecosystem.

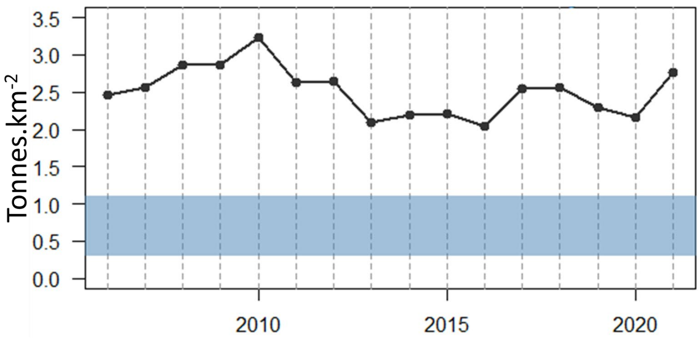

Figure 7.2 Rythen index for the ICES IIa area. the blue shade depict the overfishing threshold proposed by Link and Watson (2019).

7.6 Human indicators

Integrated ecosystem assessment requires to consider the state and recent changes that have occurred in multiple components of the social-ecological system, from climate to ecosystem and humans. WGINOR has had, until now, a primarily focus on the physical and ecological dimensions of the ecosystem. Here, we extend the scope to examine time-series that describe the most important sectors and activities in the ecoregion (fishing, oil and gas production, and shipping) and some related pressures (species extractions). With an overall increase in total catch value and a favorable balance between operating costs and revenues, fishing profitability seems to have increased over the last decades. However, there is a high interannual variability in the catch value. The number of boats has strongly decreased from 1980 to 2005, especially for boats of overall length below 10 m, and the decrease continue at a slower pace. Similarly, the total number of fishers decreased from 1940 up to now. The main pressure associated with this activity is species extraction which can be described by time-series of catch for individual species or, to have a wider view of the ecosystem, as the total catch of all species per unit area (i.e. Ryther index, Figure 7.2). Ryther index has been computer from 2006 to 2021 from ICES official catch database, and present relatively high interannual variation. 2021 is the highest total catch since 2010 with 2.78 tonnes km^2. The volume of oil produced reached its maximum between 1995 to 2005. This period was followed by a decrease up until 2012 and has been relatively stable since then, even if the last two years (2020 and 2021) suggest that the production is increasing. Gas production has increased steadily from 1970 to 2018 and has remained stable since then. No comprehensive data on the seismic prospections are available for the Norwegian sea. Shipping activity, followed as annual time-series of CO_2 emission, has steadily increased since 2011. Passenger ships presented a decrease during the covid period in 2020 and 2021, but all other types of boats (e.g. Tankers, Cargos, offshore services, and fishing boats) were not affected. The graphical representation of the above mentioned time-series are provided in Annex 5.

8 Ecosystem Status Summary update (ToR g)

The Ecosystem Status Summary is comprised of three main sections: “highlights”, “graphical summary” and “report”. The “highlights” provide six short statements about the current state and trends in ocean climate, primary production, zooplankton, fish, seabirds, and marine mammals. The “graphical summary” is a two-page table that summarizes for each of these ecosystem components, the overall trend, the situation in the most recent year(s), the degree of certainty of the assertions and the possible implications of changes for other part of the ecosystem. The “report” provides six short chapters which contain more detailed information and figures that form the basis of the assessment. 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 a summary of the scientific information prepared by the WGINOR group and does not constitute ICES advice. The Ecosystem Status Summary is provided in Annex 4 of this report.

9 Meeting topics not included in the ToRs

At the annual meeting three topics which do not belong to a ToR were presented or/and discussed in plenary: importance of diversity, equity and inclusion when operating WGINOR, identification of potential funding sources for future WGINOR research, and development of a more diversified format for hybrid annual meetings.

9.1 Diversity, Equity, and Inclusion (DEI)

In recent years ICES has raised awareness about importance of diversity, equity, and inclusion (DEI) for all aspects of the ICES operation. ICES focus on DEI began with the current strategic plan which was released in 2019 (ICES, 2019). The first ICES gender equality plan was released in 2022 and details ICES goals and initiatives for empowering underrepresented groups within ICES (ICES, 2022b). ICES secretariat participated in chairing sessions about importance of DEI in marine science at the ICES annual science conference in 2021 and 2023. Chairs of ICES working groups have been educated about DEI issues at the annual meeting of ICES Chairs group since 2021. At the Chairs meeting in 2022 a DEI Chairs subgroup was created which aims to improve DEI at ICES and to help with implementation of ICES gender equality plan. The DEI subgroup meets approximately quarterly online to discuss DEI issues. One of its recommendations to ICES working group, from the meeting on 21 September 2023, is for working groups to develop their own DEI targets. WGINOR chairs decided to discuss DEI targets for WGINOR at the annual meeting in 2023.

The discussion about DEI at the WGINOR annual meeting begin with a presentation about history of DEI within ICES, content of the ICES gender equality plan, information on the DEI sessions at the annual science conference, and introduction to work done by the Chairs subgroup on DEI issues. At the end of the presentation there was a plenary discussion focusing on if WGINOR should have a DEI target or not and what the target should be if decided to adapt one. Discussion on targets was focused on diversity, equity, and inclusion of WGINOR membership. Conclusions of the discussion was for WGINOR to add actions to increase inclusion of WGINOR members to operation of the group. This applies both to inclusion of newcomers to become active members of the group and to strive for active role for all members of the group. Initiatives to facilitate inclusion were not discussed at the meeting and the plan is to do that at the next annual meeting in 2024.

Additionally, during the current WGINOR working term the chairs have focused on inviting early carries scientists to join the group and have encourage members with diverse scientific experience to take on management tasks within WGINOR. For example, in 2024 WGINOR has planned four intersessional meetings. One of the meetings will be chaired by an early carrier scientist and another meeting will be chaired by member with no management experience within the group.

9.2 Future meeting formats

In the last years, WGINOR meetings have followed a hybrid format with ~1/3rd of the participants present in person and 2/3rd present remotely. This situation is likely to continue in the future. The meeting lasts about 4 days which is both long - in particular for participants following online - and short, given the number of topics to be addressed. The schedule is organized in *sessions* (Annex 3, e.g. stakeholder session, session on ecosystem state) that allow participants to attend selected sessions that are most relevant to them. This is expected to continue in the future. Until now, the group meeting has run in a plenary format. The group expressed interest in running some parallel discussion sessions, rather than plenary sessions only. This could allow for better participation and ease inclusion. This new meeting format will be explored in 2024.

9.3 Funding opportunities

Major funding for research done within WGINOR, ToRs B and C, expired in December 2023. For future research, WGINOR needs to find a new funding source. The first step in that process it to identify research funds which support marine related research. It was decided to compile a list of funding agencies, national and international, to discuss at the annual meeting 2024. Anna H. Ólafsdóttir in collaboration with member from each country are responsible for compiling the list (see section 11).

10 Scientific highlights

10.1 Foodweb assessment for the Norwegian and Barents Seas

Benjamin Planque

The principle of a foodweb assessment model is similar to that of a fish stock assessment model or a climate re-analysis but applied to a foodweb rather than to a fish stock or a physical climate system. The model is composed of a "process" part that describes how consumption and predation (or fisheries catches) contribute to changes in the biomass of (tropho)species in the foodweb and of an "observation" part that connect the reconstructed foodweb dynamics to many types of observations (e.g. biomass estimates, catches, consumptions, diets, etc.). Earlier versions of a foodweb assessment model for the Norwegian Sea were presented at WGINOR and one modelling analysis, that had primary focus on trophic interactions between small pelagic fish and their planktonic prey has been published (Planque *et al*., 2022). The present food-assessment model focuses on quantifying the direct and indirect interactions between marine mammals, fish and fisheries that have happened in the last decades. The goal of the assessment is to reconstruct the past dynamics of marine mammals, fish, fisheries and of the interactions between them in a manner that is internally consistent, that is compliant with existing observations, and that accounts for uncertainties in input data and knowledge. The model includes 12 groups (mackerel, blue whiting, herring adults, herring juveniles, cod, polar cod, capelin, other demersals, minke whales, other baleen whales, toothed whales, and seals) and 14 additional groups are represented as external prey of predators (these comprise different groups of plankton, benthos, seabirds, fisheries, hunts and prey and predators located outside the geographical domain). The reconstructions are for the period 1988–2021 and for the Norwegian and Barents Seas combined (Figure 10.1). Some of the key highlight from the model outputs include:

- Complete reconstructions of biomass, diets, predation, and catches for each species, including uncertainty estimates,
- Global estimates of the trophic and fisheries fluxes in the region for the whole period,
- Derivation of simple foodweb indicators, such as consumption-over-biomass or predation-over-biomass,
- Identification of observational time-series that are <u>in</u>compatible with some aspects of the foodweb dynamics (e.g. the very low biomasses of polar cod and capelin reported in some years are not compatible with data on predator food consumption).

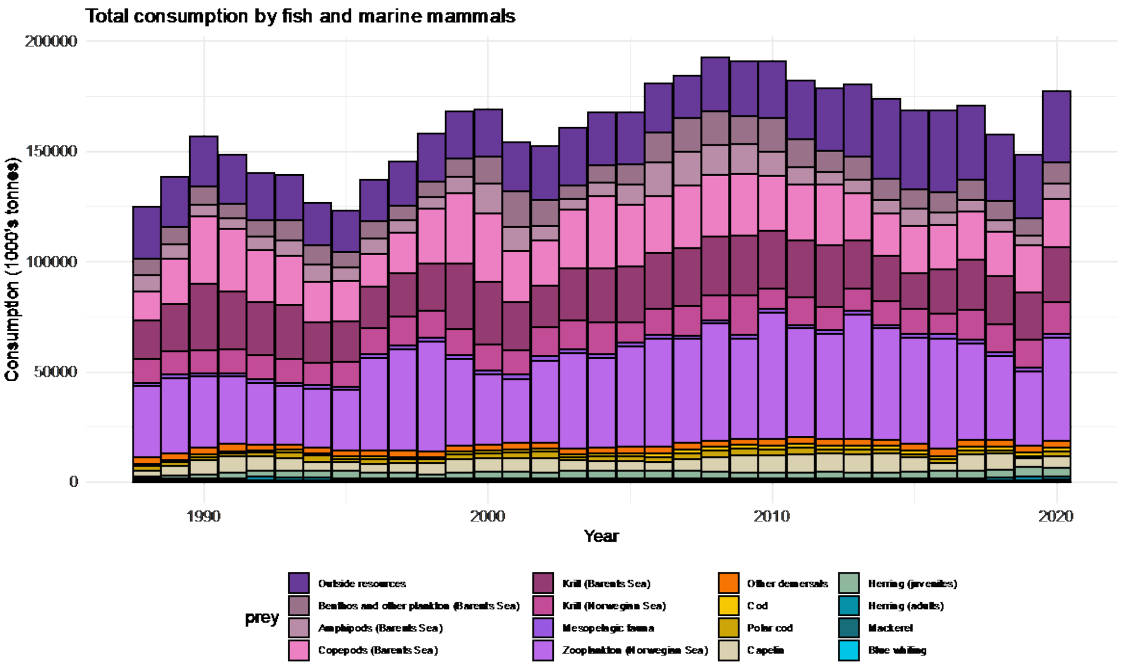

Figure 10.1 Reconstruction of the total consumption by fish and marine mammals of various prey groups during the period 1988–2021. This is the median pattern of the model. The actual uncertainties for individual prey groups and in individual years are available but are not shown here.

10.2 Poor performance of regime shift detection methods

Hannah Haines

Regime shifts have been reported as a ubiquitous feature across the world's oceans. Many regime shift detection methods are available but their performance is rarely evaluated, and the supporting evidence for regime shifts may be thin because of the nature of marine ecological time-series that are often short, autocorrelated, and uncertain. In the Norwegian Sea, a regime shift has been reported to have occurred in the mid-2000, with simultaneous changes in oceanography, plankton, and fish. Here, we evaluate the evidence of this regime shift using four commonly used regime shift detection methods (Strucchange, STARS, Envcpt and Chronological Clustering) on 32 annual time-series that describe the main components of the Norwegian Sea ecosystem, from hydrography and primary production, up to fish population metrics. We quantify the performance of each method by measuring its false positive rate, i.e. the proportion of times the method detects a regime shift that was not present in simulated control time-series. Our results show that all methods have high to very high false positive rates. This challenges the evidence of a regime shift in the Norwegian Sea and questions earlier reviews of regime shifts across the world's oceans.

10.3 Poleward spawning of mackerel - What is the main trigger – the mechanism behind observed changes?

Aril Slotte

At ICES WGINOR November 2023 the recent development of poleward spawning in Northeast Atlantic herring was addressed in a presentation. Focus was put on actual mechanisms behind the observed changes in spawning distribution. Several studies referred to during the presentation links the dynamics to ocean warming, where temperature is suggested to be driver. The main argument being correlations with temperature. I has further been argued that with this as a trigger it is possible to model the distributions and predicts future changes. In the presentation at WGINOR 2023 it was argued that temperature changes in itself and thermal spawning-niches most likely is not the mechanism for the major changes. These studies do not take into account the fact that migration potential in mackerel relies heavily on the size and condition of the fish. Results from a recent study exploring biological data from various surveys and commercial landings from May to July 2004-2021 demonstrates that the mackerel extended its spawning even farther poleward than previously assumed, all the way to 74N° during the warmer period. Still, the size of areas suitable for spawning in the Norwegian Sea feeding area was rather stable or even declining, while the body condition reached historically low levels corresponding with the poleward spawning. Hence, body condition was concluded to be the main trigger for the distributional change. It is suggested that the main strategy behind spawning so far north well into the feeding season is to secure future rather than current reproductive success, as larval conditions far north are considered disadvantages for survival. It was argued that mackerel spawning migration can be described under the hypothesis of state dependent migration. Mackerel wintering off Shetland has a long way to migrate south to spawn if they head for Spain. They need to reach large sizes and or be in good prespawning condition to undertake such migrations. In a period with slow growth and low condition, migration potential was heavily reduced. Hence, they spawned farther north to overcome migration constraints, i.e. they spawned in the direction of higher prey conditions. It is also notable that year classes starting to spawn in the north, in fact has migrated south to spawn when reaching larger sizes, despite that other studies suggest that their thermal spawning-niche has moved north. This suggest that they are not avoiding warmer temperatures in the south, but are constrained by bioenergetics. Migrating south to spawn should still be advantageous for larval survival and growth, so if they are capable they would tend to do so.

10.4 Ocean-climate conditions and spawner biomass affect the survival of blue whiting early life history stages

Costanza Cappelli

Blue whiting (*Micromesistius poutassou*) recruitment has shown wide variations since the start of available time-series in the early 1980s, with some year classes being nearly tenfold larger than others. Hitherto, no models can accurately quantify these past recruitment variations, potentially due to the lack of studies addressing blue whiting stock dynamics in relation to ocean-climate variability, constituting a major source of uncertainty for the management of this species. Here we focus on a large-scale oceanographic feature, the windstress curl (WSC), which might affect recruitment through several mechanisms, including Ekman pumping/suction of deep nutrient-rich water to the surface, meridional transports, the positions of fronts, and through lagged effect on basin-scale oceanographic properties. In particular, the long-term mean location of the transition zone in the Northeast Atlantic between ocean areas having positive and negative WSC (i. e., the WSC zero-line) coincides with the location of the largest known blue whiting spawning area in the Northeast Atlantic Ocean. Consequently, WSC fluctuations in this region could potentially affect blue whiting recruitment and population levels, possibly through changes in upwelling/downwelling intensities, vertical mixing, and lateral transport processes. We hypothesize that WSC variability affects the environmental conditions (i.e. temperature and salinity) and the drift patterns experienced by eggs and larvae in the spawning grounds, and ultimately regulates blue whiting survival and recruitment in the North Atlantic Ridge area.

We assess the relationship between WSC variability in the zero-line region and a blue whiting recruit survival index between 1980 and 2021. We found that coupling stock-recruitment relationships to local indices of WSC variability near the zero-line significantly increased explanatory power (up to 45%), especially if the recruit index was lagged 1 year behind the WSC variations (i.e. WSC variations lead year-class variations). The 1-year lag is consistent with a literature-reported ca. 1 year response time of ocean properties to WSC variations in this region. Using WSC as a main driver of blue whiting survival greatly improves the prediction abilities of blue whiting recruitment, increasing the forecast horizon one year ahead of spawning for identifying major recruitment variations and improving stock assessments. It also suggests new processes driving blue whiting survival which can be mechanistically investigated in the future and could potentially inform sustainable and ecosystem-based management practices for this important fishery resource.

11 Actions

Several intersessional meetings and activities planned for 2024

It is not possible to conduct all activities and discussions that are relevant to WGINOR during the annual meeting. For this reason, and based on the success of this approach in earlier years, the working group has planned to progress on specific issues by organizing several short, online, intersessional meetings and by following up some issues by correspondence. Below is the list of actions to be conducted by WGINOR group members intersessionally. When individuals have been identified to conduct these actions, their name is provided in parentheses, otherwise the actions are relevant to all group members.

1. Provide, update or revise the meta data for every WGINOR time-series, according to the new format introduced at the 2023 annual meeting. Follow up by correspondence and finalize before annual meeting 2024 (Anna).
2. Compile a list of national and international research funds which could support WGINOR research. Follow up by mail and finalize before annual meeting 2024 (Anna).
3. Organize an intersessional meeting to discuss and select time-series of biogeochemistry, including contaminants, OA, and nutrients (Per).
4. Organize an intersessional meeting to discuss and select time-series of primary production, including VGPM, Copernicus, Bio-ARGO (Benjamin).
5. Organize an intersessional meeting to discuss and select time-series of marine mammal populations (Hiroko and Stine).
6. Organize an intersessional meeting to discuss and select time-series of human indicators (Lucie)
7. Follow up by correspondence the revision of the WGINOR polygons (Benjamin)

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Annex 1: List of participants

2023

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Annex 2: Resolutions

2021/MA2/IEASG00 The Working Group on Integrated Assessment of the Norwegian Sea (WGINOR), chaired by Anna H. Ólafsdóttir, Iceland and Benjamin Planque, Norway, will work on ToRs and generate deliverables as listed in the Table below.

	Meeting dates	Venue	Reporting details	Comments (change in Chair, etc.)
Year 2022	14-18 November	Tromsø, Norway	Interim report by 15 January 2023 to IEASG	New incoming Co-Chair, Benjamin Planque, Norway
Year 2023	20–23 November	Tórshavn, Faroe Islands	Interim report by 15 January 2024 to IEASG	
Year 2024	4–8 November	Reykjavík, Iceland	Final report by 15 January 2025 to IEASG	

Terms of Reference a) – g):

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 important signals for management.	Addresses needs in the Science Plan for developing understanding of the ecosystem and its responses to human impact and other pressures. In addition, start developing reporting formats to meet the needs of ecosystem-based advice.	6.5	years 1-3	WG report to SCICOM and ACOM January following each year
B	Utilize multispecies and ecosystem models to evaluate effects of single and multispecies harvest control rules on fishing yield and ecosystem state of the pelagic ecosystem in the Norwegian Sea.	Addresses needs in the Science Plan for developing ecosystem-based advice for sustainable use of marine ecosystems resources.	5.3	years 1-3	WG report to SCICOM and ACOM January following each year
C	Continue development of forecast products (1–5 years) for ocean climate and initiate development of forecast products for other ecosystem components 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	Continue improvement of workflow, transparency, and replicability.	Develop data sharing plans towards FAIR data principles.	3.2	years 1-3	WG report to SCICOM and ACOM January following each year
E	Develop a two-way dialogue between WGINOR and relevant stakeholders and managers in Norway, Faroe Island, and Iceland.	Guiding 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	Compile information for future ecosystem overview revisions based on the ICES technical guidelines.	Summarize key achievements in developing an understanding of the ecosystem and its responses to human impact and other challenges.	6.5	year 1-3	WG report to SCICOM and ACOM January following each year
G	Annually review and revise the ecosystem status summary to report trends and recent changes	These summaries will provide information on annual trends will also provide the foundational material for the ecosystem overview revision.	6.5	year 1-3	Norwegian Sea ecosystem status summary

Summary of the Work Plan:

Year 1	Work on ToRs a-g
Year 2	Work on ToRs a-g
Year 3	Work on ToRs a-g

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 has been developed with input from relevant projects at the involved institutions and provides the platform for doing this part of the ToR. Term of Reference b) This will be supported by work conducted in the IMR-project “Sustainable multi-species harvest from the Norwegian Sea and adjacent ecosystems” (SIS harvesting project), which represents a continuation of the work done in WGINOR during the last three-year term. Term of Reference c) This will be supported by work conducted in the SIS harvesting project and by oceanographic information collected during cruises in the Norwegian Sea and surrounding waters and supplied by satellite-based monitoring. The SIS harvesting project provides resources needed to complete development of a forecast system.

	Term of Reference d) This will be based on experiences made during implementation of this ToR. Some support from ICES secretariat may be required to implement FAIR, TAF, data profiling, and related approaches. Term of Reference e) This will be conducted on a national basis, at the time/place of the WGINOR annual meetings. No additional support required. Term of Reference f) Update of the elements of the ecosystem overview 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. ToR f's expected deliverables was updated to be clearer on the group's plans to support the ecosystem overview revisions. Term of Reference g) Was added as the result of discussions following a recommendation from WGINOR to ACOM about their plans to produce the Norwegian Sea ecosystem status summary annually.
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	WGWIDE
Linkages to other committees or groups	IEASG
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: Final Agenda

Day #1 – Monday 20th November

10:00-10:30 **(11:00-11:30 Norwegian time)**	Welcome, ICES Code of Conduct/etiquette/sharepoint, new members, round table, adoption of the agenda.	*[ICES secretariat, Anna, Benjamin]*
10:30-11:15	Update on ecosystem state I: physical oceanography, primary production (ToR A)	*[Øystein, Kjell Arne, Benjamin]*
11:15-12:00	Update on ecosystem state II: zooplankton and fish (ToR A)	*[Cecilie B, Sólva, …]*
12:00-13:00	Lunch	
13:00-13:45	Update on ecosystem state III: seabirds and marine mammals (ToR A)	*[Tycho, Hiroko, Stine…]*
13:45-14:30	Update on ecosystem state IV: human activities and anthropogenic pressures (ToR A)	*[Lucie]*
14:30-14:45	Excel data sheet: guidelines for updates and edits	*[Anna]*

Day #2 – Tuesday 21st November

08:00-08:45 **(09:00-09:45 Norwegian time)**	*Time-series I: Intersessional meetings:* *- selection of climate time-series* *- selection of fish time-series*	*Benjamin, Anna, Hjalmar*
08:45-09:30	*Time-series II: Ecosystem level time-series:* *- Ecosystem Fishing Indicator* *- Foodweb indicators*	*Lucie, Benjamin*
09:30-10:00	*Break*	
10:00-10:30	*Time-series III: Time-series of fish distribution*	*Hiroko*
10:30-11:00	*Time-series IV: plans for selection of plankton, top predators, and human activities time-series.*	*Discussion*
11:00-12:00	*Lunch*	
12:00-12:45	*Emerging issue I: Underwater noise*	*Paul*
12:45-13:30	*Emerging issue II: Deep-sea mining*	*Gabrielle*
13:30-13:45	*break*	
13:45-14:15	*Management Strategy Evaluation – an update*	*John*
14:15 – 14:45	*Diversity, Equity, and Inclusion goals for WGINOR*	*Anna*

14:45 – 15:15	*Introduce ICES new guidelines for stakeholder participation*	*Gro*

Day #3 – Wednesday 22nd November

09:00-09:30 **(10:00-10:30 Norwegian time)**	Science highlight I: Foodweb assessment for the Nordic Seas	*Benjamin*
09:30-10:00	Science highlight II: Evidence for regime shift in the Norwegian Sea	*Hannah*
10:00-10:30	Science highlight III: Poleward spawning of Atlantic mackerel (Scomber scombrus) is facilitated by ocean warming but triggered by energetic constraints.	*Aril*
10:30-11:00	Break	
11:00-12:15	Open session - WGINOR polygons - time-series intersessional meetings - metadata & excel file format - description of phenomena - forecasts - preparation for the stakeholder session	
12:15-13:15	Lunch	
13:30	Stakeholder session Welcome and round the room	 *Eydna*
13:35	Presentation about WGINOR	*Benjamin/Anna*
13:50	Oceanography	*Hjálmar*
14:10	Primary- and secondary production	*Sólvá E.*
14:30	Break (30 min) and conversation	
15:00	Pelagic fish	*Jan Arge*
15:30	Questions and conclusions	*Eydna*
16:00	End of stake-holder session	

Day #4 – Thursday 23rd November

09:00-10:30 **(10:00-11:30 Norwegian time)**	Ecosystem state summary. Finalization of highlights and graphical summary	*All*
10:30-11:00	Break	

11:00-12:45	Science highlight IV – blue whiting recruitment: Costanza (FAMRI) Intersessional actions SIS-Høsting II – science and opportunities Reflections on emerging issues and stakeholder sessions Future format of WGINOR Recommendations	*Costanza*
12:45	Lunch + end of the meeting	
13:45 – 16:00	Do your homework before it’s too late.	*All*

Annex 4: Ecosystem Status Summary

This ecosystem status summary provides a short description 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 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 assessments for the Norwegian Sea (WGINOR) and is a summary of the scientific information prepared by the group. It does not constitute ICES advice.

Highlights

- In recent years the inflows of both Atlantic and Arctic water have been relatively fresh. At the same time the relative heat content has indicated a warm state, connected to reduced local ocean-to-air heat loss, and the increasing trend in relative freshwater content has stopped. The outlook for the coming years upstream, the Subpolar Gyre index is in a weak state indicating a change to warmer and more saline Atlantic inflow to the Norwegian Sea.
- During the period 2003 to 2023 primary production has varied slightly from year-to-year and without noticeable trend. The timing of the peak of production has gradually shifted to a later date by 10 days per decade.
- Zooplankton spring biomass, measured since 1995, declined in the mid-2000s. Since then, there has been no clear trend but variations between years. The biomass has been low in some subareas the last few years.
- A decline in spawning biomass started around 2009 for Norwegian spring-spawning herring and around 2015 for mackerel. These declines continued in 2023. Blue whiting biomass increased by more than a third in 2023, driven by historically high recruitment of two year classes.
- Long-term decrease in breeding numbers for Atlantic puffin and black-legged kittiwake continues at the Norwegian coast. Common guillemot numbers are still low but have increased markedly over the last decade.

Abundance indicators suggest declining population levels for hooded and grey seals, low levels for harbour seals, and highly uncertain for harp seals. Harbour porpoise bycatch levels estimated over the period 2006-2018 were unsustainable. The distribution of baleen whales has gradually shifted towards the Barents Sea and the North Sea. The abundance of minke whales in the region is estimated to have increased considerably in the last years.

Graphical summary

Topic	Overall trend	Situation in 2022/2023	Certainty	Possible implications
Ocean climate	Generally, warm and saline conditions prevailed from the early 2000s until 2016. Since 2012, temperature of the Atlantic inflow has been close to the long-term mean while salinity has been below the long-term mean since 2016. The extent of Arctic Water has increased from 2017.	The temperature of the Atlantic inflow is close to the long-term mean while salinity is below the long-term mean. The extent of Arctic Water continues to increase but the recent decline in relative heat content has ceased. A present relative weak North Atlantic Sub Polar Gyre (SPG) may lead to a warmer and more saline Atlantic Inflow in coming years.	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 and import of Arctic zooplankton.
Primary production	There is no trend in the level of spring and summer primary production in the Norwegian Sea deep basins since 2003. The timing of peak production has gradually shifted to a later date over the last two decades.	The primary production for 2022 is low ($150 g·C·m^{-2}$) but within the range of previously observed values. The timing of the peak production in 2022 is average (day 160).	Certain: Phytoplankton estimates are based on satellite data covering the productive season with high geographic resolution. The production model is not calibrated for high latitudes and absolute estimates of primary production are uncertain.	Change in timing can lead to seasonal match/mismatch with reproduction and feeding of zoo and ichtyo-plankton.
Zooplankton biomass	Spring biomass of mesozooplankton was at a higher level from 1995 to mid-2000s and has been at a lower level in the following years. Summer biomass shows an increasing trend or no trend from 2010 until 2023	Biomass in 2023 was at similar level as the previous year for all subareas and both seasons but increased in the eastern Lofoten Basin in summer.	Moderately certain: plankton is patchily distributed, which leads to uncertain estimates. The timing of seasonal development relative to time of sampling can affect the level of biomass measured.	Reduced zooplankton biomass may have caused reduced food resources for planktivorous feeders, including pelagic fish. in the recent decade.
Zooplankton spatial distribution	Spring distribution of zooplankton has changed from higher biomasses in Arctic water in the west to become evenly distributed in the Norwegian Sea.	In 2023, the zooplankton was relatively evenly distributed in spring but with a confined high-concentration area in Arctic waters.	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

Pelagic fish biomass	Spawning-stock biomass of Norwegian spring-spawning herring and mackerel continued to decline while blue whiting increased sharply to a record high value.	Herring spawning-stock biomass decreased by 10% and mackerel by 7% whereas blue whiting increased by 36% compared to previous year. Estimated recruitment of blue whiting is at a historical high for two year-classes. Fishing remains above scientific advice for all stocks.	Highly certain for herring and blue whiting, moderately certain for mackerel due to repeated revisions of stock perception from assessment: estimates are based on quantitative stock assessments.	Changes in pelagic fish biomass have direct implications for fisheries opportunities.
Pelagic fish spatial distribution	Since the mid-2000´s, mackerel distribution expanded westward into Icelandic and Greenlandic waters, then retracted eastward from 2015. By 2020, most of the mackerel stock was feeding in the Norwegian Sea. In 2022, mackerel expanded westward again to west coast of Iceland but density was low.	No mackerel in Greenlandic waters. Similar presence and density in Icelandic Waters in 2023 as measured in 2022.	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 long-term declines for most species, including common guillemot, Atlantic puffin, and black-legged kittiwake.	No clear signs of improvements, except common guillemot abundance appears stable in colonies which provide shelter from eagle predation.	Highly certain: Trends are derived from dedicated monitoring.	Many bird colonies are at risk of extinction, and some have already disappeared.
Marine mammals	Decline or sustained low levels of pup production in several seal species. Long-term shift in summer distribution of baleen whales from the Norwegian Sea to the Barents Sea. Unsustainable levels of harbour porpoise bycatch.	No new data on abundance and distribution.	Highly certain: Trends in pup production are based on dedicated surveys. Moderately certain: Data are scarce on bycatch and productivity-connectivity for harbour porpoises	Changes in marine mammals affect foodweb structure and long-term viability of marine mammal populations

Climate

Current status and recent changes

The Norwegian Sea ocean climate and its interannual variability is determined by the amount of Atlantic water flowing into the area (warmer and more saline), the amount of Arctic water flowing in (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].

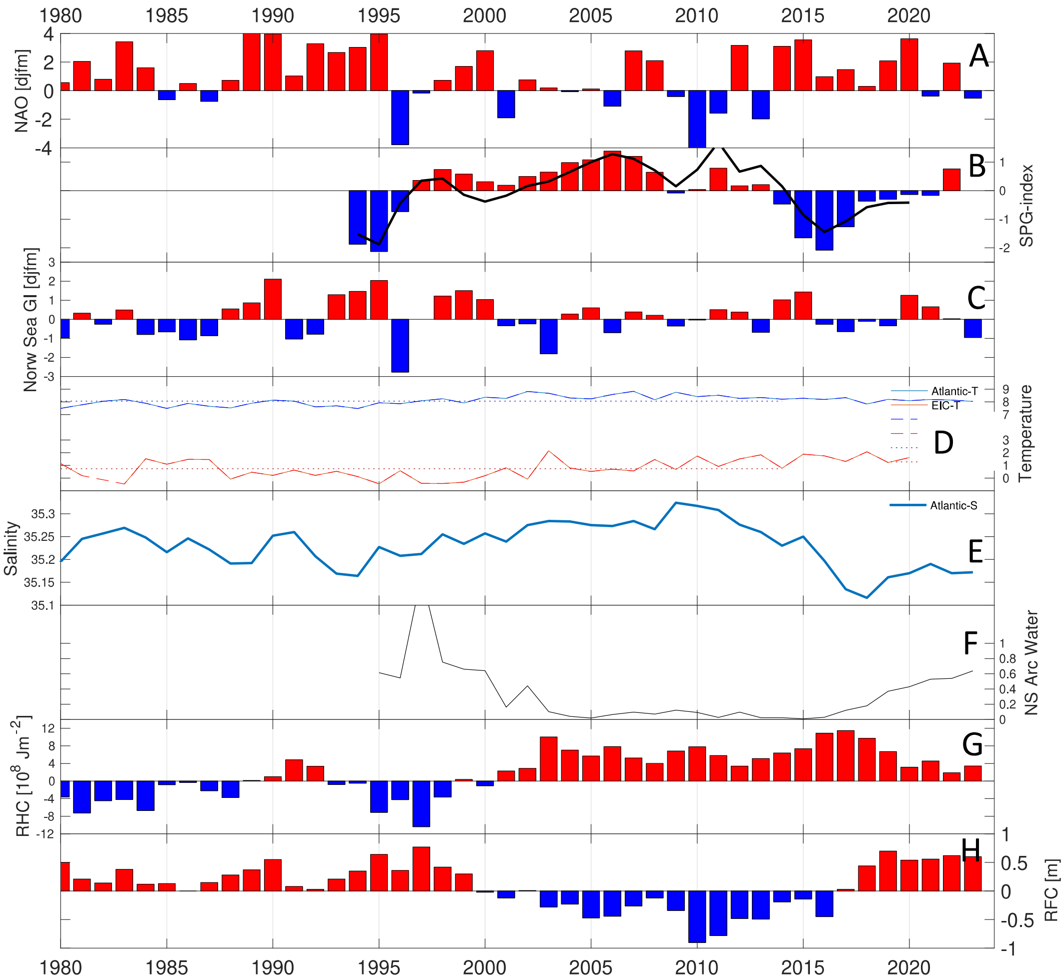


Figure A4.1 A subset of climate indicators for the Norwegian Sea: a) North Atlantic Oscillation Index (NAO), b) Subpolar Gyre index (SPG, note that strong gyre is represented by negative values and weak gyre by positive values), c) Norwegian Sea Gyre index, d) Atlantic Water Temperature at Svinøy section and East Icelandic Current Temperature, e) Atlantic Water Salinity at Svinøy section, f) Arctic Water amount in the Norwegian Sea, g) relative heat content (RHC) and h) Relative Freshwater Content (RFC).

Total heat content and freshwater content in the Norwegian Sea is estimated from *in situ* measurements of temperature and salinity. These data indicate a trend from cold and freshwaters in the mid-1990s until about 2003 when the state changed to warm and saline, which prevailed until about 2016 (Figure A4.1G, H). Since 2016, the freshwater content has increased considerably. This has been associated with a gradual decrease in heat content, although this decrease is less than expected. The inflowing Atlantic water, which is monitored in the Svinøy section (at about 63°N) largely follows these changes (Figure A4.1D, E), but since 2012, the temperature has been close to the long-term mean. The amount of Arctic Water in the Norwegian Sea has increased since 2016 after being low for more than a decade (Figure A.1F). In summary, the temperature of Atlantic inflowing water has been close to the long-term mean while the amount of Arctic Water in the Norwegian Sea has increased.

Possible reasons for recent changes

The strength of the Subpolar Gyre in the Labrador and Irminger Sea influences the properties of the Atlantic water flowing into the Norwegian Sea, e.g. temperature, salinity, and nutrients. When the gyre is strong, it brings increased amounts of cold and freshwater 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 (positive SPG index), the inflowing Atlantic water becomes more influenced by the warmer and relatively saline water from the Gulf Stream.

In addition, atmospheric conditions influence the ocean climate in the Norwegian Sea. Important variability in atmospheric conditions can be measured through the North Atlantic Oscillation (NAO) index. When the NAO-index is in a positive phase, the Subpolar Gyre tends to be strengthened, and inflowing Atlantic water thus becomes colder and fresher. At the same time, ocean to air heat loss in the Norwegian Sea also tends to decrease 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 relatively strong to a weak Subpolar Gyre from 1995 to 1996, and hence warmer and more saline Atlantic source water flowing into the Norwegian Sea (Figure A4.1B, D, E). During the 2010 the NAO-index was mainly in a positive phase that coincide with a relative strong SPG especially from 2015–2017 – that likely is connected to the fresher Atlantic Inflow during some years after. However, the in the 2020s the NAO has been in a more negative state, and with an accompanying weakening SPG. The overall freshening is also influenced by eastward expansion of Arctic Water into the Norwegian Sea (Figure A4.1F). 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

Net primary production (NPP) is calculated based on optical signals (e.g. ocean color and infrared radiation) measured by the MODIS satellite and represent the production of biomass available to other organisms in the ecosystem. The Vertically Generalised Production Model (VGPM [3]) is used to derive NPP from satellite observations.

Annual estimates of NPP integrated for spring and summer have remained stable over the observation period (2003–2023) around 170 grammes carbon per square meter per year ($gC \cdot m^{-2} \cdot y^{-1}$) ± 15% (Figure A4.2). Years 2006 and 2007 had the lowest reported primary production while 2019 was the year with highest reported primary production. The apparent increasing trend observed in 2010-2020 has halted and recent observations have returned to average-low values. Absolute estimates of NPP may be biased, as satellite measurements are restricted to the upper water column, and NPP estimates rely on parameterization originally developed for lower latitudes. However, relative changes in NPP between years are considered robust.

Behind the interannual variations in the seasonal timing of the peak of production there is a general trend of peak production occurring at later dates. This has gradually shifted from day 150 to 170, i.e. 10 days per decade.

Possible reasons for recent changes

There is no clear reason for the change in seasonal timing of the peak in primary production. Increased flow of fresh Arctic water into Nordic Seas has increased stability of surface layer stratification [4] and this could be involved in delaying NPP.

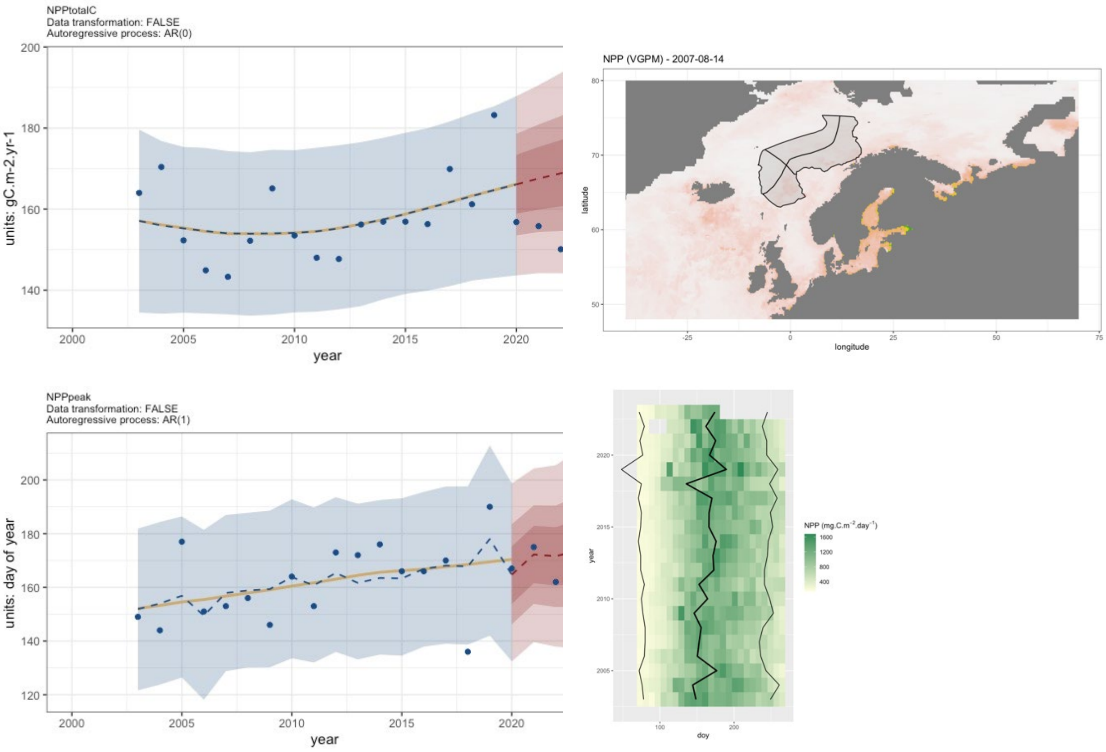


Figure A4.2 Net primary production. Upper-left panel: annual estimates of spring-summer NPP (observations shown as blue dots). Lower-left panel: annual estimates of the timing of peak production. Upper-right panel: estimated NPP (mg·C·m-2·day-1) over the Northeast Atlantic (snapshot on the 14 August 2007). The Norwegian Sea polygon used for annual estimates is highlighted. Lower-right panel: seasonal and interannual variations in NPP. The left, central and right lines show respectively the timing of start, peak and end of the production season.

Zooplankton

Current status

The zooplankton biomass indices, for all four subareas of the Norwegian Sea in spring, May (28 years) and summer, July and August (14 years) were either at similar levels, slightly lower or slightly higher in 2023 compared to 2022 (Figure A4.3). An exception was summer biomass in the eastern Lofoten Basin which increased significantly in 2023. In 2021, a decrease in spring zooplankton biomass was observed at the western Norwegian Sea Basin, and the biomass has been at a low level since then. In 2023 the biomasses were generally at similar levels in all subareas and seasons, but with somewhat lower values in the western Lofoten Basin.

Recent changes

There have been two main changes in spring zooplankton biomass during the last three decades: 1) There has been a long-term decline in all subareas, and 2) the previously higher zooplankton level in Arctic water north and east of Iceland, and in the frontal region between Atlantic and Arctic waters in the western Norwegian Sea Basin, has been reduced to a lower level than 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. In the mid-2000, the indices decreased and remain at a lower level. The largest decline was in Arctic water east and north of Iceland, with approximately 60 % reduction from the "high-biomass" period to the "low-biomass" period. During the last decade, zooplankton biomass in the eastern areas has shown an increasing tendency.

Possible reasons for recent changes

The reasons for the changes in zooplankton biomass are not obvious. The period with lower zooplankton biomass coincides with higher-than-average heat content in the Norwegian Sea (see the climate section of this annex (Annex 4) and reduced inflow of Arctic water into the southwestern Norwegian Sea [5]. The higher spring biomass in the years 1995–2005 is concurrent with higher Arctic inflow in the Norwegian Basin [5]. Phenological drivers, such as match/mismatch with the phytoplankton bloom, may also have affected zooplankton abundance. The high biomass of pelagic fish (see the pelagic fish section of this annex (Annex 4) 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 [6], and there is no time-series on the biomass of carnivorous zooplankton stocks or consumption. Zooplankton biomass estimates are uncertain because of the naturally high spatial patchiness of zooplankton and these uncertainties are accounted for in the reported series (Figure A.43a,b). Additional uncertainties in the year-to-year changes in biomass may arise from the rapid seasonal changes in biomass relative to the duration of the survey and different timing of the zooplankton seasonal development between years.

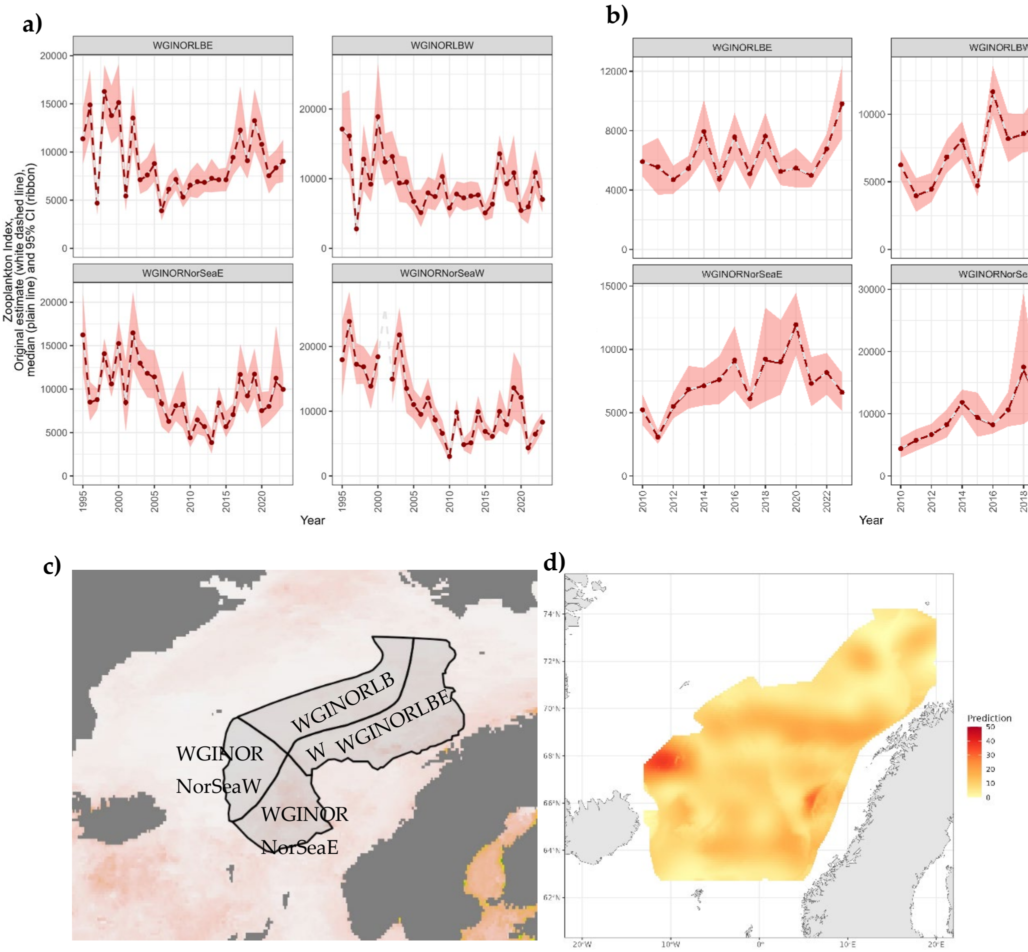


Figure A4.3 Indices of zooplankton biomasses (mg dry weight m-2) in the upper 200 m of the water column in the Norwegian Sea and adjacent waters, a) in May during the period 1995–2023, b) in July/August during the period 2010–2023. Also displayed c) the four subareas used for analysis along with d) zooplankton biomass distribution in May 2023.

Pelagic Fish

Current status

Three fish stocks dominate the pelagic ecosystem of the Norwegian Sea: Norwegian spring-spawning herring (NSSH, *Clupea harengus*), Northeast Atlantic mackerel (*Scomber scombrus*), and blue whiting (*Micromesistius poutassou*). In 2023, estimated spawning-stock biomass (SSB) for all three stocks ranged from 3.7 to 6.2 million tonnes [7–9]. Combined SSB for all three stocks was 13.6 million tonnes (Figure A4.4a).

Combined catch of the three stocks was 2.9 million tonnes in 2022, of which approximately 1.0 million tonnes was blue whiting, 1.0 million tonnes was mackerel, and 0.8 million tonnes was herring [7–9]. Current exploitation levels, relative to biological reference points, show that fishing pressure on all three stocks is above that which leads to maximum sustainable yield (F_{MSY} [7–9]). Furthermore, herring exploitation is above management plan fishing targets (F_{mgt}). Stock status, for all three stocks is above all biological reference points related to the risk of impaired reproductive capacity. However, herring SSB is very close to biological reference limits (MSY $B_{trigger}$), as the 95 % SSB confidence limits include the reference limits and is predicted to decline below MSY $B_{trigger}$ in year 2024.

Recent changes

The 2023 stock assessment results show that herring Spawning-stock biomass (SSB) is in decline again, 10% from 2022 to 2023, after a slight increase in 2021. The cumulative biomass decline from last biomass peak, in 2008, to 2023 is 48% [8]. Mackerel SSB also began declining again in 2023, by 7% compared to previous year, after several years of similar biomass values. Biomass peak was in 2015 and the cumulative decline is 43% in 2023 [7]. Blue whiting SSB continued increasing and was estimated 36% higher in 2023 compared to 2022 and in projected to increase another 9% in 2024 [9].

The distribution area of herring in May changed as limited herring was present in the southeast and northeast parts of the Norwegian Sea in 2023 compared to 2022 [10,11]. By July 2023, the herring had shifted westward and northward compared to May [11,12]. The mackerel distribution in the Nordic Seas in summer 2023 was similar to the observed distribution in summer 2022 with the western boundary of mackerel presence located west of Iceland (longitude 27 °W) [12,13]. The distribution of blue whiting in the spawning area expanded in 2023 compared to 2022 with blue whiting also present in the northern part of spawning grounds which was not recorded in 2022 [14,15].

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 [8] (Figure A4.4b). There is no indication that another large year-class will enter the spawning stock in the coming years. Fishing above the advised level has accelerated the stock decline during a period of low recruitment. Since 2013, unilaterally determined quotas have led to annual commercial catch being 31% higher than the advised total allowable catch (TAC) on average [8].

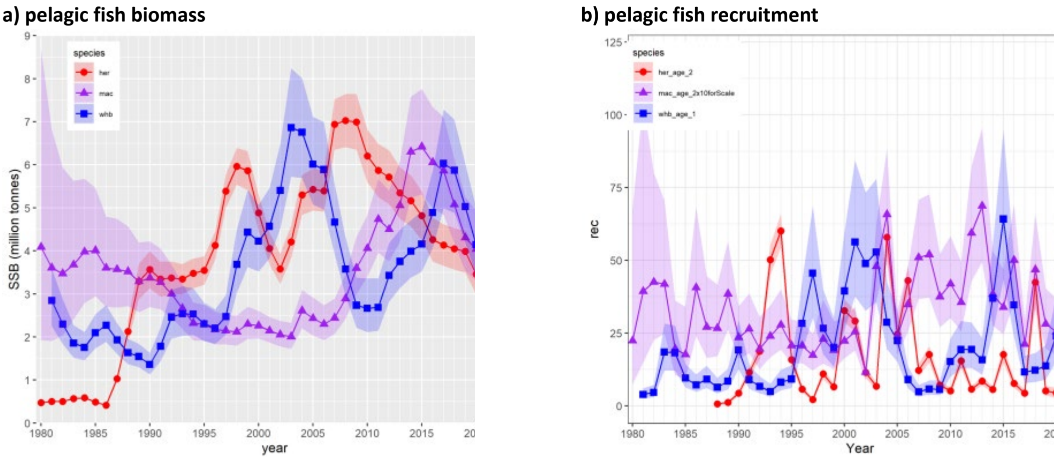


Figure A4.4. a) estimated spawning-stock biomass (lines) including 95% confidence intervals (shaded areas) for Norwegian spring-spawning herring (red filled circles), mackerel (purple filled triangles) and blue whiting (blue filled rectangles) from first stock assessment year, ranges from 1980 or 1988, to 2023 [7–9]. B) estimated year-class size at recruitment for Norwegian spring-spawning herring (age 2; red filled circle), mackerel (age 2; purple filled triangles) and blue whiting (age 1; blue filled triangle) from first year of assessment, ranges from 1980 to 1988, to 2023 [7–9]. Note mackerel recruitment is multiplied by 10 to be on the same magnitude as values for herring and blue whiting.

The 2023 assessment changed the perception of the mackerel stock, SSB revised upward and fishing mortality downward, and the revision is greater in the years prior to 2018 compared to years 2019 to 2022 [7]. It is not properly understood why the perception changed in the 2023 assessment. Systematic revisions in perception of the stock have occurred repeatedly in last several assessments and suggest lack of robustness in the assessment which could be due to model misspecifications or conflicting trends in the five input time-series. Since 2010, unilaterally determined quotas have led to annual commercial catch being 40% higher than the advised TAC on average. Fishing above advised TAC is believed to have contributed to the observed decline in spawning stock size.

Sharp increase in blue whiting SSB is driven by recruitment of two record large year classes, 2020 and 2021, to the spawning stock [9]. Biomass is estimated to be record high for the assessment period. The 2020 year-class is considered fully recruited to the spawning stock and is the biggest year-class in the stock. Since 2015, unilaterally determined quotas have led to annual commercial catch being on average 35% higher than the advised TAC [9]. The blue whiting fishery targets few age classes, mostly 3–5 year-olds, hence the stock declines quickly when poor recruitment coincides with excessive fishing as seen after the last SSB peak in 2017.

Seabird

Current status

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 three pelagic species are the black-legged kittiwake (*Rissa tridactyla*, hereafter kittiwake), the Atlantic puffin (*Fratercula arctica*, hereafter puffin) and the 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 in this part of the Norwegian Sea 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 feeds 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.

Recent changes

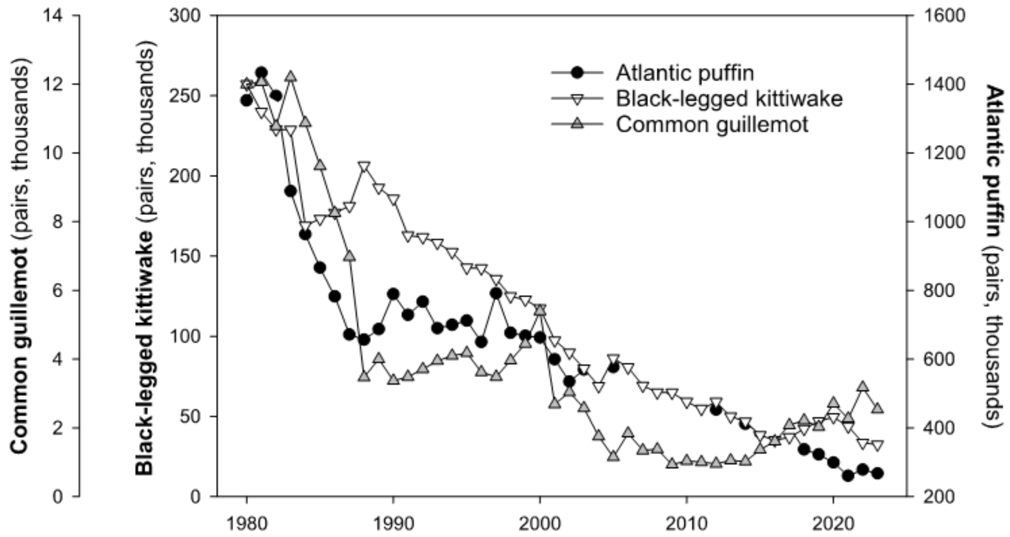
For the three pelagic species, time-series of their population development in the eastern Norwegian Sea (Figure A4.5a) were derived from their estimated breeding numbers in 2013 [16] and annual monitoring of trends in selected breeding colonies (Runde (62.4°N), Sklinna (65.2°N), Røst (67.5°N) and Anda (69.1°N, only kittiwake and puffin)). The remote island of Jan Mayen (71.1°N) in the northwestern Norwegian Sea holds only < 10,000 pairs of kittiwakes, < 5000 pairs of puffins and < 1000 pairs of common guillemots. Monitoring there 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 87% since monitoring started in 1980. Its outlook is grim, with several large colonies already gone extinct and many more risking extinctions within few decades. In the same area and period, the breeding population of puffins has declined by 80% and that of common guillemots by 79%. The small remaining population of common guillemot breeds under boulders and in crevices where the birds are less exposed to predation by white-tailed eagles and has shown clear signs of increase over the last decade. The species is still considered to be at high risk of extinction as a breeding species along a large part of the Norwegian mainland coast.

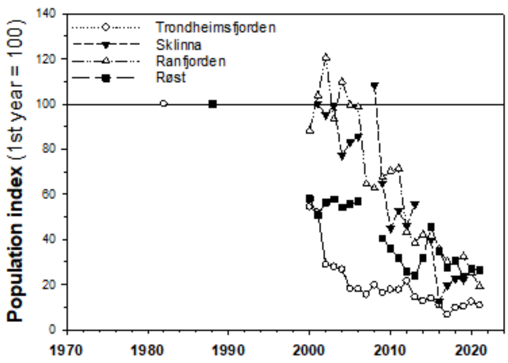
For the two coastal species, trends in breeding populations in the eastern Norwegian Sea (Figure A4.5 b,c) are monitored in selected areas along the mainland coast (Trondheimsfjorden (63.4°N, only eider), Sklinna (65.2°N), Ranfjorden (66.2°N, only eider), and Røst (67.5°N). Data from 2022-2023 have not been added yet but these are not expected to change the overall trends.

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) population trends for black-legged kittiwake, common guillemot and Atlantic puffin



b) population trends for common eider



c) population trends for European shag

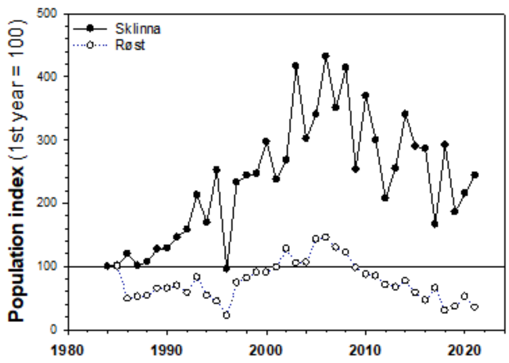


Figure A4.5 Population trends for seabirds breeding in the Norwegian part of the eastern Norwegian Sea since 1980, divided by (a) pelagic feeding species black-legged kittiwake, common guillemot and Atlantic puffin, (b) coastal benthic feeding common eider and (c) coastal fish-feeding European shag.

Possible reasons for recent changes

The largest changes in seabird numbers in the eastern Norwegian Sea are linked to ocean climate variability [17,18] and most likely mediated through substantial changes in prey abundance and availability with dire consequences for reproductive success and recruitment [19–24]. To some degree, this has also affected survival rates [25–27], which in addition can occasionally be severely hit by extreme weather events [28–31]. 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 [23,32,33] and increased predation from white-tailed eagles [34,35], as well as contaminants [36] and human disturbance [37]. The magnitude of seabird bycatch in some of Norway's most important fisheries has also been quantified in a series of recent studies [38–40]. Outbreaks of highly pathogenic avian influenza (HPAI) hit many colonies of seabirds along the Norwegian coast in 2022 and 2023. Apparently, black-legged kittiwakes were among the species most affected, together with great skuas and northern gannets. Studies have been initiated to quantify the population level impacts.

Marine mammals

Current status

Nine marine mammal species are closely associated with core ecological processes and human activities in the Norwegian Sea area. Minke (*Balaenoptera acutorostrata*), fin (*Balaenoptera physalus*), humpback (*Megaptera novaeangliae*) and sperm whales (*Physeter macrocephalus)* dominate in biomass but are mainly present in summer and autumn; hooded seals (*Cystophora cristata*) and northern bottlenose whales (*Hyperoodon ampullatus*) have a partially arctic distribution; while harbour porpoises (*Phocoena phocoena*), grey seals (*Halichoerus grypus*) and harbour seals (*Phoca vitulina*) are resident on the continental shelf of Norway. All nine marine mammal species have been significantly affected by historic harvesting levels, but only minke whales, grey and harbour seals are currently hunted in the area. Killer whales (*Orcinus orca*) may occur across the Norwegian Sea and year-round but are mainly associated with the herring and mackerel migrations. Marine mammals are significant determinants of energy flow through foodwebs. Skern-Mauritzen *et al*. [41] recently estimated the total annual biomass consumption by marine mammals in the Norwegian and Greenland Seas at 4.6 (CI: 1.9–8.6) million tonnes. This exceeds the estimated 1.45 million tonnes removed by fisheries. More than 60% of the marine mammal consumption is comprised by euphausiids and other non-commercial crustaceans [41]. While there is a potential for direct competition with fisheries for capelin, herring and gadoids, marine mammals may also promote ecosystem productivity through enhancing nutrient recycling [42].

Recent changes

Commercial sealing is believed to have reduced the abundance of the Northeast Atlantic hooded seal population by more than 80% from the mid-1940s to 1980. After that, abundance models have shown a continued slow decline, despite full protection since 2007 [43]. It should, however, be noted that the uncertainty around the postwar population size is considerable and that the modelling framework for this species is going through a revision. Harbour and grey seals are subject to a quota regulated hunt and some incidental bycatch along the Norwegian coast [44,45]. Over the past decade, declines observed in central Norway have led to full protection in some areas [44,45]. New surveys have shown continued low levels of pup production in both grey seals and hooded seals [45].

Fin and humpback whales have shown strong recoveries in the Northeast Atlantic over the past decades [46–48] and there is evidence of a recent long-term shift in distribution from the Norwegian Sea to the Barents Sea ecoregion, particularly for humpback whales [47]. The abundance estimate of Northeast Atlantic minke whales has increased considerably. These three baleen whale species are pelagic feeders with variable preferences for crustaceans and small fish.

Relative abundance indicators suggest stable occurrence of the deep-diving sperm whale in the Norwegian Sea area over the period 2002-2018 [46,47]. During the same period, abundance estimates for harbour porpoises and killer whales have been highly variable and do not show a clear trend. Abundance trends are not available for northern bottlenose whales, but sightings of this deep-diving species doubled during the last whale survey cycle (2014-2018) compared to previous cycles [46,47].

Moan *et al*. (2020) [49] reported that the annual bycatches of harbour porpoises in Norwegian waters ranged from 1151 to 6144 for the period 2006 to 2018, with an average of about 2900. While this was considered unsustainable, there was an overall reduction to a sustainable annual average of about 1600 porpoises during the last five years of the study. However, more recent estimates that corrected for 'drop-out rates' of animals from the nets during hauling suggested that porpoise bycatch rates for the same area are still not sustainable [50].

Possible reasons for recent changes

Bycatches in bottom-set gillnets are the suspected culprit for the reductions in grey seal pup production along the Norwegian coast [45,51], but seal predation by killer whales could also play a role [52]. The overall reduction in harbour porpoise bycatches over the last 10 years are possibly due to reduced effort in the monkfish fishery.

The lack of recovery in the Northeast Atlantic hooded seal population is not well understood. Maximum abundance of this population was recorded prior to the development of modern offshore fisheries in the 1950s and 60s, which could have changed the carrying capacity for hooded seals. Information on hooded seal diet is scarce but several commercial prey species have been identified from analyses of stomach content and fatty acids [53–55]. Changes in the availability and condition of sea ice used for haul-out off east Greenland may also have affected the energy balance of hooded seals and are likely linked to increased predation rates by polar bears [56,57].

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Annex 5: Analysis of trends and recent changes (ATAC)

Benjamin Planque and Lucie Buttay

16 November 2023

A5.1 Principles

In the ATAC analysis, the idea is to model trends (and eventually autoregressive processes, AR) for each individual time-series. This is done for a standardized period of time, here from 1980 to 2020. The models are used to estimate the prediction errors, which are presented as the 95% confidence bands of prediction. The same models are then used to produce forecasts, and associated forecasting errors (or forecasting bands) for the last years of the time-series. When recent observations are available, these can be compared to the expected forecast values and forecast bands.

The interpretation is done in two ways:

- The long-term evolution of each time-series is interpreted based on the estimated trend and autoregressive process. This highlights if the series has been e.g. increasing, decreasing or following other long-term patterns. It also highlights if there is a short-term 'memory' in the time-series (i.e. the value observed in one year depends on the value(s) observed in the preceding year(s).
- The recent changes are addressed by comparing the recent observations (in the most recent years) against the forecasts/forecast bands. If the forecasts lie within the forecast bands, they were "expected" based on earlier trends & AR & prediction errors. If they are outside the forecast bands, they indicate that the recent observations in the time-series are departing from the earlier trend.

The modelling is done with the BRMS package. The plotting is done using the ggplot2 package

A5.2 Modelling of the trends, prediction and forecasting bands for the period 1980-present using the brms package

This is done using the following steps:

1. three models are constructed for each time-series:
   - a GAM model (splines) without autoregressive process: *brm(y ~ s(x))*
   - a GAM model (splines) with autoregressive process AR(1): *brm(y ~ s(x), autocor = cor_ar(p=1))*
   - a GAM model (splines) with autoregressive process AR(2): *brm(y ~ s(x), autocor = cor_ar(p=2))*
2. the best of the three models is selected, based on the LOO (Leave One Out criteria)
3. the trend and predictions are calculated.
4. the prediction percentiles for 2.5%, 12.5%, 25%, 75%, 87.5%, 97.5% are calculated.
5. a new "truncated" model is fitted to the time-series up to 2020. This model has the same form (ie., same AR process) as the best model fitted on the whole time-series.
6. the truncated model is used to make forecasts for 2021, 2022 and 2023.
7. the forecasts and forecast bands (50%, 75% and 95%) are calculated.

8. the full model, the truncated model, the trends, predictions and forecasts are archived. Note that for all models we assume a Gaussian distribution of the errors. For some time-series that depart from normality the original data have been pre-transformed using a double square root. This provides a useful rescaling of the data which is expected to function well for models that assume normality. For time-series shorter than 20y, the models with AR process are not fitted because the estimation of AR coefficients is unreliable. In those cases, the trend-only model is selected by default.

A5.3 Standardized time-series graphs

The standardized representation is highlighted in Figure A5.1. Each plot corresponds to one time-series for the WGINOR set, with the following:

- observations shown as blue dots
- the truncated trend (without AR) shown as a dark yellow plain line.
- the truncated model (= trend+AR) shown as a blue dashed line. If there is no AR process the trend and the model sit on top of each other.
- the 95% prediction band for the period 1980 to 2020 indicated as a grey ribbon.
- the forecasts values for the period 2021 to 2023 indicated as a dark red line.
- the forecast bands for 50%, 75% and 95% indicated as dark/medium/light red ribbons.

When the observations in the last three years are on the edge or outside the forecast bands, this can be interpreted as a departure (a stall) for the trend in recent years.

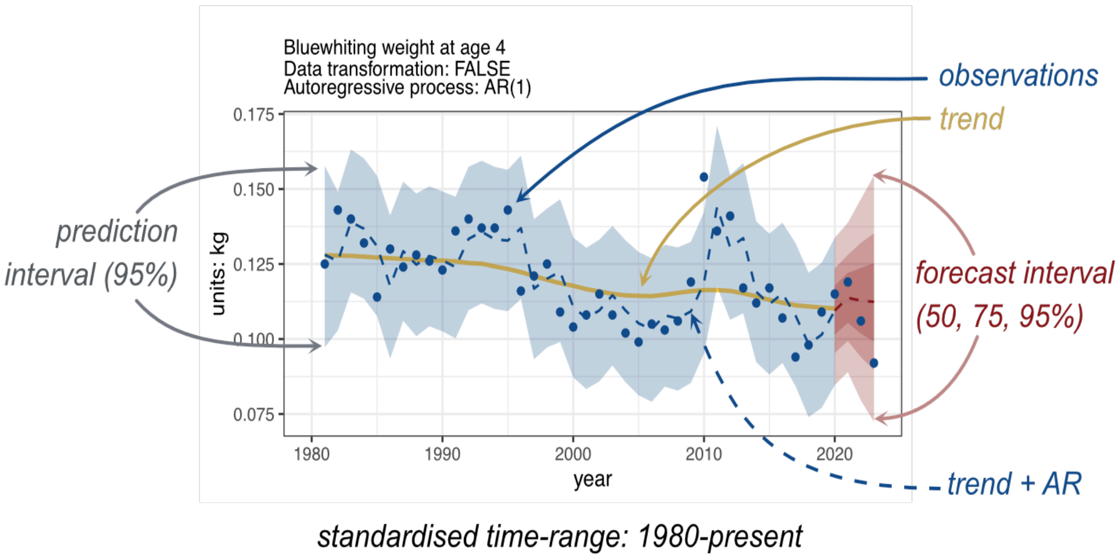
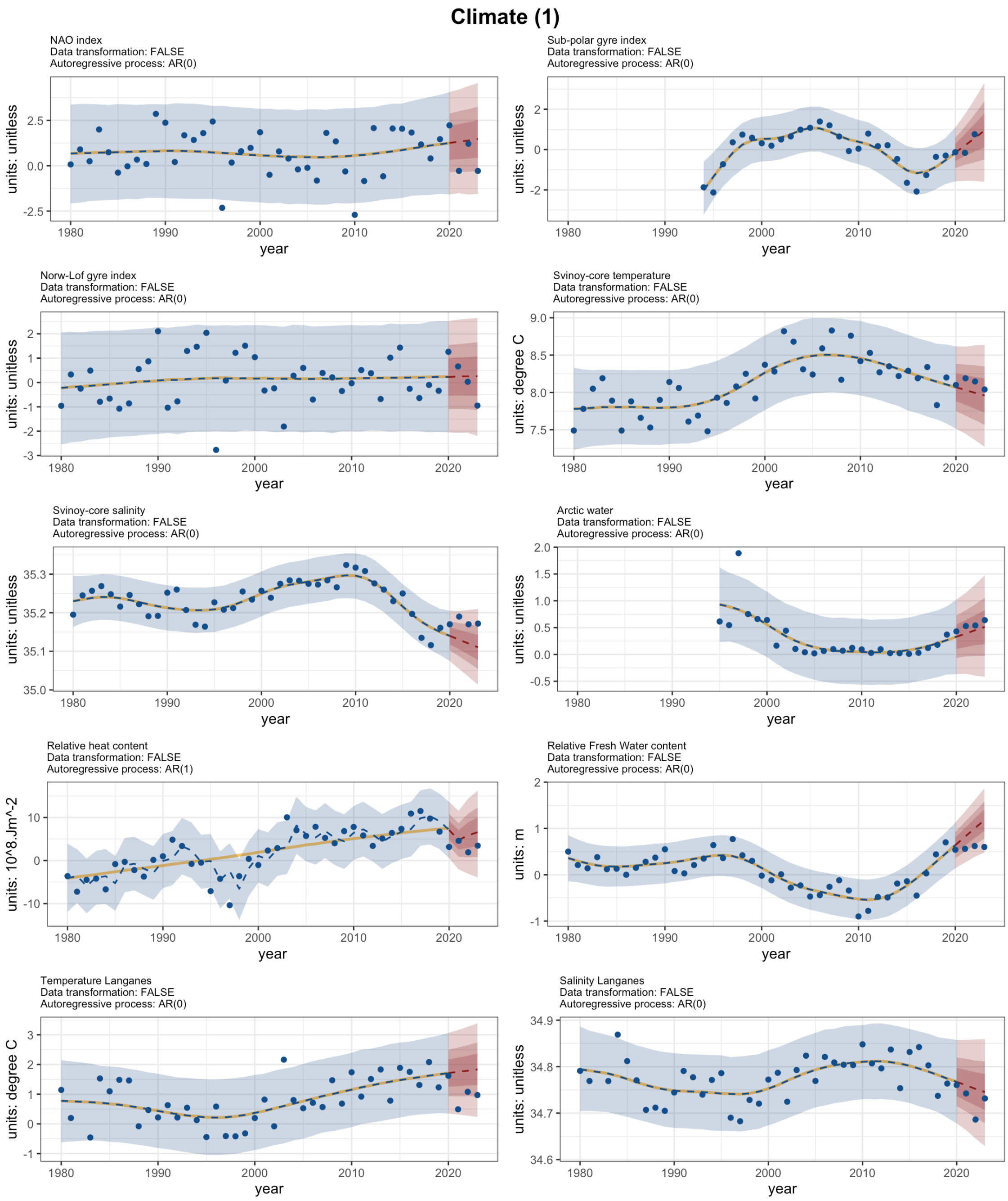
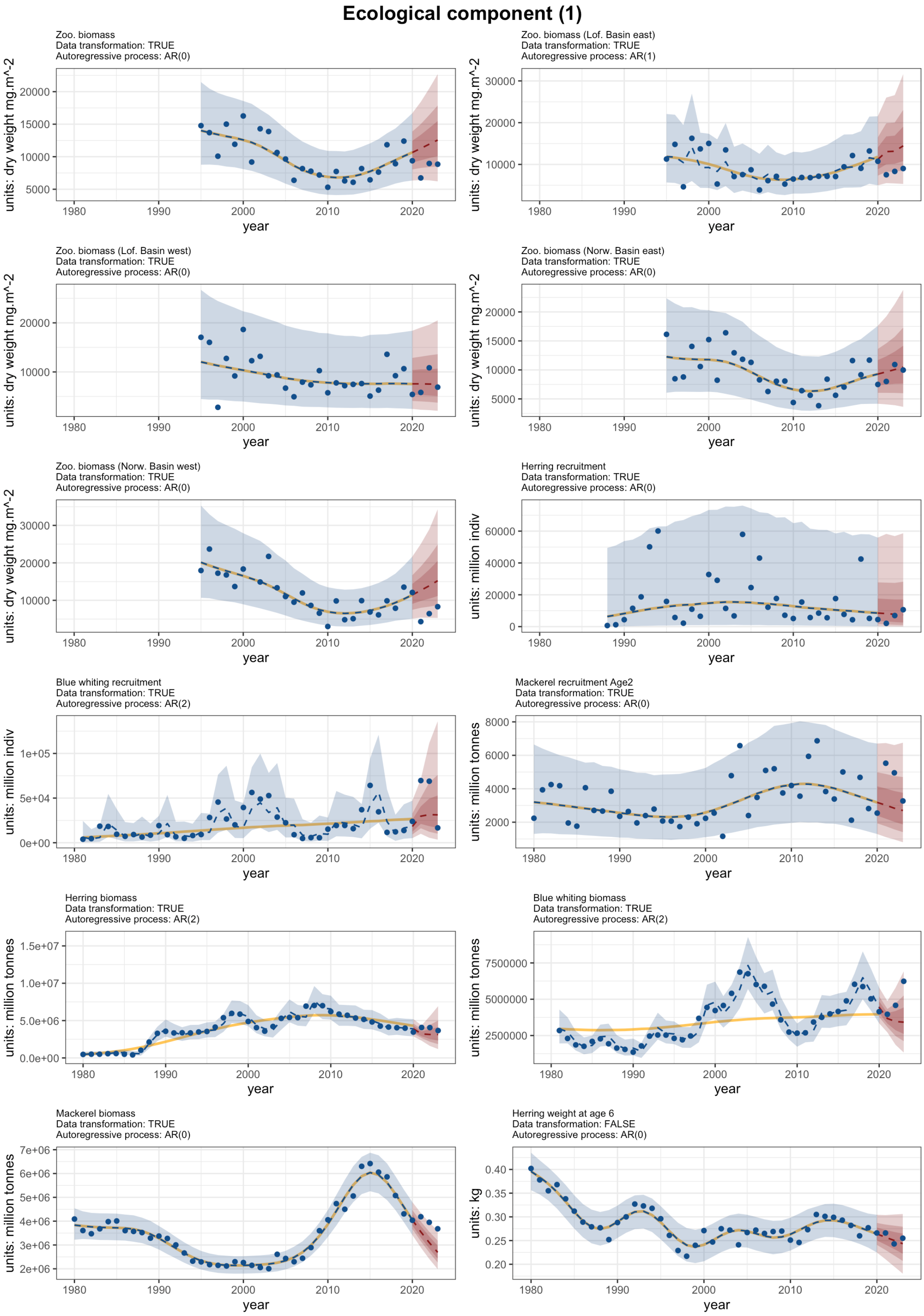
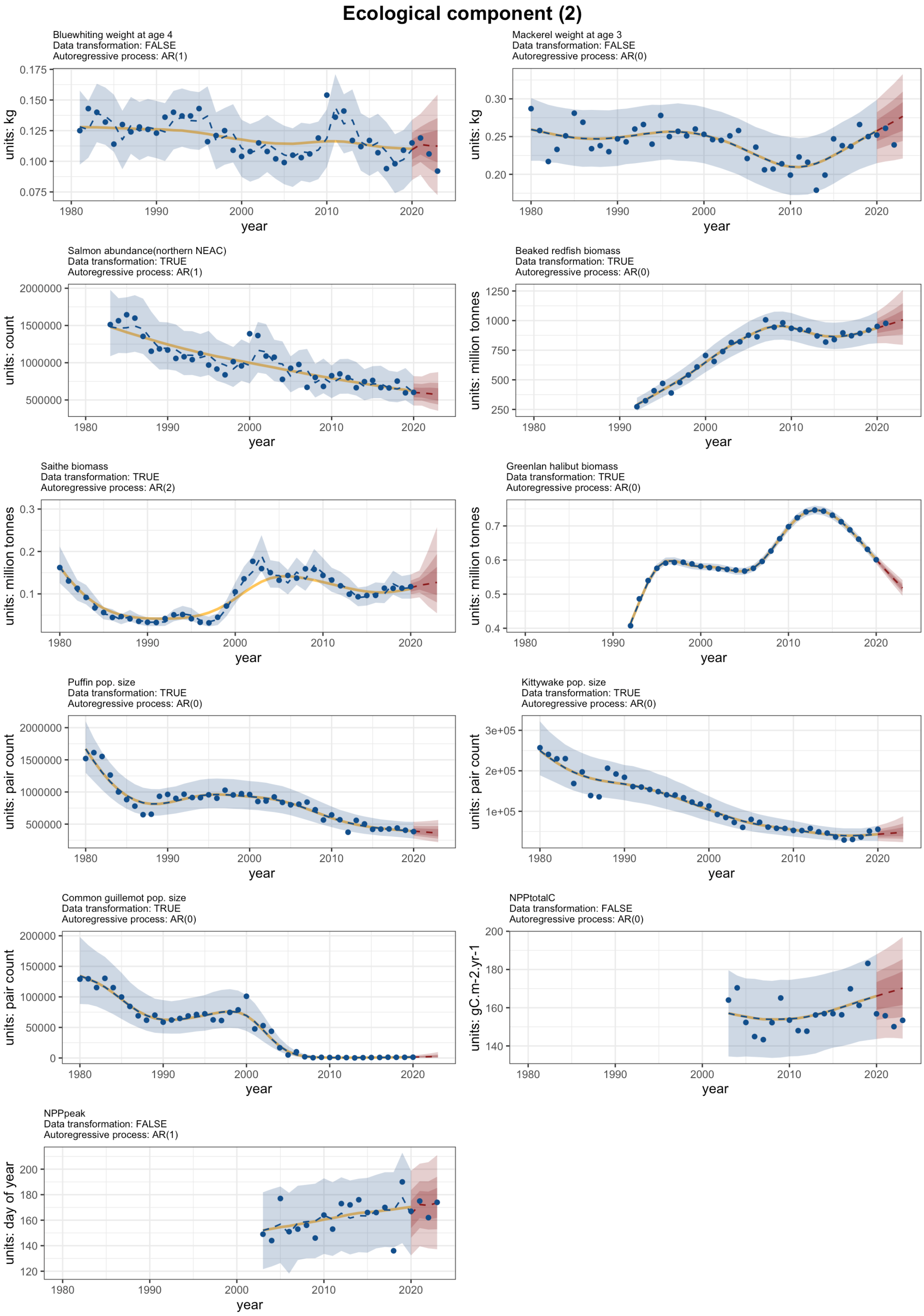


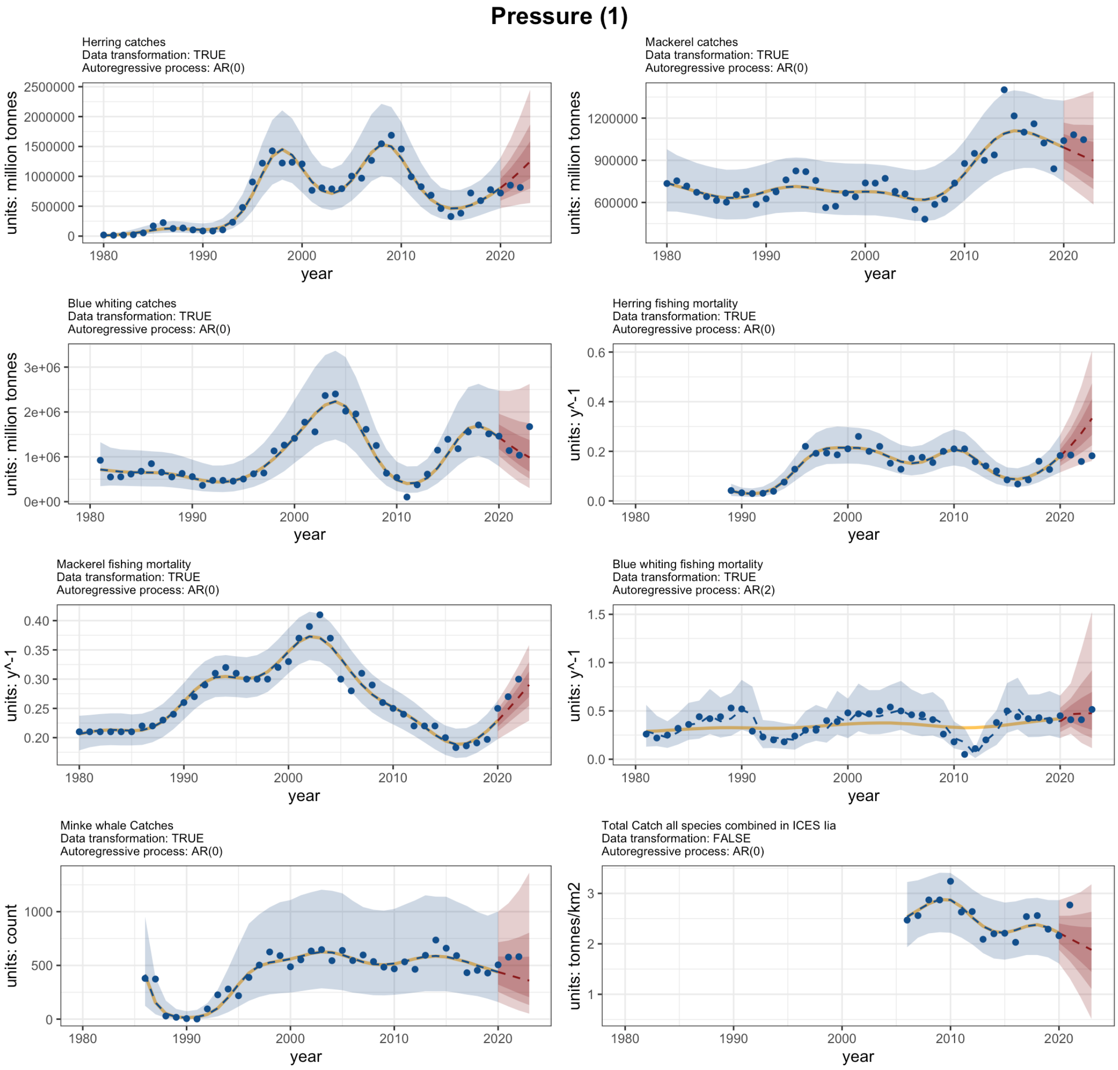
Figure A5.11 An example of ATAC results highlighting the different graphical elements used for the interpretation of temporal changes.

A5.4 Results

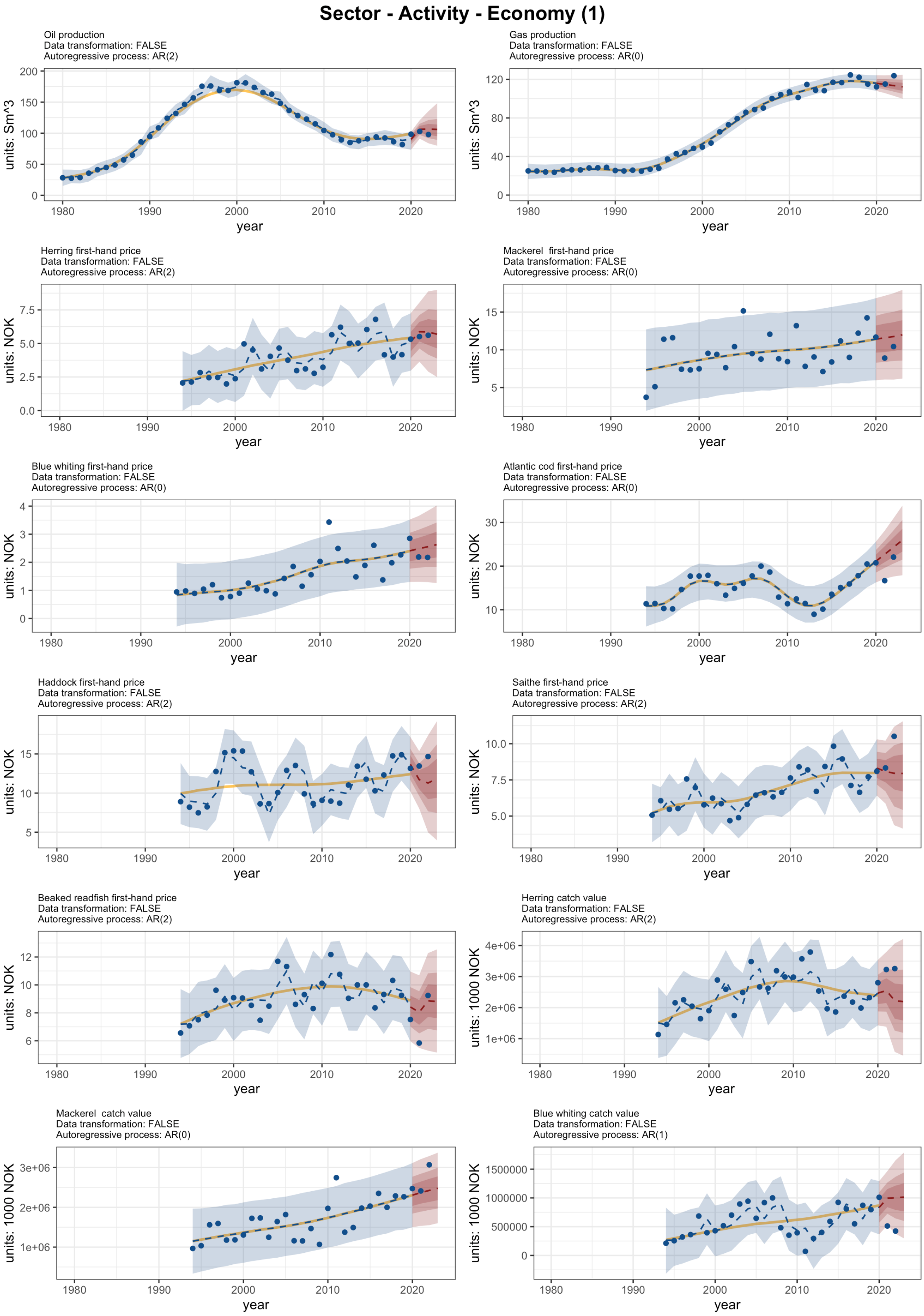

Climate (1)
NAO index
Data transformation: FALSE
Autoregressive process: AR(0)
units: unitless
year
Sub-polar gyre index
Data transformation: FALSE
Autoregressive process: AR(0)
units: unitless
year
Norw-Lof gyre index
Data transformation: FALSE
Autoregressive process: AR(0)
units: unitless
year
Svinoy-core temperature
Data transformation: FALSE
Autoregressive process: AR(0)
units: degree C
year
Svinoy-core salinity
Data transformation: FALSE
Autoregressive process: AR(0)
units: unitless
year
Arctic water
Data transformation: FALSE
Autoregressive process: AR(0)
units: unitless
year
Relative heat content
Data transformation: FALSE
Autoregressive process: AR(1)
units: 10^8.Jm^-2
year
Relative Fresh Water content
Data transformation: FALSE
Autoregressive process: AR(0)
units: m
year
Temperature Langanes
Data transformation: FALSE
Autoregressive process: AR(0)
units: degree C
year
Salinity Langanes
Data transformation: FALSE
Autoregressive process: AR(0)
units: unitless
year


Ecological component (1)
Zoo. biomass
Data transformation: TRUE
Autoregressive process: AR(0)
Zoo. biomass (Lof. Basin east)
Data transformation: TRUE
Autoregressive process: AR(1)
Zoo. biomass (Lof. Basin west)
Data transformation: TRUE
Autoregressive process: AR(0)
Zoo. biomass (Norw. Basin east)
Data transformation: TRUE
Autoregressive process: AR(0)
Zoo. biomass (Norw. Basin west)
Data transformation: TRUE
Autoregressive process: AR(0)
Herring recruitment
Data transformation: TRUE
Autoregressive process: AR(0)
Blue whiting recruitment
Data transformation: TRUE
Autoregressive process: AR(2)
Mackerel recruitment Age2
Data transformation: TRUE
Autoregressive process: AR(0)
Herring biomass
Data transformation: TRUE
Autoregressive process: AR(2)
Blue whiting biomass
Data transformation: TRUE
Autoregressive process: AR(2)
Mackerel biomass
Data transformation: TRUE
Autoregressive process: AR(0)
Herring weight at age 6
Data transformation: FALSE
Autoregressive process: AR(0)
units: dry weight mg.m^-2
units: million indiv
units: million tonnes
units: kg
year

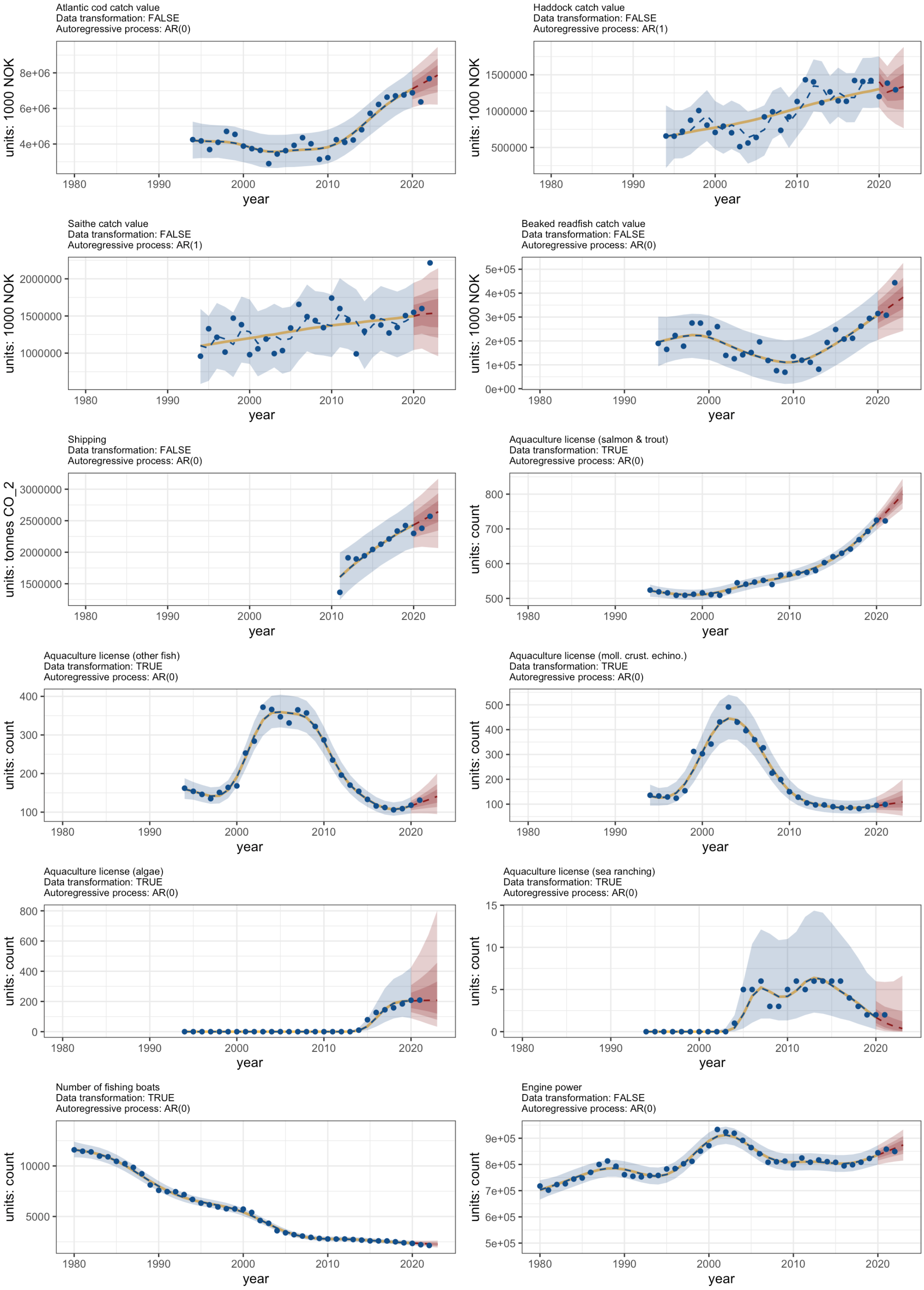

Ecological component (2)
Bluewhiting weight at age 4
Data transformation: FALSE
Autoregressive process: AR(1)
units: kg
year
Mackerel weight at age 3
Data transformation: FALSE
Autoregressive process: AR(0)
units: kg
year
Salmon abundance(northern NEAC)
Data transformation: TRUE
Autoregressive process: AR(1)
units: count
year
Beaked redfish biomass
Data transformation: TRUE
Autoregressive process: AR(0)
units: million tonnes
year
Saithe biomass
Data transformation: TRUE
Autoregressive process: AR(2)
units: million tonnes
year
Greenlan halibut biomass
Data transformation: TRUE
Autoregressive process: AR(0)
units: million tonnes
year
Puffin pop. size
Data transformation: TRUE
Autoregressive process: AR(0)
units: pair count
year
Kittywake pop. size
Data transformation: TRUE
Autoregressive process: AR(0)
units: pair count
year
Common guillemot pop. size
Data transformation: TRUE
Autoregressive process: AR(0)
units: pair count
year
NPPtotalC
Data transformation: FALSE
Autoregressive process: AR(0)
units: gC.m-2.yr-1
year
NPPpeak
Data transformation: FALSE
Autoregressive process: AR(1)
units: day of year
year



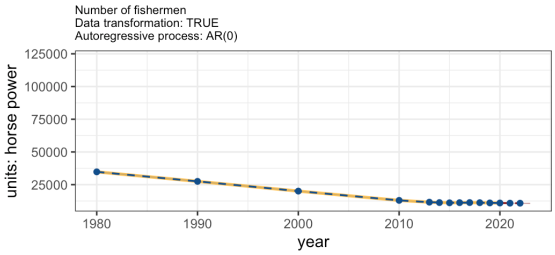
Pressure (1)
Herring catches
Data transformation: TRUE
Autoregressive process: AR(0)
units: million tonnes
year
Mackerel catches
Data transformation: TRUE
Autoregressive process: AR(0)
units: million tonnes
year
Blue whiting catches
Data transformation: TRUE
Autoregressive process: AR(0)
units: million tonnes
year
Herring fishing mortality
Data transformation: TRUE
Autoregressive process: AR(0)
units: y^-1
year
Mackerel fishing mortality
Data transformation: TRUE
Autoregressive process: AR(0)
units: y^-1
year
Blue whiting fishing mortality
Data transformation: TRUE
Autoregressive process: AR(2)
units: y^-1
year
Minke whale Catches
Data transformation: TRUE
Autoregressive process: AR(0)
units: count
year
Total Catch all species combined in ICES IIa
Data transformation: FALSE
Autoregressive process: AR(0)
units: tonnes/km2
year


Sector - Activity - Economy (1)
Oil production
Data transformation: FALSE
Autoregressive process: AR(2)
units: Sm^3
Gas production
Data transformation: FALSE
Autoregressive process: AR(0)
units: Sm^3
Herring first-hand price
Data transformation: FALSE
Autoregressive process: AR(2)
units: NOK
Mackerel first-hand price
Data transformation: FALSE
Autoregressive process: AR(0)
units: NOK
Blue whiting first-hand price
Data transformation: FALSE
Autoregressive process: AR(0)
units: NOK
Atlantic cod first-hand price
Data transformation: FALSE
Autoregressive process: AR(0)
units: NOK
Haddock first-hand price
Data transformation: FALSE
Autoregressive process: AR(2)
units: NOK
Saithe first-hand price
Data transformation: FALSE
Autoregressive process: AR(2)
units: NOK
Beaked readfish first-hand price
Data transformation: FALSE
Autoregressive process: AR(2)
units: NOK
Herring catch value
Data transformation: FALSE
Autoregressive process: AR(2)
units: 1000 NOK
Mackerel catch value
Data transformation: FALSE
Autoregressive process: AR(0)
units: 1000 NOK
Blue whiting catch value
Data transformation: FALSE
Autoregressive process: AR(1)
units: 1000 NOK
year

Sector - Activity - Economy (2)



Sector - Activity - Economy (3)



Annex 6: TREC and FO

WGINOR Trend analyses applying TREC and FO detection

Hiroko Solvang

For WGINOR time-series data, the following trend analyses are conducted to investigate the changes of long-term trend. The basic model is $yy(nn)$=$tt(nn)$+$uu(nn)$ where $yy(nn)$ is NN observed time-series data for nn=1,…,NN, $tt(nn)$ is trend model (assuming non-stationary process), and $uu(nn)$ is stationary process. For the trend component $tt(nn)$, we apply two kinds of trend models, polynomial regression model and the second order difference equation model. The estimates by the former model indicate the simple trend pattern classifying common trend patterns (TREC). The estimates by the later trend model are used for forecasting the recent years (FO detection).

TREC – trend estimation and classification

Trend estimation and classification analyses (ICES JMS 2020) are applied to 26 WGINOR time-series data recorded in the period from 2003-2023 without any missing. The analysing flow is as below (Figure A6.1): 1) estimate trend by a polynomial trend model for time-series data in a fixed period; 2) classify the estimated trends into two groups presenting upward or downward using discriminant analysis; and 3) more specific common patterns are considered and allocate general icons to the common trend groups.

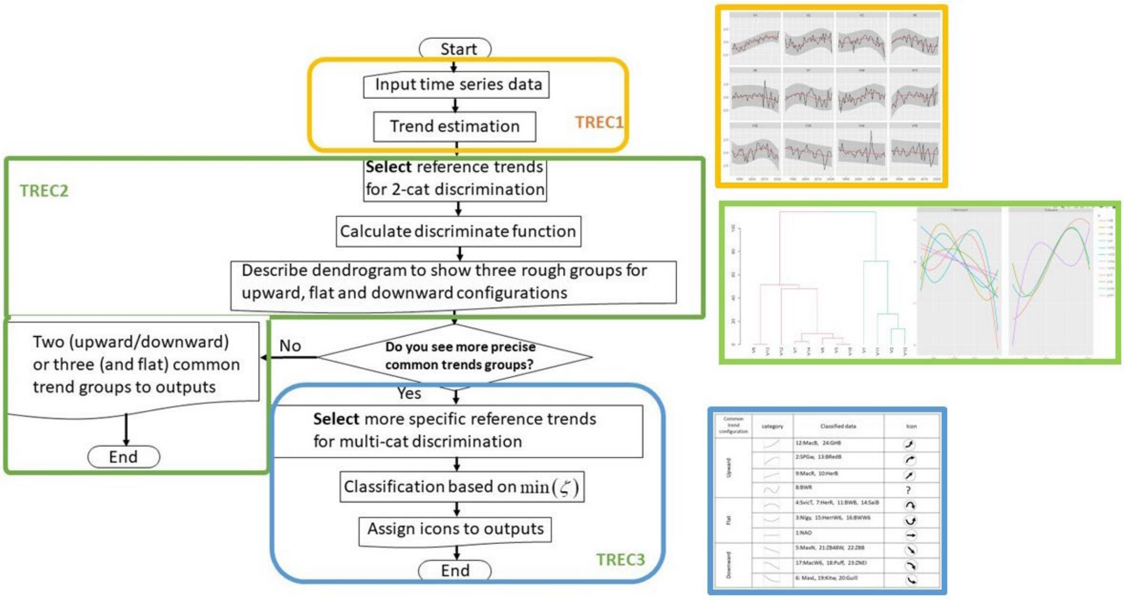


Figure A6.1 Analytical flow for trend estimation and classification.

The polynomial order is considered for 1-3 and the best fit model is identified by AIC. The numerical procedure is conducted by the R package trec (SoftwareX 2023).

The outputs for estimated trend and the classification are as follow, see Figure A6.2 and Table A6.1.

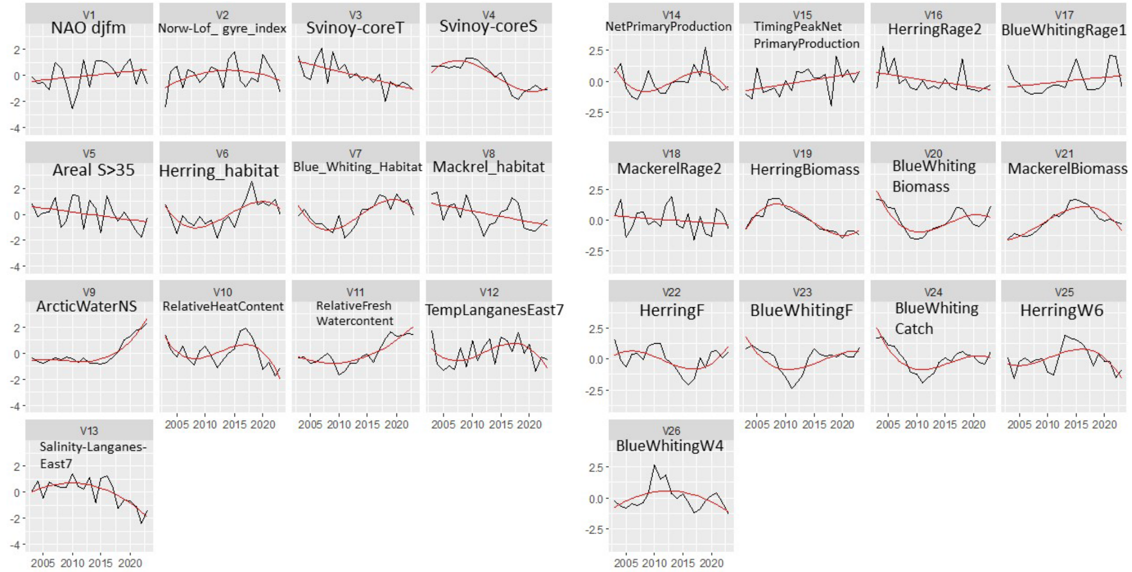


Figure A6.2 TREC analysis results for 26 time-series in the WGINOR dataset for the period 2003–2023.

Table A6.1 The common trends for WGINOR time-series data in 2003-2022.

Climate
Primary Production
Pelagic

upward	icon	downward	icon
1: NAO djfm, 15: Timing PeakNetPrimaryProduction 17: BlueWhitingRage2		3: Svinoy-coreT, 5: Areal S>35, 8: Herring habitat, 16: HerringR age2,18: MackerelR age2	
6: Herring habitat, 7: Blue Whting habitat		10: Relative Heat Content	
9: ArcticWarterNS, 11: RelativeFreshWaterContent		13: Salinity Langanes East7	
12:TempLaganesEast7, 14:NetPrimaryProduction		4: Svinoy coreS, 19: Herring Biomass	
21:MackerelBiomass		22: Herring F	
23:BlueWhitingF		20: Blue Whiting Biomass, 24: Blue Whiting Catch	
2:Norw-Lof gyre index		26: Blue Whiting W4	
25: Herring W6			

Flagged Observation (FO) detection

For FO detection, the second order differential equation model is applied to estimate the trend of individual WGINOR time-series data (Figure A6.3). The model is represented by state space form and trend component is predicted by Kalman filter algorithm. This model format is a Bayesian time-series model and the system noise of the trend model (which is available to obtain flexible trend patterns) becomes a hyperparameter in the model. Originally, the optimum hyperparameter was found by grid research to obtain smoothed trend. This analysis applies a numerical optimization procedure within a region to obtain smoothed trend.

The trend model is identified based on the data until 2020, and the predicted values in 2021-2023 are calculated by the estimated trend model through 'prediction' in Kalman filter and the values are compared with the real observations in 2021-2023. The final trend estimation is obtained by a smoothed values obtained by fixed-point smoother algorithm from 'filtering' of Kaman filter.

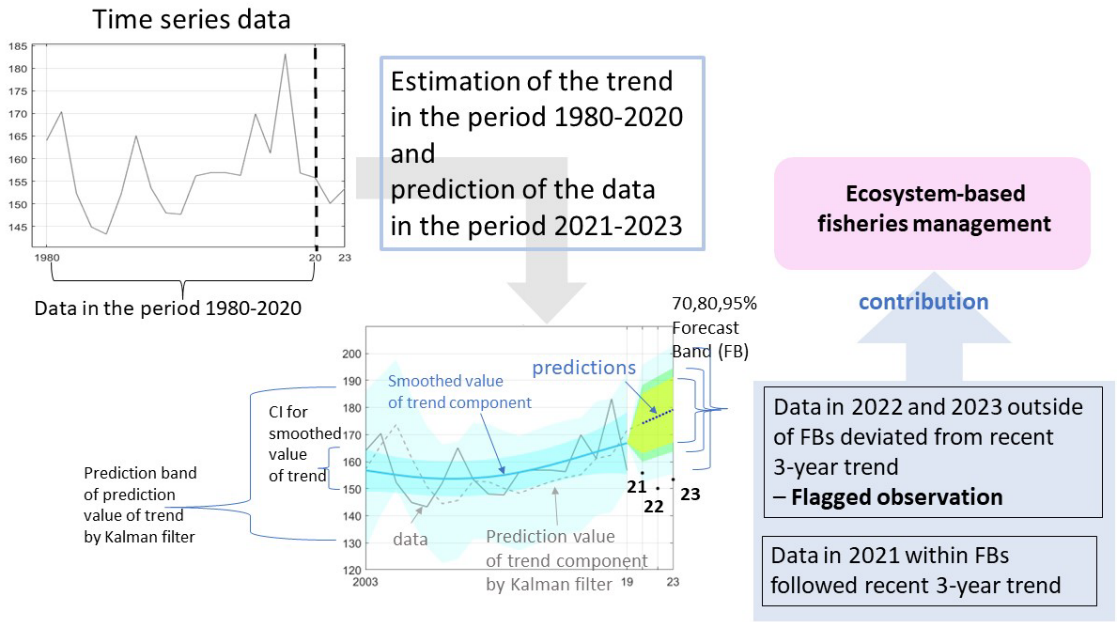


Figure A6.3 Analytical steps for calculating flagged observations for time-series in WGINOR dataset.

To improve the prediction in the recent three years, the model $y(n)$=$t(n)$+$u(n)$ can expand $y(n)$=$t(n)$+$x(n)$+$e(n)$ where $x(n)$ is a cyclic component and $e(n)$ is an observation noise sequence. For $x(n)$, an auto-regressive model is suit to express cyclic component. The number of time points should be over 50 (practically, but theoretically over 100 time points) at least. Since 10 time-series in WGINOR includes over 50 time points, the model including cyclic component is considered for the data. In this case, the system noises of trend and cyclic components and the auto-regressive coefficients are identified by numerical optimization to obtain the optimum decomposition for the data variation at a time point.

These methods (estimate trend and prediction based on the state space modelling with Kalman filter algorithm) have been already established as 'Seasonal Adjustment' in statistical time-series analysis (Kitagawa G, Gersch W. Lecture Notes in Statistics 116. New York: Springer-Verlag 1996; Kitagawa G. Second Edition, London, New York: Chapman & Hall/CRC; 2021). Based on the procedure, the calculation code was re-written in Matlab (grid searching is available in R, but the version of numerical optimization is still working) placing in the sharepoint.

The outputs for FO detection are as displayed in Figure A6.4 and Table A6.2. In the case of the data including over 50 years, comparing with only trend model, if AIC indicates larger for the model including cyclic model, it notices tr + ar(0) beside title of the plot:

Climate variables:

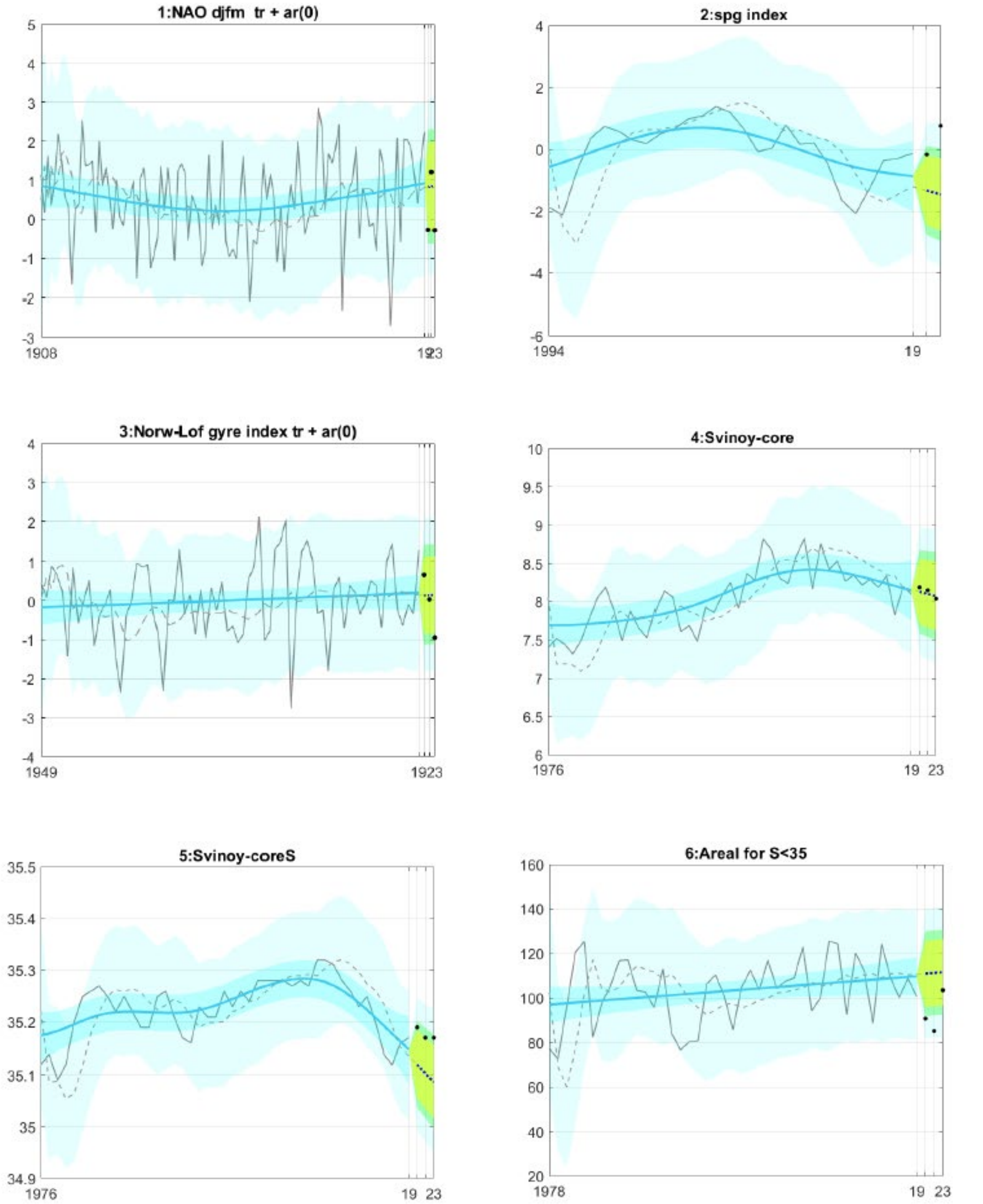


Figure A6.4 Results of flagged observation analysis of 31 time-series included in the WGINOR dataset. Note the time-series cover different time periods (page 1 of 5).

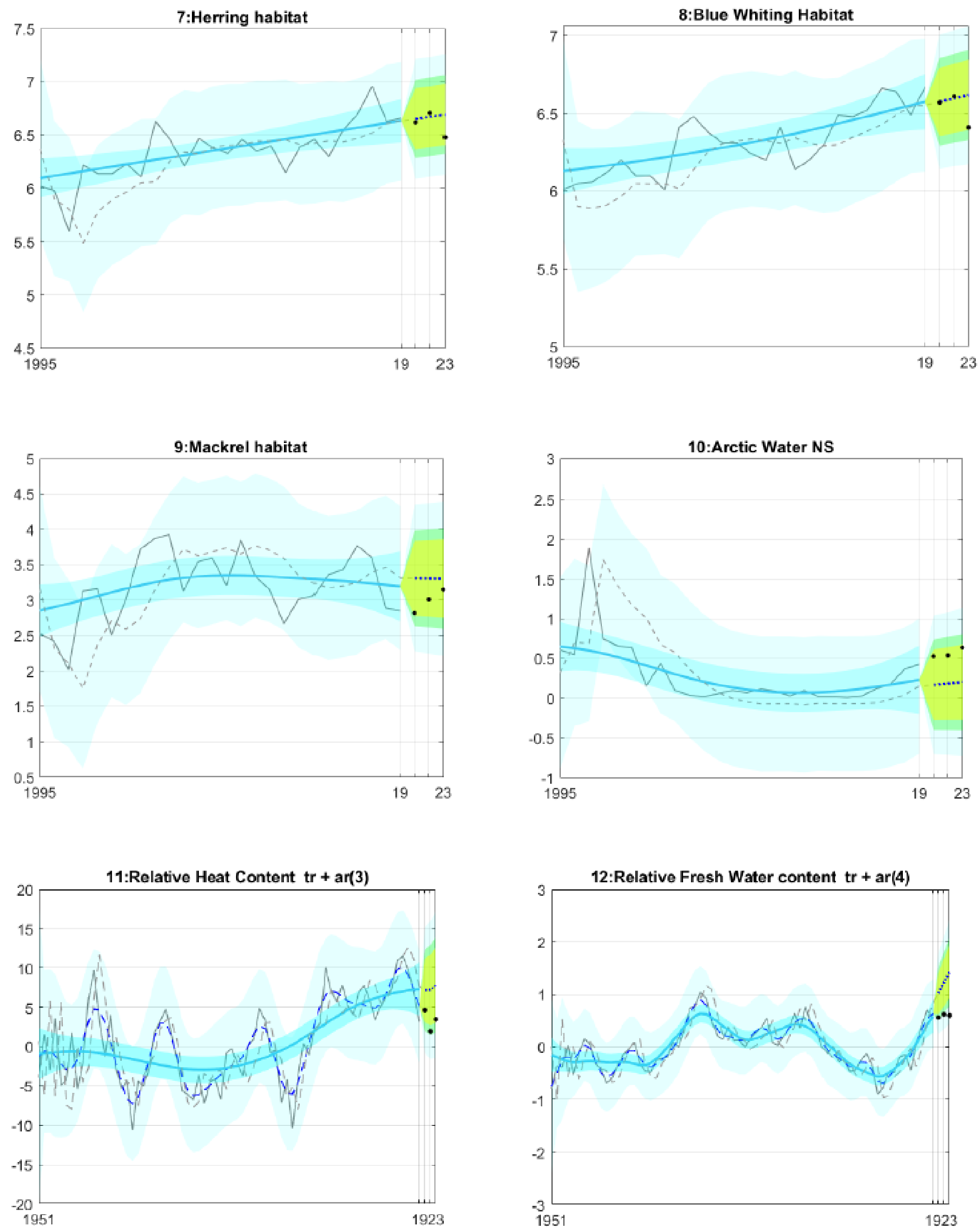
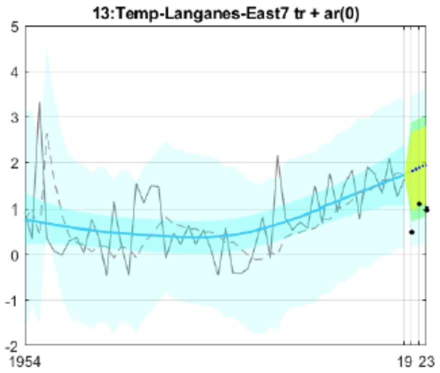
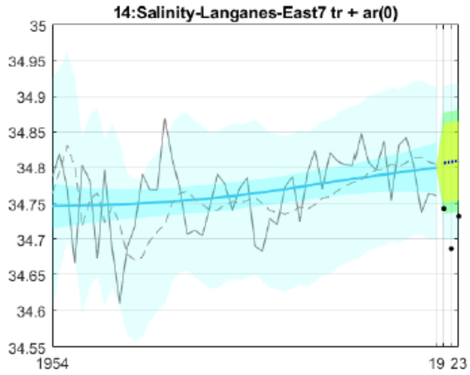
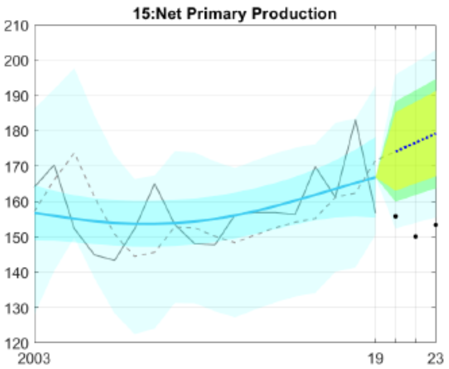


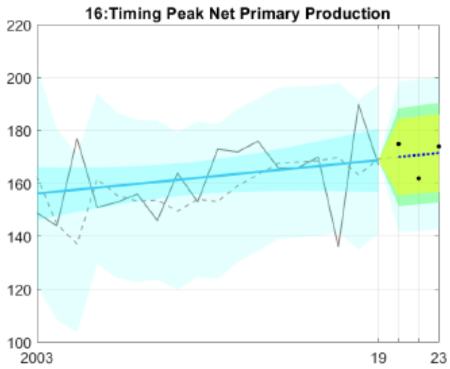
Figure A6.5 Results of flagged observation analysis of 31 time-series included in the WGINOR dataset. Note the time-series cover different time periods (page 2 of 5).



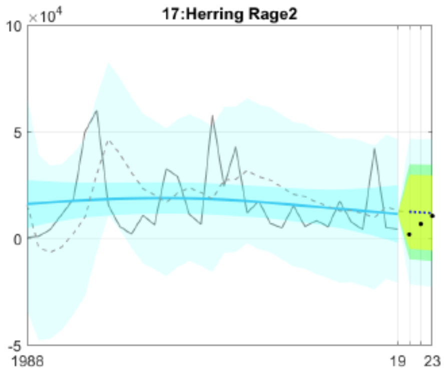


Primary production





Pelagic fish



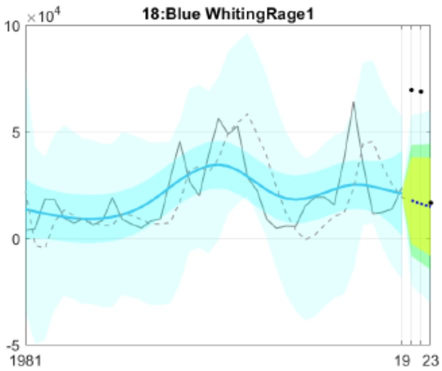


Figure A6.6 Results of flagged observation analysis of 31 time-series included in the WGINOR dataset. Note the time-series cover different time periods (page 3 of 5).

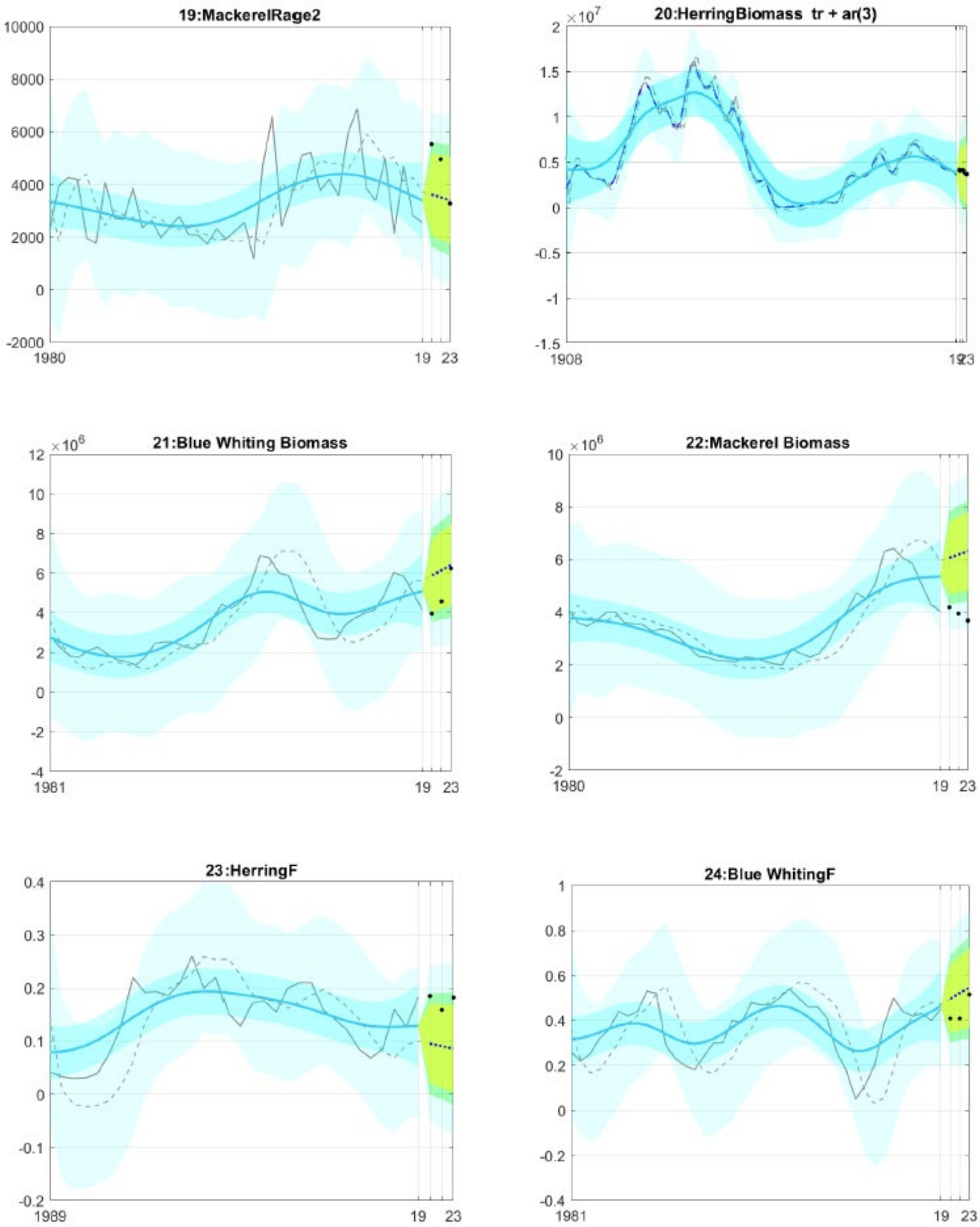


Figure A6.7 Results of flagged observation analysis of 31 time-series included in the WGINOR dataset. Note the time-series cover different time periods (page 4 of 5).

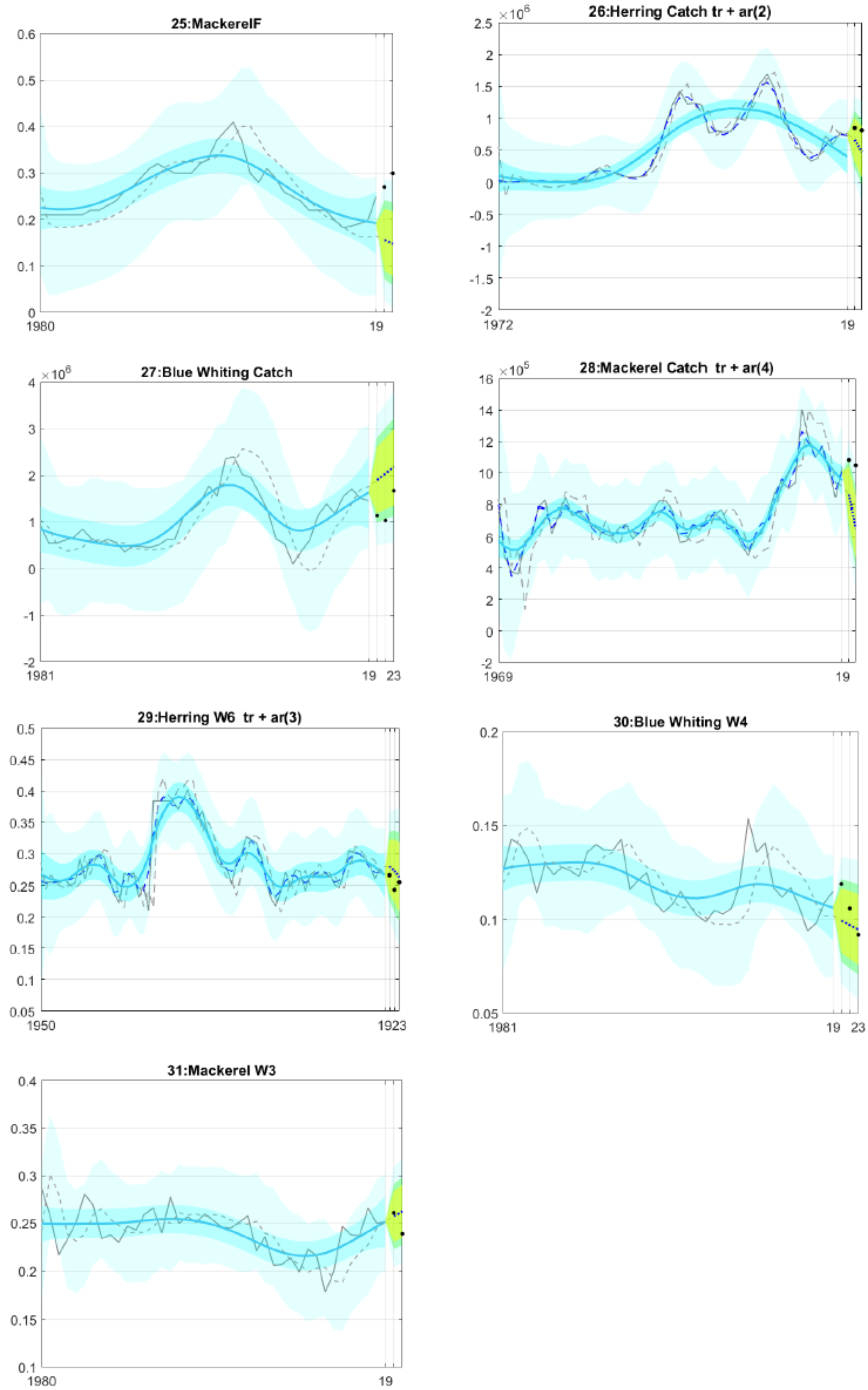


Figure A6.8 Results of flagged observation analysis of 31 time-series included in the WGINOR dataset. Note the time-series cover different time periods (page 5 of 5).

Table A6.2. Results for flagged observation analysis showing for which time-series measurements are above model predictions (Upper) and below model predictions (Below).

Table: Data presenting FOs sequentially

Upper	Below
2: spg index	6: Areal for S<35
5: Svinoy-coreS	9: Mackerel habitat
10: Arctic Water NS	11: Relative Heat content
18: Blue WhitingR age1	12: Relative Fresh Water content
23: HerringF	13: Temp-Langanes-East7
25: MackerelF	14: Salinity-Langanes-East7
26: Herring Catch	15: Net Primary Production
28: Mackerel Catch	17: Herring R age2
	21: Blue Whiting Biomass
	22: Mackerel Biomass
	24: Blue Whiting F
	27: Blue Whiting Catch
	28: Mackerel Catch
	29: Herring W6

Annex 7: Meeting minutes from online intersessional meeting for selection of fish time-series

WGINOR intersessional meeting September 20, 2023, from 10:30 -12:30 GMT time.

Online meeting attended by: Benjamin Planque, Lucie Buttay, Hiroko Solvang (HS), Eydna í Homrum,

Jan Arge Jacobsen, Sigurvin Bjarnason, Thassya C. dos Santos Schmidt, Warsha Singh, Anna H.

Ólafsdóttir (AHO).

Meeting topic: Discussion about current FISH time-series in the WGINOR dataset. Which time-series should remain included, which should be eliminate, and which should be added.

Meeting minutes:

Meeting began by AHO giving a presentation about what the time-series are used for in WGINOR work, background information on indicators in integrated ecosystem assessments and GOOS Essential Ocean Variables (EOV).

Next was a discussion about current FISH time-series in the dataset about which to keep and which to eliminate.

It was decided to select one time-series to describe a phenomenon to describe, to use variables for a stock level, to include uncertainties if possible, and is time-series created by WGINOR then document in data source and calculations detail and store in open database.

For pelagic fish recruitment it was decided to keep Herring age2, mackerel age2 and blue whiting age1 from the WGWIDE assessment and drop the mackerel age0 and the mackerel juvenile index from the dataset. It was also decided to add uncertainties to the dataseries.

For pelagic fish biomass it was decided to keep the stock biomass from the WGWIDE assessment and to drop biomass indices from scientific surveys. It was also decided to add uncertainties to the dataseries.

For pelagic fish catch decided to keep as is a point estimate with no uncertainty, not available. Use ICES landings.

For size-at-age interested in a variable that tracks changes at stock level. Decided to use weight in the stock from WGWIDE as at stock level and long-time-series. Discussed which age to use and the agreed criteria was first age when approximately 90% of year-class or more was mature. That is for herring age6, for mackerel age3, and for blue whiting age4. Length-at-age in the fall from IMR will be removed from dataset (no longer updated).

For other species than pelagic fish it was decided to remove saith and halibut time-series as their distribution is limited to small area, shelf edge, of the ecoregion. Also, in the saith index only 2 of 4 saith stock components are included index. Decided to keep red fish and salmon indices in dataset as is as their stocks are distributed all over the ecoregion.

There was a discussion about more time-series on stock size that could be added to the dataset in the future such as lumpfish (aiming for presentation at WGINOR annual meeting 2023), mesopelagic fish (acoustic sA-values of everything for NO red fish survey), and pink salmon (invasive species).

Currently there are no time-series which describes distribution of the three pelagic fish stock in the WGINOR dataset. GOOS EOV states that measurements on stock geographical distribution are important variables to monitor the ecosystem. Information of distribution of mackerel, herring and blue whiting are available annually from two research surveys called IESNS, conducted annually in May from 1995 to current, and from IESSNS, conducted annually in July from 2010 to current.

As a first step to add pelagic fish distribution time-series to the dataset HS presented analysis done on mackerel distribution from the IESSNS survey for the period 2010 to 2020 at the meeting. In the survey time-series, extreme catches in some years causes bias in centre-of-gravity calculations. It was decided to discuss the issue in more detail at the annual meeting in November 2023.

It was also decided to focus on finalizing time-series describing mackerel distribution in July (IESSNS) before any work will be done on describing herring and blue whiting distribution.

Any time-series on pelagic fish distribution will have to be calculated, documented, and archived in open access database by WGINOR members.

Data from the IESNS and IESSNS are partly openly available in ICES acoustic database. Participants in the IESNS and IESSNS aim to have the whole time-series publicly available in the ICES acoustic database before the next mackerel benchmark which is hoped to be in 2025. The IESNS and IESSNS time-series must become publicly available in the ICES acoustic database before WGINOR published any kind of distribution time-series using the data if we want to make it reproduceable and to archive in publicly accessible database.