Integrated Arctic Observation System

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Deliverable 6.3

Extension of ecosystem management systems - v1

Use existing environmental and fisheries reporting and management systems of the Barents Sea and off Greenland to demonstrate how data from an iAOS may allow for implementing similar procedures in other parts of the Arctic

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20	UPM		**43**	NMEFC	
21	UB		**44**	RADI	
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EXECUTIVE SUMMARY

The aim of D 6.3 is to u*se the existing environmental and fisheries reporting and management systems of the Barents Sea and off Greenland to demonstrate how data from an iAOS may allow for implementing similar procedures in other parts.*

In **Case Barents Sea**, established and proposed indicators by the Barents Sea management plan, are selected for modelling and the results evaluated. Here we have used NORWEgian ECOsystem box Model (NORWECOM E2E) and NOrwegian and BArents Seas Atlantis ecological model (NoBa Atlantis), two complementary and very different end-to-end ecosystem models. They show how the indicators function according to evaluating state of and trends in ecological conditions, how to make such analyses cost-effective and what data are essential or not, including suggestion for indicators that may be added. The results from the models indicate that spatial and temporal scales for observations used in the calculation of the indicators are very important. Some areas are more important to sample than others, and the months in which they are sampled play an important role. To pick up on any changes in management, a suite of indicators should be used, as suggested in the Norwegian ecosystem-based management plans. Therefore, both simple and complex indicators are necessary to understand the whole picture. The next steps will be to investigate if there exists a smaller selection of indicators that provides a sufficient description of the system and any changes in it.

There are no ecological models for Greenland coastal waters in place, whereas there are some global or Atlantic Ocean models with coarser horizontal resolution applied to open waters provided by the Copernicus Marine Ecosystem Monitoring Service (CMEMS). An aim of the **Case Off Greenland** (Disko Bay) was to demonstrate downscaling from large-scale regional models to fine-scale local models of Arctic coastal waters. The applied model of Disko Bay is the first local-scale, ecological model for Greenland marine coastal waters using available iAOS forcing data. It was developed in the FlexSem model system, a versatile tool suitable to resolve coastal waters on an unstructured mesh (Larsen et al., 2020), The model resolves the Disko Bay with a high horizontal resolution (down to 1.8 km) in comparison to the regional models providing the open boundary data. The sea surface temperatures were improved in FlexSem by implementing a full surface radiation model forced with model data of wind speed, cloud cover, specific humidity and ice cover. Freshwater inputs were improved by including state-of-the-art data of meltwater run-off from the PROgramme for Monitoring the Greenland Ice Sheet (PROMICE). The model showed in general good agreement with vertical profiles of temperatures and salinity, except that bottom values were underestimated compared to CTD data. The biogeochemical model Ecological ReGional Ocean Model (ERGOM) was applied to the Disko Bay set-up with a few changes (picoalgae, *Calanus finmarchicus*, background light attenuation) applicable to Arctic waters. The first results showed overall good agreement with climatology data. In the next version, the model needs improvement on the microzooplankton parametrization, light attenuation from ice meltwater and *C. finmarchicus* behavior.

We consider what kind of data be essential for holistic and integrated modelling of Arctic marine ecosystems, and iAOS will be an important source for such data. Further, the steps to take for applying model analyses for new regions are suggested. These suggestions are to be included in the INTAROS roadmap.

This report is based on the preliminary results of task 6.2 “Improved ecosystem understanding and management”, in dialogue with Task 6.8. and the results and experiences will be used as platform for further work on the next Deliverable D 6.13, where dialogues with tasks 6.3 and 6.6 will also be established.

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1. Introduction

1.1 Background and aim

The ambition of WP6 is to demonstrate application of an integrated Arctic Observing System (iAOS) by delivering a suite of products targeted at issues of societal importance for Europe and on global scale. These pilot applications will demonstrate services towards selected, but diverse groups of end-users. Further, WP6 aims to demonstrate how the iAOS may be applied to further develop the accuracy of climate models, improve the understanding of biogeochemical cycles and ecosystem functioning, enhance fisheries and environmental management, increase the level of preparedness towards natural hazards, and develop better management and decision making concepts for selected local communities. Through WP6 INTAROS will demonstrate enhanced data search and retrieval, assimilation into models, validation of estimated and projected climate parameters, scientific analysis, decision-support and policy making on local, regional and pan-Arctic scale. This report is presenting D 6.3, based on the case study areas the Barents Sea and Disko Bay, as a part of the deliverances from tasks 6.2 and 6.8 (tasks 6.2; 6.8).

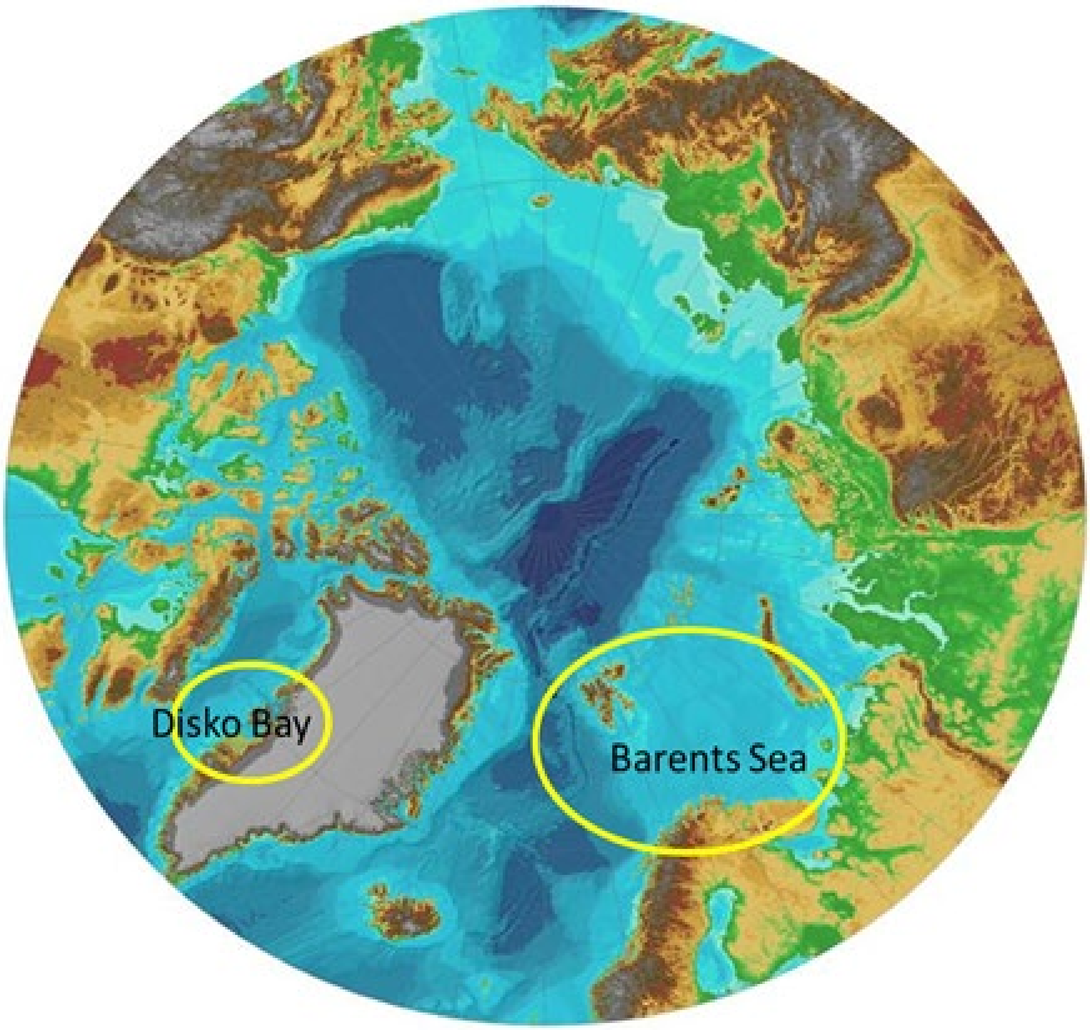


Figure 1. Overview over the two study case areas; the Barents Sea. And Disko Bay, Greenland

Task 6.2 use selected cases to analyse how data, including data to be incorporated in the INTAROS iAOS, may contribute to advances in ecological and environmental understanding and allow for expanding existing environmental and fisheries reporting and management systems into new geographic areas. This task is tightly linked with targeting fisheries and management of marine arctic resources, through especially task 6.8 (Fisheries and environment management).

Task 6.8 demonstrates the use of INTAROS iAOS based products for managers, particularly those responsible for the management of the environment and living marine resources. The demonstrations are given in the form of software available through the INTAROS Portal (WP5), reports and direct interaction at workshops and one-to-one meetings. The expected impact is to provide a scientific basis for better-informed decisions and better-documented processes for managers and policy makers on local, regional and pan-arctic scales.

These Tasks are using the Barents Sea and Disko Bay, Greenland, as cases to demonstrate how data from an iAOS may allow for implementing similar procedures in other parts of the Arctic. IMR is in lead of task 6.2 and the Barents case while AU leads task 6.8.

Greenland iceberg. Photo Eva Friis Møller, AU

Sea ice front, the Barents Sea. Photo Gro I. van der Meeren, IMR

2. Case Barents Sea

2.1 Description of the case study area

Physical factors that make arctic marine ecosystems unique are a high proportion of shallow continental shelves, strong seasonality, low temperature, extensive permanent and seasonal ice-cover, and a large supply of freshwater from rivers and melting ice. Because of these conditions, many of which are challenging for marine biota, arctic marine ecosystems have a large number of specialists, many of which are not found elsewhere. These organisms have, through time, been able to adapt to the environment, but they are still challenged by extreme inter-annual variations. The Barents Sea is one of the shallow shelf seas that collectively form the Arctic continental shelf (Figure 2.1). Its western boundary is defined by the shelf break towards the Norwegian Sea, the eastern boundary by Novaya Zemlya, the southern boundary by Norway and Russia, and the northern boundary by the continental shelf break towards the deep Arctic Ocean. Stretching from 70N to over 80N, it is subject to large seasonal variations in light levels, experiencing 24 hours of darkness in winter and of sunlight in summer.

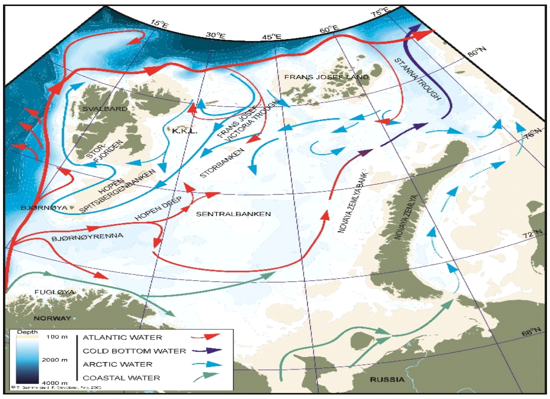


Figure 2.1 Water currents and depths of the Barents Sea (source IMR)

The possible pathways by which climate variability may affect ecological processes are many and vary across a broad range of temporal and spatial scales. Climate variability affects fish both directly through physiology, including metabolic and reproductive processes, as well as through affecting their biological environment (predators, prey, species interactions) and abiotic environment (habitat type and structure). Furthermore, ecological responses to climatic variation may be immediate or lagged, linear or nonlinear, and may result from interactions between climate and other sources of variability. The relationship between the physical and biological conditions in the Barents Sea has been discussed in hundreds of papers since Helland-Hansen and Nansen (1909). The most updated thorough description of the Barents Sea ecosystem is given in books edited by Sakshaug et al. (2009) and Jakobsen and Ozhigin (2011). Both books give a comprehensive description of the Barents Sea ecosystem including the physical oceanography, a description of most levels of the food web, and the interactions between the physical and biological components of the entire system. There is ample evidence of the effects of climate variability on the marine ecosystems, e.g. the response of the abundance and distribution of fish species associated with short- and long-term temperature changes. These occur as direct physiological responses as well as indirectly through effects on the prey, predators or competitors. However, many aspects of the interaction between the atmosphere and the ocean, and between climate and the marine ecosystem require a better understanding before the high levels of uncertainty associated with present predicted responses to climate change can be significantly reduced (Hollowed and Sundby, 2014; Hollowed et al., 2018). This understanding can only be achieved through monitoring and research. The latter should include comparisons between and among other subarctic and arctic regions. Predicting the responses of the ecosystem to future climate change in the Arctic is of great interest to scientists, governments and fishing communities. The possible pathways by which climate variability and change may affect ecological processes are many and can vary across a broad range of temporal and spatial scales (Ottersen et al., 2010). Ecological responses to climatic variation can be immediate or time-lagged, linear or nonlinear, and may result from the amplification of climate effects due to fishing (Planque et al., 2010; Simpson et al., 2011; Haug et al., 2017). The Barents Sea fisheries are managed as a joint agreement between Russia and Norway, as the ecosystem monitoring is a joint ecosystem survey every year and international collaboration on the assessment of the commercial fish stocks through working groups within the International Council for Exploration of the Sea (ICES).

2.2 Climate of the Barents Sea

Like the atmosphere, the ocean undergoes variability at a multitude of temporal scales from daily to centennial and longer. Since we are primarily interested in the responses of the ecosystem to ocean variability and these are mostly at interannual time scales and longer, it is these that we will focus upon. Figure 2.2.1 (A) show the temperature variations in the Barents Sea since 1900. Three types of natural variability may be seen, as pointed out by different authors (Drinkwater et al., 2011); 1) annual variations, 2) decadal variations and 3) multidecadal variations (60-80 years). In addition to the natural variability we have climate change. The influx of Atlantic water to the Barents Sea from southwest is mixed with Arctic water from the north and northeast. These water masses and their distribution and overlaps, and define three different zones, the boreo-Atlantic Zone in in Southwest and west, the Arctic zone in north and northeast and the mixed zone in the Central Barents Sea (Figure 2.2.1 B). As illustrated by 2.2.1 B, the areas with different water masses may vary from year to year, which may have great impact on the ecosystem. Most likely, the extent of Atlantic water vary with the temperature of the Atlantic water presented in Figure 2.2.1 C. According to the most recent data, there has been a decrease in the temperature of Atlantic water the last five years. The North Atlantic is a region with big multidecadal variations (Kushnir, 1994; Knight et al., 2005; Keenlyside et al., 2008), and observations shows periods of 60-80 years (Keenlyside et al., 2008). Skagseth et al. (2008) showed that long-term variations in the Barents Sea followed the index for the Atlantic Multidecadal Oscillation (AMO). Even though there is large uncertainty about the mechanisms behind the multidecadal oscillations, it is accepted that the meridional overturning circulation (MOC) is important (Keenlyside et al., 2008). A few models indicate a reduced MOC during the next decades, and the following cooling may postpone the anthropogenic heating that is expected in the ocean during the coming 10-15 years (Wood, 2008; Kerr, 2008).

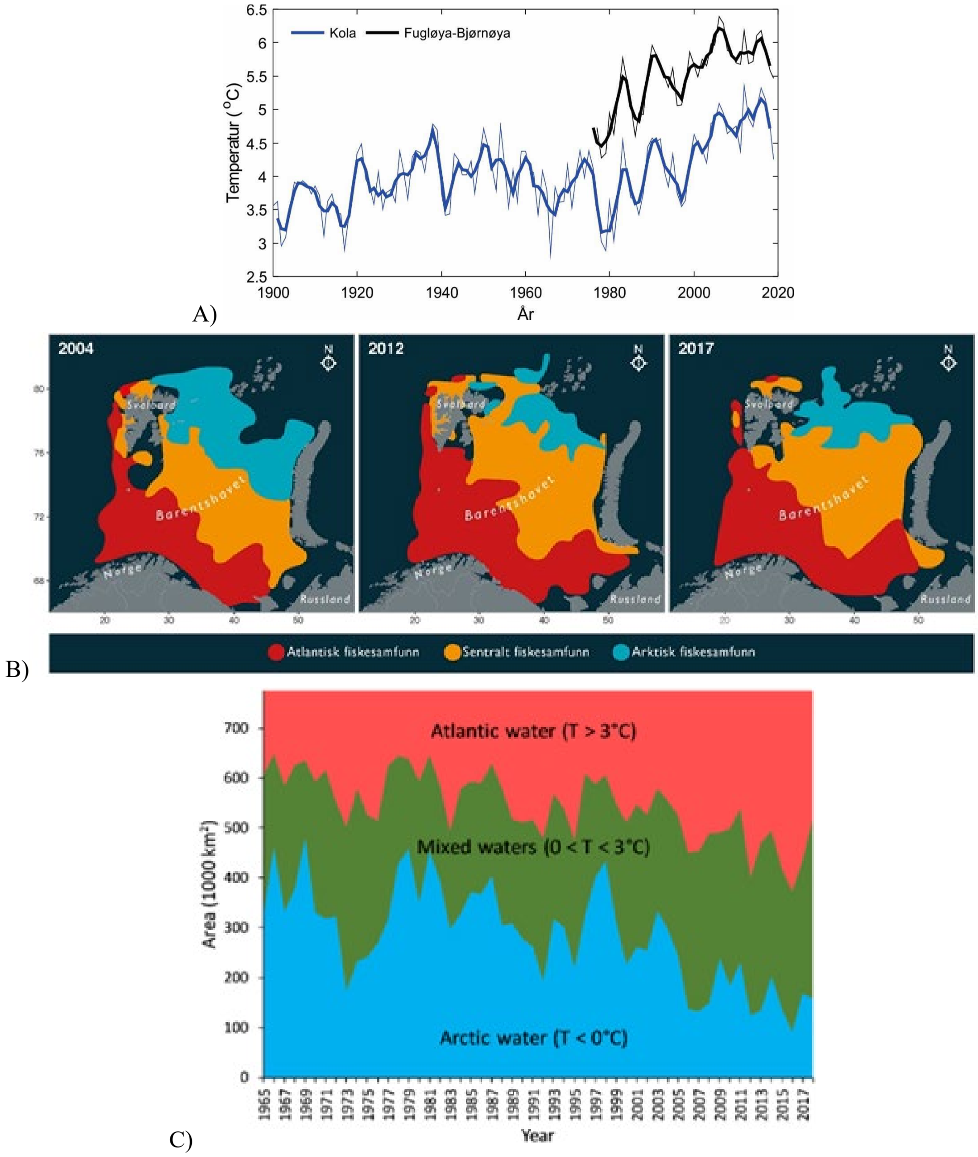


Figure 2.2.1: *Barents Sea te Kola and Fugløya-Bjørnøya transects –(A), fish community distribution (Arctic, Central, Atlantic) –(B), and area of water masses in the Barents Sea (71-79°N, 25-55°E) in August-September 1965-2018 (based on 50-100m averaged temperature) – (C)*

2.3 The Norwegian management plan for the Barents Sea Ecosystem

Ecosystem managements are developed to consider the multiple anthropogenic and climate-driven changes in relationship to how they can affect marine ecosystems (Butchart et al., 2010; Frank et al., 2005). To assess the status of marine ecosystems worldwide, a range of indicators have been suggested, defined, calculated and evaluated, to track ecosystem status and inform managements (Shin and Shannon, 2009; Coll et al., 2016). The indicators for the Barents Sea Holistic Management plan were selected through scientific workshops assessing the quality of data for each suggested indicator, the length of time series, the access to systematic updates. These indicators should show the development of entire the ecosystem

role, including physical and chemical oceanography, phytoplankton and zooplankton, benthic, fish, sea birds and sea mammal populations and communities. The same process was later done in a joint Russian-Norwegian report describing the species and functional groups of the Barents Sea and suggesting indicators to be used in a future Russian ecosystem-based management plan for the Russian sector of the Barents Sea (McBride et al., 2016). In 2006, an integrated management plan for the Barents Sea-Lofoten area were endorsed by the Norwegian Parliament, and later updated in 2011 (St. meld. 2006 (2005-2006); St. meld. 2015 (2014-2015). The Barents Sea Management Plan (BSMP) includes by 2020 a large selection of indicators, a majority being simple ecosystem indicators describing temperature, primary production, biomasses and distributions of a selection of species in the Barents Sea (Olsen et al., 2011; Anon., 2015).
However, the expression "indicators" as used in the management plan is not well defined in the BSMP. In the present work an indicator will be understood as: a quantity based on calculating trends and changes in ecological key species or processes by a selection of one or more single parameters with known or perceived relationship, where a parameter is an observation or model value of one particular physical or biological component.
For this report a narrower definition is defined (Table 2.3); *Based on calculating trends and changes in ecological key species or processes, by a selection of one or more single parameters with known or perceived relationships*. For data on temperature, salinity, stock size, etc, the expressions parameters indices will be used.
Although reference points and thresholds are implemented in most of the biological indicators, suggestions for actual measures to be taken if the indicator crosses the thresholds, are not part of these plans. That responsibility is placed within each of the management bodies, to continue to govern and regulate human activities separately in the separate fields of for instance shipping, fisheries, energy etc.

In this present work, the main focus has been to evaluate the appropriateness and significance of the indicators in the BSMP. Using two different end-to-end ecosystem models, NORWECOM.E2E and NoBa Atlantis, time series of a set of the proposed indicators have been estimated using the suggested methodology in BSMP under a future climate projection. Indicators based purely on observations are often limited by the existing monitoring programs, and sampling schemes will largely affect the quality of the indicators. Through an Observing System Simulation Experiment (OSSE) this has been investigated, and the design of a minimum cost monitoring program has been suggested. The BSMP suggest 70 different indicators, with different degree of covariance. To reduce the number of indicators, the models have been used to search for an optimal indicator subset, and finally the present use of reference points have been discussed.

2.4 Material and methods

2.4.1 Data and the subareas applied in the Barents Sea management report-

The data sets used for indicators in the existing management plans consists mainly of a simple time series (Table 2.4.1)(Arneberg et al., 2020). However, to develop indicators to measure changes that is expected to be sensitive to human impact and climate change and variation, more complex time series are being developed (Tables 2.4.1; 2.4.2A,B)(Jepsen et al., 2019; Siwertson and Arneberg, 2019). These data sets cover a large part of the ecosystem from ocean physics to fish and marine mammals. Some of the suggested indicators are spatial, with a focus on ecosystem-type. The Barents Sea is a shelf sea bounded by a shelf break towards the Norwegian Sea and one towards the arctic. The shelf is further dominated

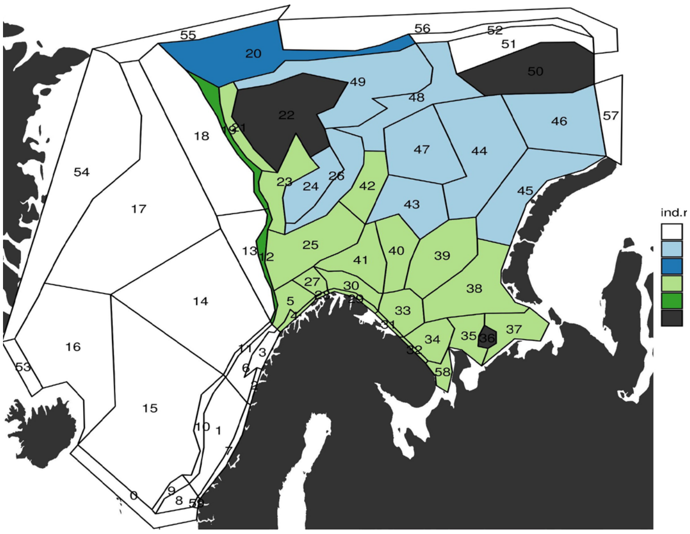


Figure 2.4.1: *The polygons in NoBa Atlantis, in addition to their role in the indicators. The six different categories are outside of Barents Sea (white), land (dark gray), Arctic shelf (light blue), Arctic shelf edge (darker blue), Atlantic shelf (light green) and Atlantic shelf edge (darker green). These domains were used for calculation of all the spatial indicators.*

by Atlantic water in the south and Arctic in the north. Due to this it is decided to divide the Barents Sea into four different areas based on ecosystem-type: Atlantic, Arctic, Atlantic edge and Arctic edge. Further, as these areas are large and some processes might only occur in parts of, or to different times within, each area, a further division into sub-areas have been suggested (see Figure 2.4.1). The total area is very different between these four. While the Atlantic shelf (light green; figure 2.4.1) covers an area of roughly 800 000 km^2 , the Arctic shelf (light blue) an area of about 710 000 km^2, the Arctic shelf edge (darker blue) only covers 76 000 km^2, while the Atlantic shelf edge is even smaller; 32 000 km^2. Some of the indicators can be estimated for each sub-area, but the ecological conditions are suggested to be reported for the whole ecosystem-type area. The NoBa Atlantis polygons (2.4.1) are suggested for sub-areas. More details on the indicators, areas and sub-areas can be found in Jepsen et al. (2019). As the list of indicators is comprehensive, this study focuses on the selection listed in Table 2.4.1. The BSMP is intended for a general overview of the ecosystem state and trends, initially without actual indicators for human impacts. However, as cumulative effects are important, two fisheries-related indicators were included in the set of complex indicators; catch at trophic level and catch in functional groups. A short explanation of these can be found at the end of Table 2.4.1 and in Table 2.4.2A. Also, the relationship between the three functional groups (e.g. pelagic:benthic) and the three trophic levels are included in the calculations. For the calculation of total biomass in functional groups and at trophic level, we have followed the categories defined by the assessment tool development project (Jepsen et al., 2019) and converted the components included in NoBa and Norwecom.e2e correspondingly to these. The trophic levels of the different components are listed in table 2.4.2B (MacKenzie et al., in prep). Trophic level 1 includes primary producers. Trophic level 5 is only represented by polar bears and are excluded from all calculations. For the rest of the components, it was decided to use the values calculated for the complex set of indicators (Siwertson and Arneberg, 2019).

***Table** 2.4.1: Selected indicators included in the BSMP, which are evaluated by using Norwecom.e2e and NoBa Atlantis. In addition, two indicators on the relationship between the functional groups and two fisheries indicators (catch at trophic level and in functional groups) are added to the list. The biological parameters already operationalized in ecosystem state indicators are tagged in the right-hand column (Arneberg et al., 2020). The remaining parameters in the present Norwegian management plan are added to the end of the table, to provide a full list of present indicators for up to 2020.*

Components	Explanation	Data Source	Comments	Operational indicator by 2020
Temperature	Annual (mean) temperature (50-200m)	NMD	Per area, NORWECOM	X
Freshwater height	Reference salinity 35psu	NMD	Per area, NORWECOM	
Ice cover	Annual mean ice concentration	NSIDC, doi: 10.5067/8GQ8LZQV L0VL	Per area, NORWECOM	X
Net primary production	gC m-2 year-1	NASA/MODIS, doi: 10.5067/AQUA/MODIS/L3M/CHL/2018 Oregon State ,	Per area, NORWECOM	X
Diatom:Flagellate ratio	diatoms to flagellates NPP ratio		Per area, NORWECOM	
pH		NMDJ/.Norw./Russ Ecosyystem Survey	Per area, NORWECOM	X
Herring abundance	Abundance of juvenile herring in the Barents Sea	NMDJ/.Norw./Russ Ecosyystem Survey	Age class 1-4, NoBa	X
Biomass at trophic level	Total biomass at trophic level 2, 3, and 4	NMDJ/.Norw./Russ Ecosyystem Survey	See Tab 2.4.2B for details, NoBa	
Biomass in functional groups	Fraction of biomass at the three levels	NMDJ/.Norw./Russ Ecosyystem Survey	See Tab 2.4.2B for details, NoBa	
Population size NEA cod	Total biomass of NEA cod in the Barents Sea	NMDJ/.Norw./Russ Ecosyystem Survey	Includes whole stock, NoBa	X
Catch at trophic level	Total catch at TL 2,3 and 4	NMDJ/.Norw./Russ Ecosyystem Survey	See Tab 2.4.2B for details, NoBa	
Catch in functional groups	Total catch in the three groups	NMDJ/.Norw./Russ Ecosyystem Survey	See Tab 2.4.2A for details, NoBa	
Relationship between functional groups	Development between total biomass in the groups	NMDJ/.Norw./Russ Ecosyystem Survey	See Tab 2.4.2A for details, NoBa	
Relationship between trophic levels	Development between total biomass at trophic levels	NMDJ/.Norw./Russ Ecosyystem Survey	See Tab 2.4.2B for details, NoBa	
	Additional parameters used as indicators in the Barents Sea holistic management plan			
Physical indicators	Atlantic water masses; Nutrients;			X

Plankton	Species composition zoo plankton; Spring bloom timing; Biomass zooplankton	X
Fish stocks/broodstocks	Capelin; Blue whiting; Greenland halibut; Common and beaked redfish	X
Benthos	Red king crabs, benthic societies distribution	X
Sea birds	Breeding success, several species	X
Alien species	Red king crab	
Vulnerable species and nature types	According to the Norwegian red-listed species and nature types	X

***Table** 2.4.2*

A) Components included in each of the functional groups used in the BSMP. If species listed in the BSMP were represented by functional components in the model, the whole biomass in the functional component was added.

Functional group	*Components included*
Pelagic	*Mammals, seabirds, large pelagic fish, meso-pelagic fish, mackerel, Blue whiting, NSS herring, capelin, squid and zooplankton (all)*
Benthic	*Demersal fish, flatfish, long rough dab, skates and rays, haddock and crabs*
Bentho-pelagic	*Sharks, small pelagic fish, redfish (both golden and beaked), Greenland halibut, saithe, NEA cod, polar cod and prawns*

*B) Components included at each of the trophic levels. If species listed in the BSMP were represented by functional components in the model, the whole biomass in the functional component is added. *For snow crab and flatfish, no value was available. These are therefore assumed to be similar to red king crab and long rough dab, respectively. The TL is lifted from the Ecosystem state assessment in development (MacKenzie et al., in prep).*

Trophic level (TL)	*Components included*
TL = 2	*Benthic detrivores (2.2), zooplankton (all)*
TL = 3	*Humpback whales (3.6), minke whales (3.4), fin whales (3.4), bearded seals (3.4), harp seals (3.8), small pelagic fish (3.9), large demersal fish (3.2), flatfish (3.7*), long rough dab (3.7), meso-pelagic fish (3), mackerel (3.7), beaked redfish (3.7), NSS herring (3.2), NEA cod (3.7), polar cod (3.1), capelin (3.2), prawn (3), squid (3.7), benthic carnivores (3)*
TL = 4	*Killer whales (4.5), sperm whales (4.4), hooded seals (4.2), ringed seals (4), arctic seabirds (4), boreal seabirds (4), sharks (4.3), large pelagic fish (4.4), golden redfish (4), skates and rays (4), Greenland halibut (4.5), haddock (4.1), saithe (4.4), blue whiting (4), red king crab (4), snow crab (4*)*

2.4.2 Physical forcing and set-up

Physical forcing is taken from a downscaling of the Norwegian Earth System Model (NorESM1-ME, Tjiputra et al., 2013) with the Regional Ocean Modeling System (ROMS, Shchepetkin and McWilliams (2005)) under the RCP4.5 emission scenario. The Norwegian

Earth System Model (NorESM1-ME) is a fully coupled climate carbon cycle model developed in Norway in collaboration with researchers from the National Center for Atmospheric Research (NCAR) in the United States. The ROMS model set-up is initialised from the NorESM1-ME model, and outputs from NorESM1-ME are also used at the open boundaries and as atmospheric forcing. The model domain for the ROMS downscaling covers the North Atlantic, the Nordic and Barents Seas, and the Arctic Ocean from 30ºN to the Bering Strait, with a horizontal model resolution of approximately 10 x 10 km. More details on the set-up and performance of the downscaling can be found in Sandø et al. (2018).

2.5 Modelling

2.5.1 NORWECOM.E2E

The NORWegian ECOlogical Model system End-To-End (NORWECOM.E2E), a coupled physical, chemical, biological NPZD model system (Aksnes et al., 1995; Skogen et al., 1995; Skogen and Søiland, 1998), was developed to study primary production, nutrient budgets and dispersion of particles such as fish larvae and pollution. The model has been validated by comparison with field data in the Nordic and Barents seas (Skogen et al., 2007; Hjøllo et al., 2012; Skaret et al., 2014). The model is further extended with a module to project ocean acidification (Skogen et al., 2014), and has modules with Individual Based Models (IBMs) for key species in the Nordic and Barents seas such as *Calanus finmarchicus* (Hjøllo et al., 2012) and pelagic fish (Utne et al., 2012). In the present study the model is run in offline mode using the NPZD and ocean acidification modules (see Figure 2.5.1).

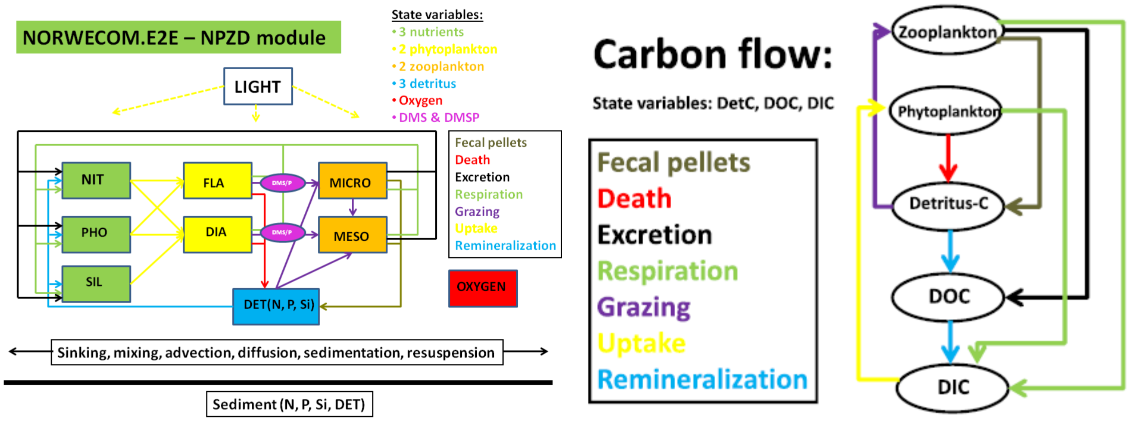


Figure 2.5.1: Schematics of the NORWECOM.E2E NPZD module (left) and the carbon flow (right)

Physical ocean fields (velocities, salinity, temperature, water level and sea ice) from the ROMS downscaling (Section 2.2) has been interpolated from 5-daily means and used as physical forcing together with daily atmospheric (wind and short wave radiation) fields from the NorESM1-ME simulation. The horizontal grid used (Figure 2.5.2) is identical to a subdomain of the original ROMS grid.

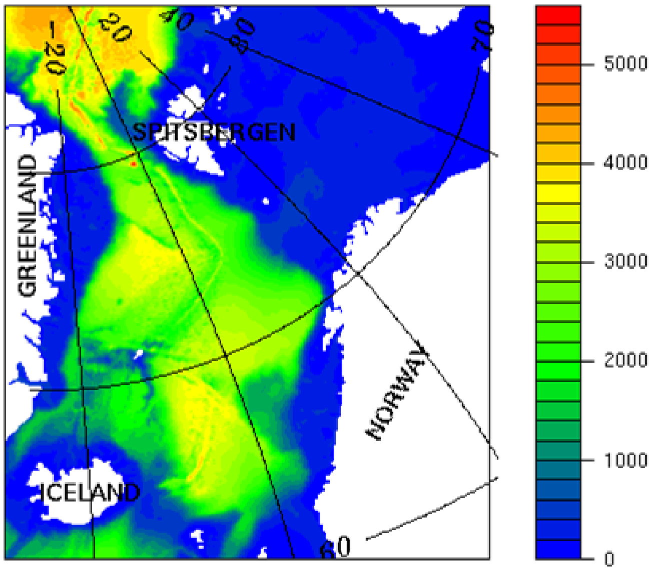


***Figure** 2.5.2: Model domain for NORWECOM.E2E with bathymetry. Colors denote water depth in meters.*

The simulation started on January 1, 2006. After a 12year spin-up (running the first year 12 times) the full model period (2006-2070) was run sequentially. The time step used was 3600 seconds. The biochemical model is coupled to the physical model through the light, the hydrography and the horizontal and vertical movements of the water masses. For more details see description in Skogen et al. (2014, 2018).

2.5.2 The Nordic and Barents seas Atlantis model - NoBa

The Nordic and Barents Seas Atlantis model is an application of the Atlantis framework (e.g. Fulton et al., 2011, Weijerman et al., 2016, Audzijonyte et al., 2017), implemented for the Nordic and Barents seas Hansen et al. (2019a,b). Atlantis is an end-to-end model, including multiple modules depending on the complexity of the model (Figure 2.5.2.1).

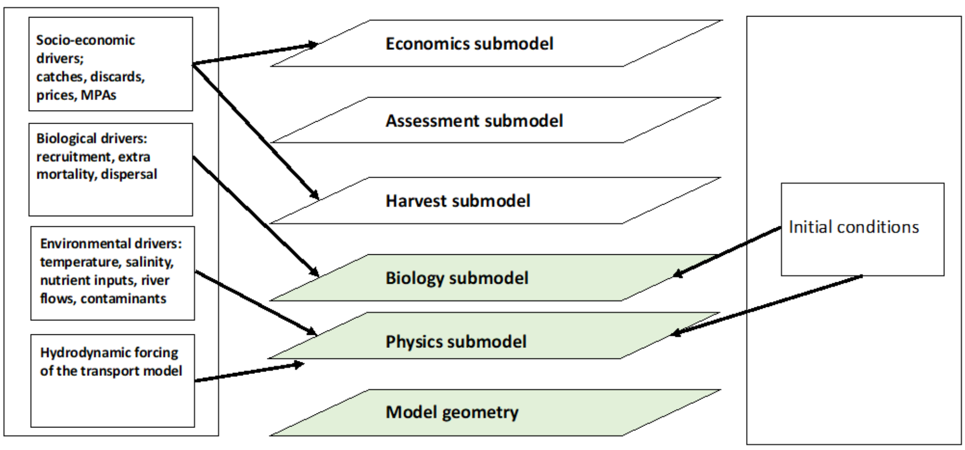


***Figure 2.5.2.1:** Modules in Atlantis. Light green is always turned on (for functionality), whereas those in white can be turned off/on after needs. NoBa has been running with the three green modules, in addition to*

the harvest sub-model. On the righthand side, it is indicated where initial conditions are needed, whereas the boxes on the left-hand side indicate where the different drivers are added.

In this study, the harvest module was included in addition to physics and biology. Atlantis includes bottom-up forcing by using the same physical forcing as Norwecom.E2E for the period from 2006-2068. However, the model started with spin-up in 1981 (looping 1981 24 times), using two other applications of the ROMS model to cover the period until 2006 Hansen et al. (2019b). The model grid covers 4 million km^2 by 60 polygons (Figure 2.4.1), which have up to 7 vertical layers depending on the mean depth of the polygon. The version applied here included 53 functional groups and species, representing key components of the ecosystems in the Nordic and Barents Seas. These represented 'everything' from phytoplankton, bacteria, zooplankton to fish, seabirds and marine mammals (Figure 2.5.2.2).

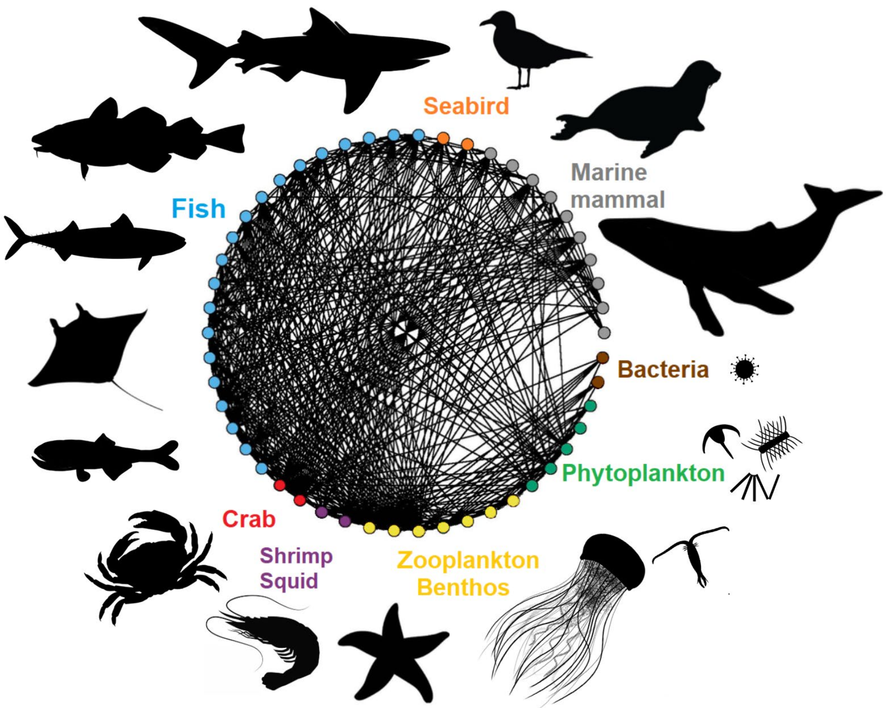


Figure 2.5.2.2: Diet matrix from NoBa Atlantis, displaying the complexity of the foodweb. Illustration by Ina Nilsen.

The components are coupled through a somewhat flexible diet matrix, where the prey availability for the predator is defined (Audzijonyte et al., 2017). Fisheries for the 12 components in the model that are harvested, were implemented as time series of fisheries mortality for the period from 1981-2017. From 2017 and onward, the fisheries followed a flat maximum sustainable yield (MSY) fishery for a majority of the commercially important species, prawns, capelin and snow crabs being the only ones excluded from this strategy. In this study, 112 simulations were run (Hansen et al. 2019b). These were divided into eight different scenarios, defined by four different fractions of maximum sustainable yield (F_{msy})(0.6, 0.8, 1.0 and 1.1) and for each of these the number of components harvested were either a) currently harvested only ('comm only') or b) currently harvested + additional species ('all in'). Within each scenario there were 14 different simulations, each somewhat changing the bottom-up forcing (represented by mesozooplankton growth). Among the additional five species were mesozooplankton and meso-pelagic fish, relevant to include because of a recent increased interest in harvest of these components. The additionally harvested components were fished at F_{msy} adviced by ICES in 2017 and onward, to avoid making changes in the historical data for the period from 1981-2017. The changes in fisheries between the simulations provide us the opportunity to evaluate how the indicators were able to pick up differences in the harvest level or in the number of components that are being harvested.

2.6 Results

2.6.1 Long term trends of simple indicators

Some of the indices of the proposed list can be directly estimated from the models. However, as the models differ in both state variables and processes, the available modelled indices will differ between them, therefore only some examples of modelled indices from each model are given below. In Figure 2.6.1.1., time series of annual (mean) temperature – A), freshwater height – B), ice cover – C), net primary production – D), diatom to flagellate ratio – E) and pH – F) from the NORWECOM.E2E model are shown for all four areas (Arctic, Atlantic, Arctic edge and Atlantic edge) of the Barents Sea. As ocean physics is an input to the NORWECOM.E2E system, temperature, freshwater height and ice are from the ROMS downscaling (Sandø et al., 2018) that was initiated from the global model January 1, 2006. After an adjustment of the initial field the first 10 years, an increase in temperature and freshwater height and a decrease in ice cover are seen. Except for the Atlantic edge area, the modelled projected increase in temperature is around 1 °C from 2006-2070. Using the Fitting Generalised Linear Models routine in R (glm), the trend in temperature is between 0.010 and 0:014 °C pr year in these areas. Comparing the detrended annual mean temperatures, there is a significant relationship ($p<0.01$) between the Arctic and the Atlantic area ($r=0.76$), Atlantic and Arctic edge ($r=0.35$), Atlantic and Atlantic edge ($r=0.47$) and Atlantic edge and Arctic edge ($r=0.87$). Also, all sub-areas are significant correlated to the mean over the whole Barents Sea ($r=0.97$ Atlantic, $r=0.88$ Arctic, $r=0.44$ Atlantic edge, $r=0.35$ Arctic edge). A similar analysis of inter annual temperature variability, is to be done using observational data from WP5. The increase in freshwater height is up to 1 meter, with highest value in Atlantic and lowest in Atlantic edge. The ice cover in the Arctic part shows a steady decline from 40% to around 5% during the first 30 years before it stabilise at that level with some interannual variability. For the Arctic edge, the ice cover does not show any clear trend. The net primary production (NPP) show an increase in all areas from an initial level between 20-40 gC m^2 year1. The strongest increase is found in the two edge areas (0.12 and 0.09 gC m^2 year1 for Arctic and Atlantic edge respectively), while the increase is only half that in the Atlantic and Arctic areas. Comparing the detrended annual NPP, there is a significant relationship ($p<0.01$) between the Arctic and the Atlantic area ($r=0.50$) and Arctic and Arctic edge ($r=0.34$). Both the Arctic and Atlantic sub-area are significant correlated to the mean of the whole Barents Sea ($r=0.86$ and $r=0.84$ respectively). The ratio between flagellate and diatom production show no clear trend, while there is a decline in the pH just above -0.002 year 1 for all areas after an initial adjustment to a level just above 8.10.

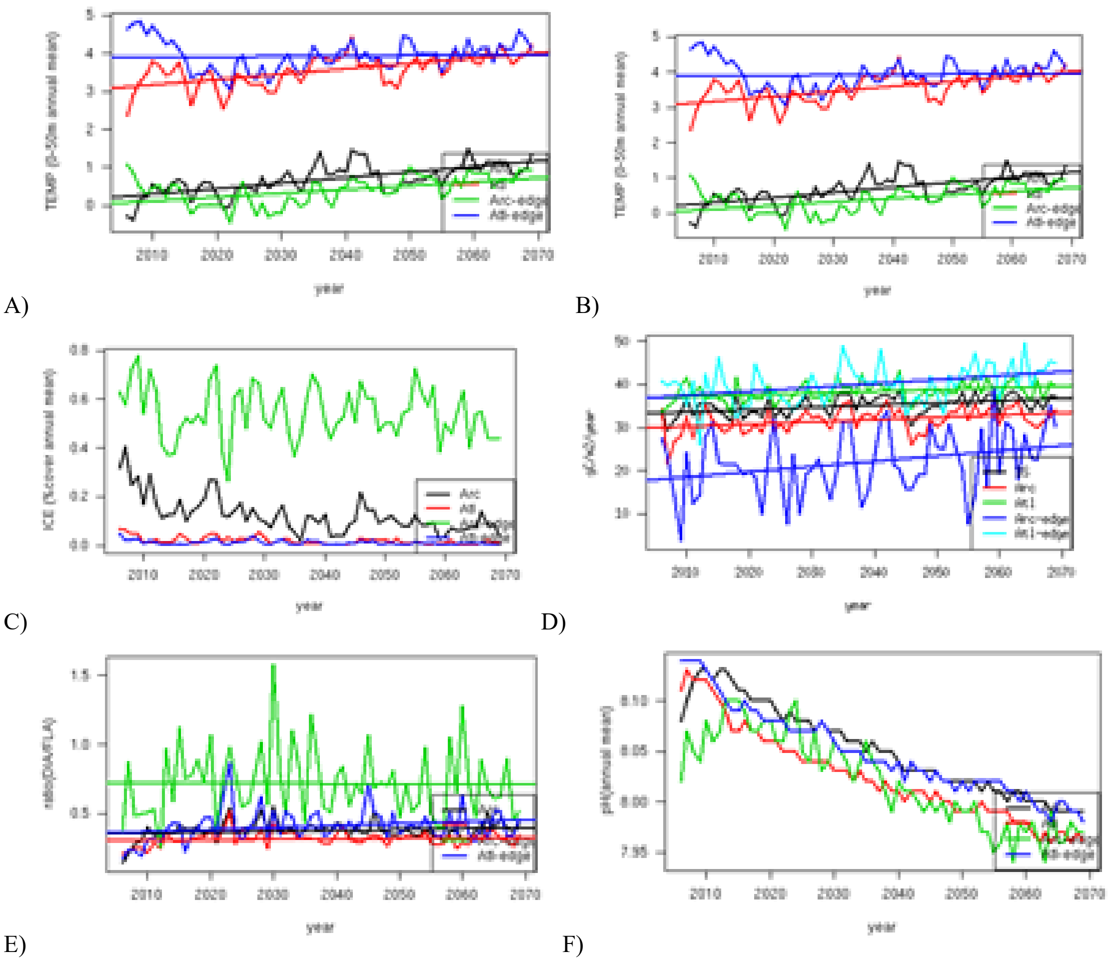


***Figure** 2.6.1.1: Time series for A) temperature (50-200 meters), B) freshwater height, C) ice cover, D) net primary production, E) ratio diatoms:flagellates and F) pH for Arctic, Atlantic, Arctic edge and Atlantic edge part of the Barents Sea, from the NORWECOM.E2E model. All values are annual means, except net primary production which is annual depth integrated value (gC m^{2} year^{-1})*

Abundance of juvenile herring and Greenland halibut and biomass of NEA cod were among the simple indicators defined by BSMP, for higher trophic levels. The development of these three can be seen in figure 2.6.1.2.

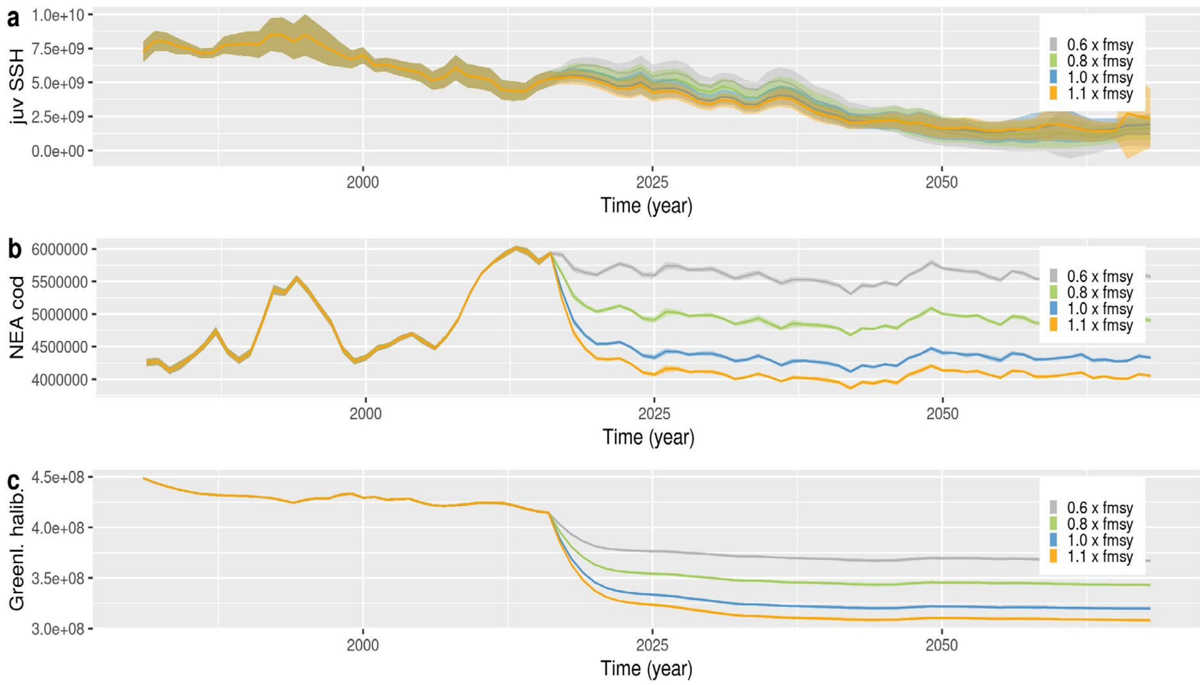
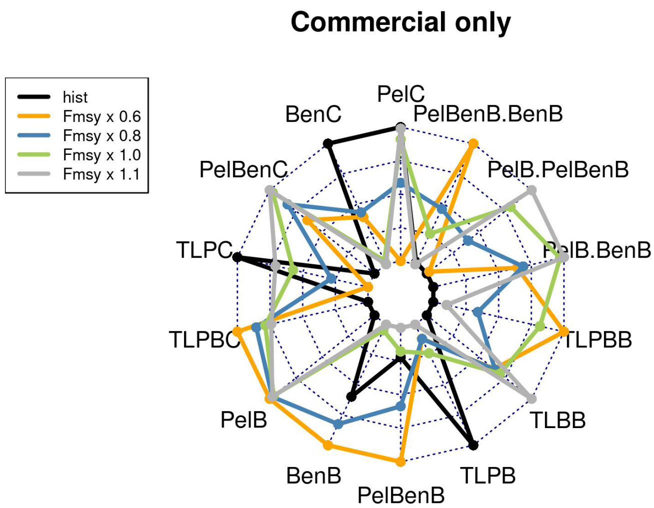


Figure 2.6.1.2: Simple indices for juvenile herring (a), northeast Atlantic cod (b) and Greenland halibut (c) for the period from 1981-2068. Shades represents one standard deviation across the 14 replicates of each scenario, whereas the solid line is the average across the simulations.

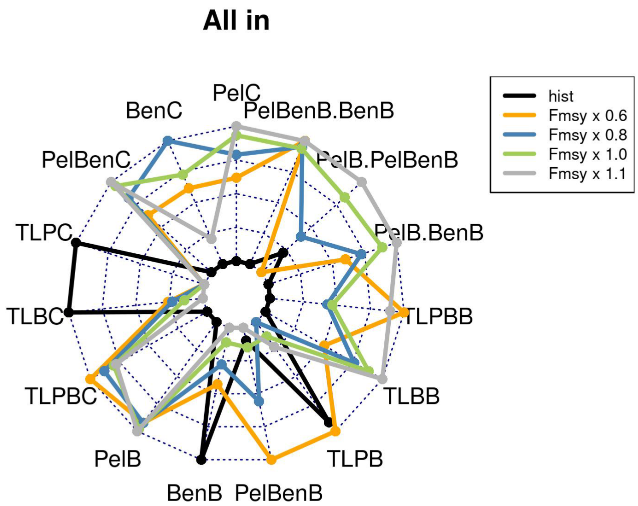
2.6.2 Complex indicators

2.6.2.1 Biomass at different trophic levels

For the whole Barents Sea, there were little to no changes in the pelagic and benthic groups. However, due to the enormous biomass in the pelagic group from the zooplankton, the other two groups (benthic and bentho-pelagic) made up only a very small part of the total biomass (less than 5%). The bentho-pelagic group experienced a large increase toward the end of the simulation, for all scenarios. This was a result of the deep-water shrimps (prawn) and saithe biomass, potentially caused by a combination of climate (slight warming) and management settings. The functional groups (pelagic, bentho-pelagic and benthic) behaved differently across the four areas. The pelagic and benthic groups had a strong correlation between the Atlantic and the Arctic shelf areas. This was not reflected in the results of the bentho-pelagic group. However, when split into seasonal signals, there were stronger correlations between the areas also for this functional group. It also meant that the time series was shorter, resulting in a more vulnerable correlation. This indicator did not pick up the differences in the harvest level between the four different harvest levels, neither between the two main scenarios (Figure 2.6.2.2). This was probably reflecting the simplified fisheries in the model, harvesting on stock level and not on area level. Comparing the different areas to the total biomass of each of the functional groups, it became clear that the differences between the common only and the all-in scenario were few (Figure 2.6.2.2). However, there was a development in the relationship between the total biomass of benthic species and the biomass within the arctic shelf edge in the all-in scenario. For this scenario, the correlation decreased with increasing fishing pressure, unlike the common only scenario, where this signal could not be found.



A)



B)

***Figure** 2.6.2.2: Indicators calculated for the historical time slice (2005-2015, in black), and for the future time slice (2055-2065) for the four scenarios. In **A)** the results from the scenarios only including the currently harvested species are displayed, while **B)** a show the scenarios including harvest on e.g. meso-zooplankton and meso-pelagic fish. The historical time slice is equal across all simulations. Indicators are all shown with maximum (best) value at the outer edge of the spider plot. The indicators shown include catches (C) and biomass (B) for the functional groups (Pel - pelagic, Ben - Benthic and PelBen - bentho-pelagic) and for the trophic levels (TL). For further information on the components included in each functional group and trophic level see Tables 2.4.2 A, B*

2.6.3 Optimal sampling strategy

When estimating the value of an index, one is often limited to available observations from existing monitoring programs. Regarding the validity of an index this is not necessarily the best approach, it can also be asked how many observations is needed to achieve an acceptable precision. The quality of observations is largely affected by the sampling scheme. Numerical models can contribute to the efficient design and optimization of observing systems for science and operational uses and Observing System Simulation Experiments (OSSE) (e.g. Arnold and Dey (1986)). Using monthly mean outputs from the NORWECOM.E2E model the following question has been asked: *which polygon in* *which month is the best one to approximate the inter-annual variability in the full regional indices*. The answer to this question has been approximated by comparing detrended annual time series (see Figure 2.6.3.1), to similar time series from each polygon and each month within a region. The results for temperature and NPP are given in Tables 2.6.3.1 and 2.6.3.2. The results clearly show that it is possible (especially for temperature) to get a high correlation with the inter annual variability using a minimum effort, but also how a bad designed monitoring program with the same effort can give low or even no representation of the real variability. While temperature is well represented with only such a minimum observational network, this is not the case for NPP. This index is therefore further investigated increasing the effort to monitor two and three polygons in the same or in different months (see figure 2.4.1). These results are shown for the Atlantic area (Fig. 2.4.1) and in Table 2.6.7. There is an increase in performance from the one month, one polygon case (0.54 see Table 5) to 0.65 in the two polygon case (polygon 5 in July and 33 in April) and 0.71 in the three polygon case (polygon 29, 30 and 33 in months August, July and June respectively). The results also show that the performance increases when distributing the effort between polygons and months instead of using all resources in one polygon or one month.

Table 2.6.3.1. Best and less (not least) good results from a one polygon, one month, monitoring program for temperature (50-200 meters) in the four Barents Sea regions from the NORWECOM.E2E model

Barents Sea regions	**Best results**			**Less (not least) good results**		
	Polygon	**Month**	**Corr**	**Polygon**	**Month**	**Corr**
Atlantic	33	August	0.92	25	July	0.73
Arctic	43	June	0.90	49	July	0.30
Atlantic edge	19	April	0.94	19	January	0.81
Arctic edge	20	June	0.96	20	January	0.81

Table 2.6.3.2. Best and less (not least) good results for a one polygon, one month, monitoring program for NPP in the four Barents Sea regions from the NORWECOM.E2E model

Barents Sea regions	**Best results**			**Less (not least) good results**		
	Polygon	**Month**	**Corr**	**Polygon**	**Month**	**Corr**
Atlantic	33	April	0.54	30	April	0.27
Arctic	47	July	0.69	47	May	0.01
Atlantic edge	19	July	0.56	12	May	0.02
Arctic edge	20	May	0.66	20	June	0.30

Table 2.6.3.3. Best results from two and three polygon monitoring programs for NPP in the Atlantic region of the Barents Sea from the NORWECOM.E2E model

Barents Sea region	**Polygon 1**	**Polygon 2**	**Polygon 3**	**Month1**	**Month 2**	**Month 3**	**Corr**
Atlantic	33			April	August		0.55
	23	32		April			0.59
	5	33		July	April		0.65
	33			April	June	July	0.61
	23	32	33	April			0.61
	29	30	33	August	July	June	0.71

2.7 Defining thresholds/reference points/directions based on the model output

In the Norwegian management plan, no thresholds or reference points are defined for physical measurements, but there are aims. However, aims, thresholds and reference points are defined for most biological indicators, based on international levels for sea bird breeding success (OSPAR), breeding stock precautionary size (ICES), red-listing (Norwegian red list) and pollution in biota, water and sediments (OSPAR and more).
In the set of complex indicators, there are no defined thresholds or reference points, but these are based on assessing if defined incidents can be observed, and assess how strong the evidence is for the trend to be reliable, based on the assessments in ICCP and IPBC. The decision in the management plan has been to use a reference level of unfished biomass for all the simple indicators. This level is more or less impossible to calculate, both based on observations, but also in the models. The level of uncertainty that would be connected to calculating this by using the currently available models would be too high to be appropriate for use in management decisions.

2.8 Discussion Barents Sea case

Using a future climate projection, several indicator time series have been computed from two ecosystem models, based on several indicators implied from and suggested for the BSMP. Focusing on the abiotic indicators, the model is initially too cold when comparing with data from WOA (2005–2012 values) and averaging over the Arctic and Atlantic part. However, the model adjusts to correct values for that period after about 5 years. The study areas cover a large area on both sides of the Arctic Front. To estimate the annual primary production under such conditions is almost impossible mainly for logistical reasons that result in a scarcity of measurements, and for the Barents Sea, estimates of primary production varies a lot between the different water masses. Titov and Orlova (2011) give a mean value for GPP in the Barents Sea of 111 gCm^2y-1, while Slagstad et al. (2011) (using the SINMOD model) give a value of 53 gCm^2y-1 for NPP. There is no general agreement on how NPP will be effected in the future Barents Sea (Steinacher et al., 2010; Skaret et al., 2014; Slagstad et al., 2015; Barange et al., 2014). Lauvset et al. (2016) mapped pH from the GLODAPv2 (Olsen et al., 2016) data set on a global 1x1 grid using the DIVA software (Troupin et al., 2012), and report on an average upper 10 meters pH in the Barents Sea of 8.11 which is in good agreement with the model after the initial adjustment. The declining trend in the simulation (-0.002 year-1) is close to both observed and predicted changes in surface pH (Lauvset et al., 2015; IPCC, 2014). Present day temperature and pH state for the 4 sub-areas will be further discussed using observations from the INTAROS iAOS.

The sampling strategy suggested through the OSSE analysis showed that it is possible to get a high degree of covariance between local monthly values to regional annual means with only a small observational effort (see more in Ch 4.2). However, the same analysis also shows that there are many pitfalls from using arbitrary observations to approximate the same without any further analysis. Except for a demonstration for the Arctic domain

(Jepsen et al., 2019), the splitting and reporting of the Barents Sea into four different areas has not been implemented yet. In this report temperature indicators are based on CTD profiles from the joint Norwegian-Russian ecosystem survey that offers a complete coverage of the Barents Sea in August/September every year, while estimates of net primary production were based on estimates downloaded from www.science.oregonstate.edu using the Vertically Generalized Production Model (VGPM, Behrenfeld and Falkowski, 1997). Some of the Barents Sea indicators are also made operational for the whole Barents Sea as part of state reports for the Barents Sea (https://miljostatus.miljodirektoratet.no/tema/hav-og-kyst/havindikatorer/barentshavet/). The temperature for the Barents Sea is here reported as two different time series from observations along the two transects: Fugløya-Bjørnøya at the Barents Sea entrance, and Vardø-N in the southeast. The 2 transects should normally be covered 6 and 4 times every year, but after 2007 the frequency has been lower. Both transects are strongly influenced by the inflowing Atlantic water and therefore shows a strong covariance. As an approximation for the whole Barents Sea, the Atlantic part is strongly connected (r=0.97) and explains a large part of the variability in the Arctic part (r=0.75) as well. The Fugløya-Bjørnøya is inside polygon area 25, while Vardø-N goes through polygon areas 30, 41 and 43. The latter one is inside the Arctic box. A full annual mean of the temperature in polygon area 25 is a good approximation to the temperature on the Atlantic box (r=0.79), but not as good as the means of polygon boxes 30 and 41 (r=0.87 and r=0.89 respectively). However, neither of these full annual means performs as well as only using the August temperature from polygon box 33 (r=0.92, see Table 2.6.3.1), a box that includes the Kola section.

The present analysis suggest the use of temperature from the ecosystem survey to be the best for producing an indicator in the Atlantic, Arctic edge and Atlantic edge area, and slightly sub-optimal for the Arctic area where preferred period is May/June, thus the methods suggested in the demonstration report for the Arctic area, serves as a good candidate when used for a Barents Sea assessment. The use of satellite-based estimates for NPP, offers a good coverage in both time and space, but are limited by clouds and information on the sub-surface. The indicator is assessed with medium good validity, but a further calibration within situ observations from the region is suggested (Jepsen et al., 2019). If such a calibration is done, in situ measurements at times and in sub-areas as proposed in Tables 2.6.3.2 and 2.6.3.3 should be prioritised.

The low response to different harvest strategies found in the complex biomass-dependent indicators shows the importance of a suite of indicators, as suggested in the management plans. The commercial species are represented by abundance or biomass indexes, which easily picks up the differences in the harvest levels. However, any increased ecosystem vulnerability (Hansen et al., 2019b) are not evident from the suggested indicators, and it should be further discussed how this can be made clearer. Although handled separately in Norway, the different sectors have very different impact on the ecosystem. The cumulative effect of them is important to evaluate, hence including at least indicators on fisheries is important.

Making the trawl ready on RV Helmer Hanssen at Svalbard 2018. Photo Gro I. van der Meeren, IMR

RV Helmer Hanssen north of Svalbard 2018. Photo Gro I. van der Meeren, IMR

3. Case Off-Greenland

3.1 Description of case study area

About 60,000 people live in Greenland and most of them along the West coast. They are traditionally highly dependent on the marine ecosystem and Greenland's economy is presently strongly related to the productivity of the marine waters. With a changing climate regime, i.e. reduction in ice thickness, an increase in commercial fisheries is likely, but also offshore resource extraction. Increased shipping activities are also to be expected due to anticipated greater use of the Northwest Passage for shipping between the Atlantic and the Pacific (Christensen et al. 2012).

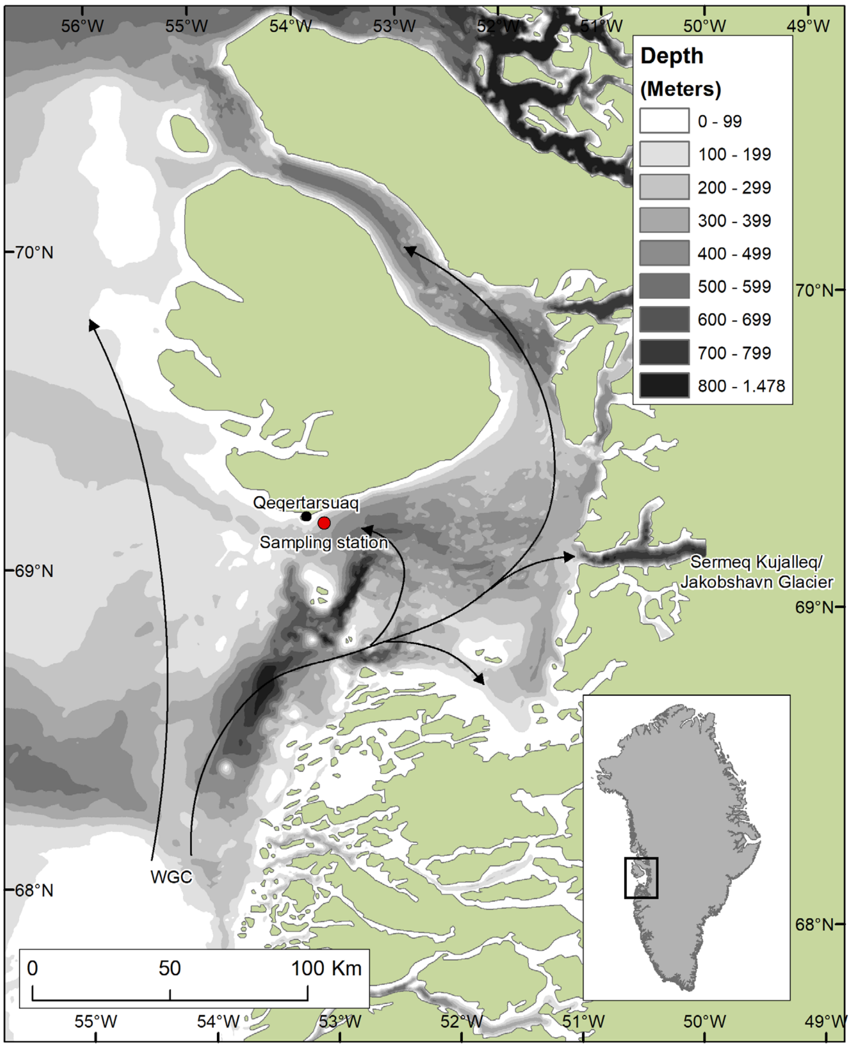
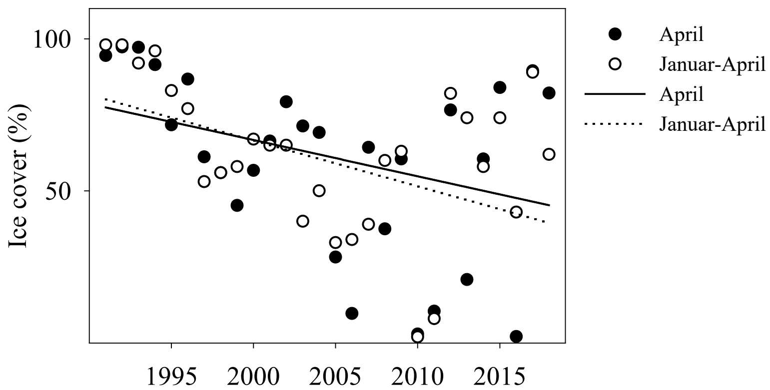


Figure 3.1.1. Map of the Disko Bay, the major pathways of the West Greenland Current (WGC), the position of the station of Qeqertarsuaq where most in situ data are available, and the bathymetry of the bay.

Disko Bay is located at the west coast of Greenland at the southern border of the Arctic sea ice and is influenced by both sub-Arctic waters from southwestern Greenland and Arctic waters from Baffin Bay (Gladish et al. 2015). The large glacier Jakobshavn isbræ is found in the bottom of the bay (Fig.3.1.1). It has been estimated that about 10% of the total Greenland ice sheet (GIS) solid ice discharge occurs from this glacier (Fig.3.1.2) (Mankoff et al. 2019), and that it drains about 5% of the GIS. Over the last three decades, Disko Bay has experienced a large decrease in sea ice cover, and also year-to-year variations have increased in the last decade (Hansen et al. 2006), the Greenland Ecosystem monitoring program, http://data.g-e-m.dk) (Fig.3.1.2). The change in sea ice conditions has been accompanied by a shift in the zooplankton community from Arctic to Atlantic species (Møller & Nielsen 2019). Disko Bay is an important "hot spot" for biodiversity and fisheries (Christensen et al. 2012), and one of the best studied areas in Greenland. Still, integration of physical measurements of oceanography, GIS discharge and the impact on the marine ecosystems has been limited.

A:



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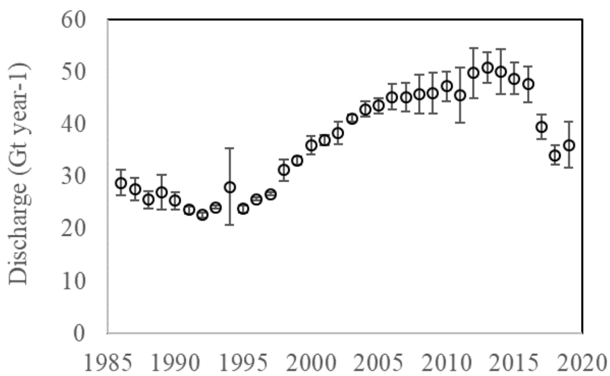

Figure 3.1.2. The sea ice cover in Disko Bay in in April and Januar-April as observed from Qeqertarsuaq (Fig. 3.1.1) (A) (Møller and Nielsen 2019)
The solid ice discharge from the Greenland ice sheet at the Jacobshavn Isbræ at the bottom of Disko Bay (Fig. 3.1.1) (B) (Mankoff et al. 2019)

There are no ecological models for Greenland coastal waters in place, whereas there are some global or Atlantic Ocean models with coarser horizontal resolution applied to open waters provided by the Copernicus Marine Ecosystem Monitoring Service (CMEMS). The aim of this task was to demonstrate downscaling from large-scale regional models to fine-scale local models of Arctic coastal waters with focus on the Disko Bay. The developed model will be used to evaluate external impacts of climate and environmental change on local marine resources to support management decisions and stakeholder involvement (task 6.8). Data assimilation of several satellite/in situ data products of the

Arctic Ocean biogeochemistry (WP5) will be implemented using state-of-art algorithmic approaches. The downscaling approach provides intelligent extrapolation of ocean parameters to un-sampled parts of the iAOS, as well as a platform to conduct observing system simulation experiments (OSSE) design studies to optimize future observational deployment. The experience from Disko Bay study will be used to evaluate how data from an iAOS may contribute to advances in ecological modelling and understanding of Arctic ecosystems and allow for expanding of developed management tools into new geographic areas, e.g. in other Greenland coastal areas.

3.2 Local modelling of the Disko Bay

3.2.1 Hydrodynamic model

A coupled hydrodynamic and biogeochemical model for the Disko Bay area, West Greenland, was set up using the FlexSem model system (Larsen et al. 2020). FlexSem is a modular framework for 3D unstructured marine modelling. The system contains modules for hydrostatic and non-hydrostatic hydrodynamics, 3D pelagic and 3D benthic models, sediment transport and agent based models (https://marweb.bios.au.dk/flexsem).

The 96300 km^2 large computational mesh for the Disko Bay area was constructed using the mesh generator JigSaw (https://sites.google.com/site/dengwirda/jigsaw) (Figure 3.1). It consist of 6349 elements and 25 z-layers with a total of 76464 computational cells. The horizontal resolution varies from 1.8 km in the Disko Bay proper, 4.7 km in Strait of Vaigat and 16 km towards the semi-circular Baffin Bay open boundary. In the deepest layers, the vertical resolution is 50 m, decreasing towards the surface, where the top 5 layers are 10 meters thick. The model has been run in yearly setup for the period from 2004 to 2018.

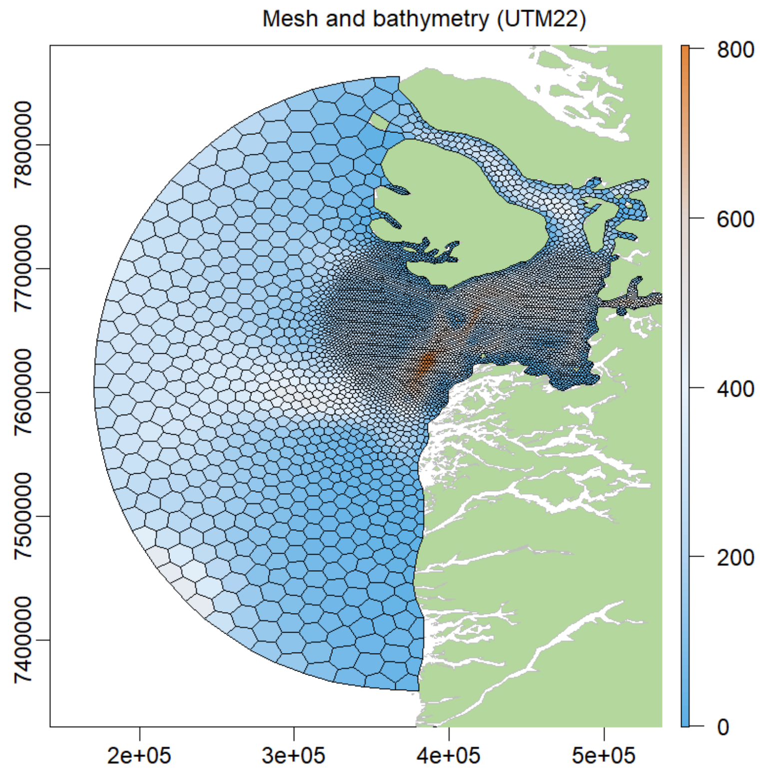

Figure 3.2.1. Computational mesh (polygons) and bathymetry for the Disko Bay area. Bathymetry is interpolated from the IceBridge BedMachine Greenland (Version 3) bathymetry and shown in colors.

3.2.2 Biogeochemical model

The biogeochemical model ERGOM was coupled to a 3D hydrodynamic module in the FlexSem framework. ERGOM simulates the cycling of nitrogen (N), phosphorous (P) and silicon (Si) and was originally applied to the Baltic Sea and the North Sea (Neumann 2000, Maar et al. 2011, Maar et al. 2016). The 11 state variables describe concentrations of four dissolved nutrients (NO_3, NH_4, PO_4, SiO_2), three functional groups of phytoplankton (diatoms, flagellates, picoalgae), micro- and mesozooplankton, detritus and oxygen (Figure 3.2.2). Cyanobacteria in the Baltic Sea version are exchanged by picoalgae in the current set-up, because cyanobacteria are less important in high-saline Arctic waters (Lovejoy et al. 2007). Chl a was estimated as the sum of the three phytoplankton groups multiplied by a factor of 2 mg-Chl/mmol-N (Neumann 2000). The calanoid copepod *C. finmarchicus* was assumed to dominate the mesozooplankton biomass (Møller & Nielsen 2019) and the physiological processes were parameterized according to previous studies (Møller et al. 2012, Møller et al. 2016). The model considers the processes of nutrient uptake, growth, grazing, egestion, respiration, recycling, mortality, particle sinking and seasonal mesozooplankton migration in the water column and overwintering in bottom waters (Figure 3.2.2). Light attenuation is a function of background (water and colored dissolved organic matter) attenuation and concentrations of detritus and Chl *a* (Maar et al. 2011). Background attenuation was changed from 0.20 m^{-1} to 0.08 m^{-1} according to monitoring data in the Disko Bay.

The pelagic ERGOM model is two-way coupled to a sediment biogeochemical model through sedimentation and resuspension of organic matter and diffusive fluxes of nutrients and oxygen (Petersen et al. 2017). Pelagic detritus and diatoms sediment into an organic detritus pool and a dead diatom pool, respectively, in the unconsolidated top layer of the sediment (Figure 3.2.3). Organic matter in the unconsolidated sediment can be resuspended, respired or gradually transferred to the consolidated sediment layer. Recycled nutrients (NH_4, PO_4 and SiO_2) in the sediment porewater are exchanged with the bottom water through diffusion and a fraction of the recycled NH_4 is lost in a coupled nitrification-denitrification process. Under oxidized conditions, PO_4 and SiO_2 are retained in the sediment by adsorption to metals and released, when the sediment becomes reduced. Benthic suspension feeders ingest phytoplankton and detritus in the bottom water, whereas deposit feeders ingest freshly deposited diatoms and detritus in the sediment. The pelagic- and benthic model parts were previously validated for the Baltic Sea - North Sea area (Maar et al. 2011, Maar et al. 2016, Petersen et al. 2017, Maar et al. 2018).

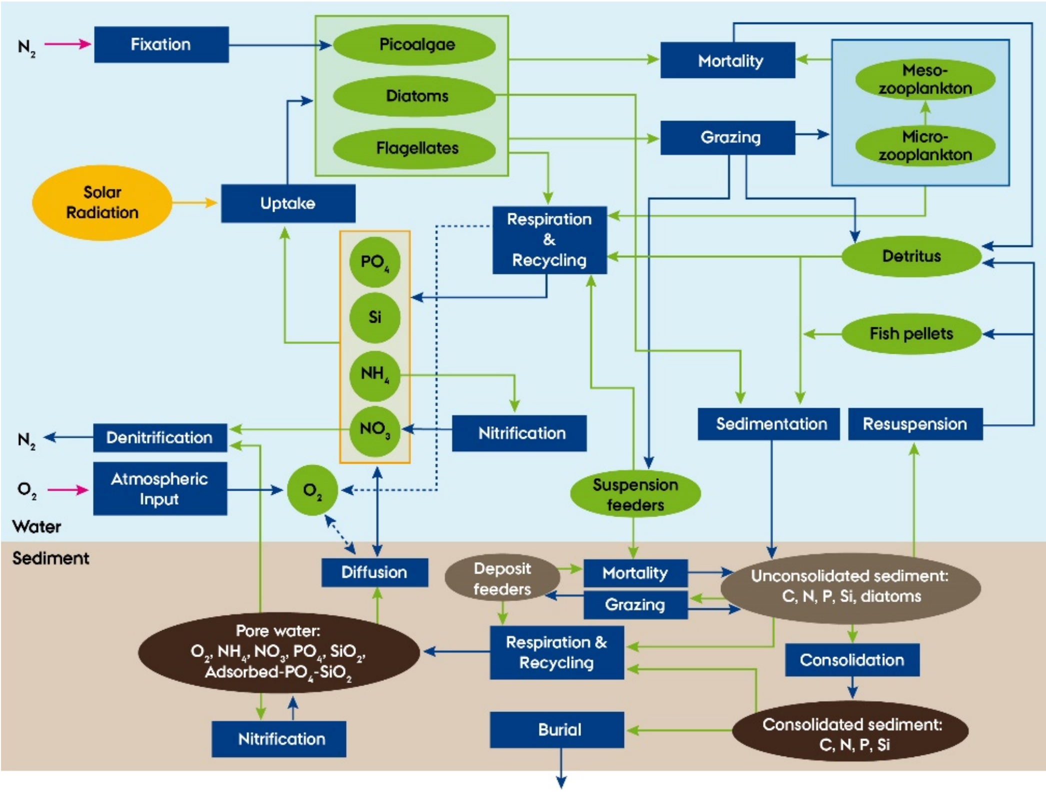

Figure 3.2.2. Model diagram showing the pelagic (green circles) and benthic (brown circles) state variables and associated fluxes (blue boxes) in the ERGOM model. The model diagram was modified from Maar et al. (2018) by exchanging cyanobacteria with picoalgae.

3.3 Use of iAOS and other data to support model development

3.3.1 Hydrodynamic model forcing data

The iAOS and other data used to set-up and improve the model is listed in Table 3.3.1. The150x150 m resolved IceBridge BedMachine Greenland, Version 3 bathymetry was downloaded from the website https://nsidc.org/data/IDBMG4 and interpolated to the FlexSem computational mesh using a distance-squared approach. The obtained bathymetry is shown in Figure 3.2.1. Meltwater run-off from the Programme for Monitoring the Greenland Ice Sheet (PROMICE) was provided by the Geological Survey of Denmark and Greenland (GEUS) and used for freshwater input (Mankoff et al. 2020). The freshwater input is estimated as ‘ice runoff = melt + condensation - evaporation + liquid precip – refreezing’, whereas precipitation, land runoff and solid ice (ice bergs) are not considered. The data set was cropped to the Disko Bay area, where 235 point sources were located. The 30 largest of these sources provide 95.7% of the total freshwater input and they were aggregated into point sources at 14 locations, distributed throughout the model domain.

At the semi-circular open boundary towards the Baffin Bay, the model was forced with velocities, water level, salinity and temperature obtained from the HYCOM-CICE model provided by the Danish Meteorological Institute (DMI) (Madsen et al. 2016). The DMI

HYCOM-CICE set-up covers the Atlantic, north of about 20°S and the Arctic Ocean, with a horizontal resolution of about 10 km. The model uses data assimilation in the surface for temperature from daily remote sensing data. Model results from the HYCOM-CICE model are also available through the Copernicus MEMS data portal on a 12.5x12.5 km grid. However, here data are only available as daily means in the period 1991 to 2018 and as hourly instantaneous from 2016 to present. Daily means are not suitable as open boundary forcing and from 2016 and onwards, the vertical resolution is coarser in the CMEMS product that in the original HYCOM-CICE output that was provided by DMI. The 2D (water level) and 3D parameters were interpolated to match the open boundary in the FlexSem Model setup using a distance square interpolation. Correspondingly, initial fields of temperature, salinity and water level were interpolated from the HYCOM-CICE model output. At the surface, the model is forced by wind drag and the surface radiance model by 2 m atmospheric temperature, cloud cover, specific humidity and ice cover. The atmospheric forcing was also provided by DMI from the HIRLAM and HARMONIE meteorological models. Ice cover was obtained from the HYCOM-CICE model output. The ice cover percentage modifies the wind drag, heat balance and light penetration in the model.

3.3.2 Biogeochemical model forcing data

Initial data and open boundary conditions for ecological variables were obtained from the HYCOM-ERSEM model at NIVA Norway (Table 3.3.1). The ERSEM model provided nutrients (ammonium, nitrate, phosphate, silicate), oxygen, detritus (small, medium and large fractions), 6 groups of phytoplankton and 3 zooplankton groups. The picophytoplankton and synechoccous functional groups from ERSEM were added to the picophytoplankton group in ERGOM, the nano-, micro-phytoplankton and prymnesiophytes were added to the autotrophic flagellates in ERGOM and diatoms were the same in both models. The detritus in ERGOM was the sum of the three detritus size fractions in ERSEM. The ERSEM data was provided as weekly means on a 1°grid (112 km lon and 40 km lat) and linearly interpolated to the FlexSem grid.

Nutrient inputs from land/ice were obtained from literature values (Table 3.3.1). For model validation, it is possible to use data from the Greenland Ecological Monitoring (GEM) program, which was established in Disko Bay in 2016. The GEM database currently contains publicly available data from only 2018, however, data from 2016 and onwards are expected to be available in the near future. The ICES database has reported data from sporadic monitoring cruises in the area, but there has been no consistent monitoring before 2016. Research data has been collected during short-term field campaigns at the Disko Bay station 69° 14’ N, 53° 23’ W from 1992 to 2012 (Møller & Nielsen 2019). A monthly climatology was calculated based on these research data and the GEM data from 1992 to 2012 and used to verify the model results for periods with few or no observations.

Table 3.3.1. Overview of iAOS and other data used in the Disko Bay model setup.

Data type	Description of data	Source
Bathymetry	Bedmachine v3, resolution of 150x150 m	https://nsidc.org/data/IDBMG4
Meteorological data	Wind velocity, 2m temp, cloud cover, specific humidity, precipitation	Data from the meteorological models Hirlam and Harmonie provided by DMI. Alternatively, Copernicus Climate Change Service (C3S) products can be used with coarser horizontal resolution: https://cds.climate.copernicus.eu
Freshwater discharges	Ice melt and surface freshwater discharges	Programme for monitoring of the Greenland ice sheet (PROMICE) data provided by GEUS. http://www.promice.org Mankoff et al. 2019. Earth Syst. Sci. Data, 11, 769–786, https://doi.org/10.5194/essd-11-769-2019, Data available at https://doi.org/10.22008/promice/data/ice_discharge Mankoff et al 2020, Earth Syst. Sci. Data Discuss., https://doi.org/10.5194/essd-2020-47, in review, 2020. Data available at https://doi.org/10.22008/promice/data/freshwater_runoff/v01
Open boundary conditions of physics	h, u, v, T, S	HYCOM-CICE model provided by DMI. (Madsen et al., 2016). See also http://ocean.dmi.dk/models/hycom.uk.php Alternatively, from year 2016 and on, Copernicus MEMS products can be used: https://resources.marine.copernicus.eu/?option=com_csw&task=results
Initial data of physics	h, T, S	HYCOM-CICE model provided by DMI. (Madsen et al., 2016). See also http://ocean.dmi.dk/models/hycom.uk.php Alternatively, Copernicus MEMS products can be used: https://resources.marine.copernicus.eu/?option=com_csw&task=results
Ice cover	Ice coverage	HYCOM-CICE model provided by DMI. (Madsen et al., 2016). See also http://ocean.dmi.dk/models/hycom.uk.php Alternatively, from 2016 Copernicus MEMS products can be used: https://resources.marine.copernicus.eu/?option=com_csw&task=results

Nutrient inputs from land	Nitrate, phosphate, silicate	Data from literature (Hopwood et al. 2019)
Open boundary conditions of biogeo-chemistry	Nutrients (ammonium, nitrate, phosphate, silicate), oxygen, phytoplankton biomass (3 groups), micro- and mesozooplankton biomass	HYCOM ERSEM model from NIVA Norway. Contact: Philip Wallhead philip.wallhead@niva.no Alternatively, Copernicus MEMS model products (25 km resolution) can be used, but with fewer variables and years https://resources.marine.copernicus.eu/?option=com_csw&task=results
Initial data of biogeo-chemistry	Nutrients (ammonium, nitrate, phosphate, silicate), oxygen, phytoplankton biomass (3 groups), micro- and mesozooplankton biomass	HYCOM ERSEM model from NIVA Norway. Contact: Philip Wallhead philip.wallhead@niva.no Alternatively, Copernicus MEMS model products (25 km resolution) can be used, but with fewer variables and years https://resources.marine.copernicus.eu/?option=com_csw&task=results
Validation data for physics	T, S	ICES database: https://ocean.ices.dk/HydChem/HydChem.aspx The Greenland Ecosystem Monitoring (GEM) database: https://data.g-e-m.dk/
Validation data for biogeo chemistry	Nutrients (ammonium, nitrate, phosphate, silicate), Chl a, micro- and mesozooplankton	ICES database: https://ocean.ices.dk/HydChem/HydChem.aspx GEM database: https://data.g-e-m.dk/ Data from literature (Møller and Nielsen 2019), own data in progress

3.4 Model results and validation

The Disko Bay FlexSem-ERGOM model was specifically developed in the project as a starting point for Greenland coastal modelling and the first model validation results are shown for some selected dates and variables. CTD profiles of temperature and salinity from the area were downloaded from the ICES oceanographic database. The hydrodynamic model was validated against a monthly climatology for the station near Qeqertarsuaq south of Disko Island for the years 1992-2012. Surface temperature and salinity showed good agreement with the seasonal development according to the climatology (Figure 3.4.1). Further, the model was compared with selected vertical profiles of temperature and salinity (Figure 3.4.2). Initially, the model was run with a simple Fick's law heat exchange at the surface, but as this proved unable to reproduce the vertical temperature profile, a full surface radiation model forced with wind speed, cloud cover, specific humidity and ice cover was added to the setup. The vertical temperature profiles were improved considerably in comparison to CTD data, when including this surface radiation model with the extra forcing (Figure 3.4.2 C, D). However, there is still some underestimation of bottom temperature and salinity probably due to the bias in the open boundary data from HYCOM-CICE.

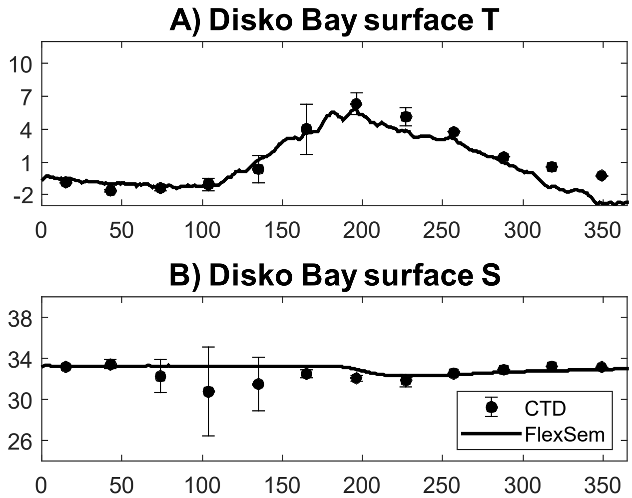

Figure 3.4.1. Time-series of A) surface temperature and B) salinity during from CTD data (means±SD: 1992-2012) and FlexSem (2004) from a station near Qeqertarsuaq south of Disko Island.

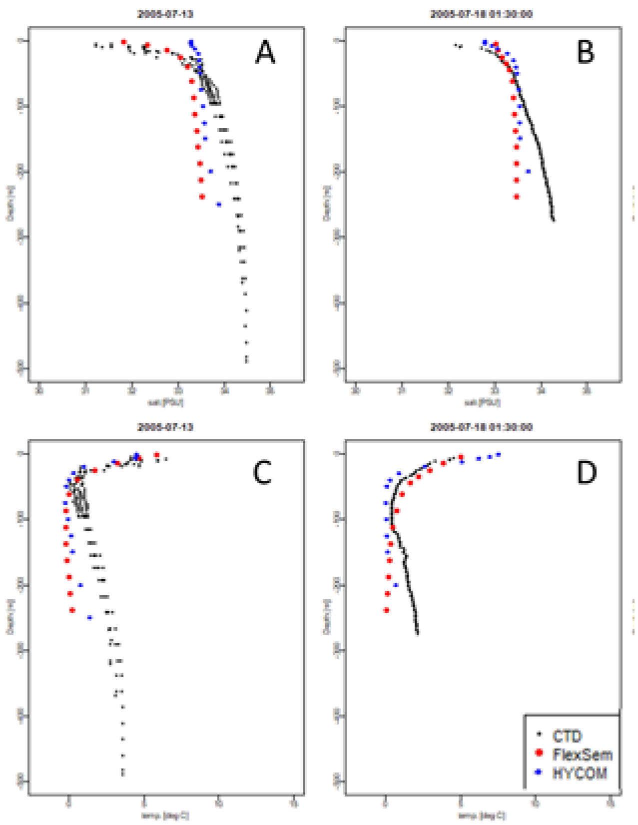

Figure 3.4.2. Vertical profiles of salinity (top row) and temperature (bottom row) for CTD data, HYCOM and FlexSem in July 2005 from at the station A, C) *of Qeqertarsuaq south of Disko Island* and B, D) *in front of the Ilulissat Isfjorden.*

The ecological model was validated for available data on surface nitrate, phosphate, silicate, Chl *a* and meso-zooplankton biomass from the Disko Bay station year 2004 using monthly climatology data from 1992 to 2018. There was a good agreement for seasonal surface nutrient- and Chl a concentration (Figure 3.4.3). The spring bloom was initiated in April followed by nitrate depletion. Ammonium, phosphate and silicate showed less depletion than for nitrate and silicate was overestimated by the model during summer. Meso-zooplankton appeared in surface waters from April and peaked between May and June in agreement with observations (Figure 3.4.3). Microzooplankton appeared later in May and peaked in June-July, but there is not enough observational data to make a climatology. These are the first results using the ERGOM parameterization from the North Sea and Baltic Sea, where only the meso-zooplankton group was changed to represent the dominant *Calanus* species, cyanobacteria was changed to the functional group pico-algae and background light attenuation was decreased. More work is needed on the parametrization of microzooplankton, vertical migration patterns of *Calanus* and effects of ice melt water on light conditions. In a next step, data assimilation of Chl *a* from remote sensing data will be tested using state-of-art algorithmic approaches.

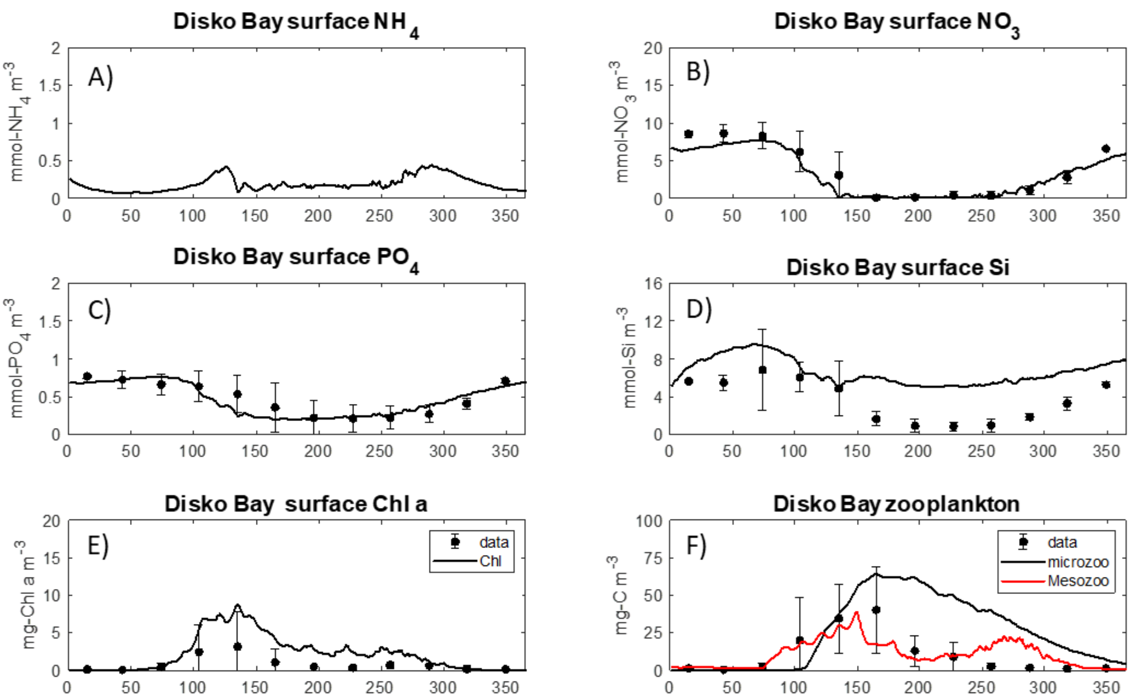

Figure 3.4.3. First results from ERGOM 2004 showing the seasonal development (days on x.axis) of A-D) nutrients, E) Chl a and F) microzooplankton and mesozooplankton south of Disko Island plotted against monthly climatology data from 1992-2018 (means ±SD).

3.5 Conclusion Disko Bay case

The applied model of Disko Bay is the first local-scale, ecological model for Greenland marine coastal waters using available iAOS forcing data. The model resolved the Disko Bay with a high horizontal resolution (down to 1.8 km) in comparison to the regional models providing the open boundary data, which had a resolution of 10 km for physics and 40 km for ecology. The sea surface temperatures were improved in FlexSem by implementing a full surface radiation model forced with model data of wind speed, cloud cover, specific humidity and ice cover. Freshwater inputs were improved by including state-of-the-art data of meltwater run-off from PROMICE. The model showed in general good agreement with vertical profiles of temperatures and salinity, except that bottom values generally were underestimated for both HYCOM-CICE and FlexSem in comparison to CTD data.

The biogeochemical model ERGOM was applied to the Disko Bay set-up with a few changes (picoalgae, *Calanus*, background light attenuation) applicable to Arctic waters. The first results showed overall good agreement with climatology data. In the next version, the model needs improvement on the microzooplankton parametrization, light attenuation from ice meltwater and *Calanus* behavior. Further, the model will be run for a longer time-period and scenarios of climate and environmental change will be conducted to evaluate the effects on productivity and implications for local fishery. The present study has demonstrated how intelligent extrapolation of ocean parameters to un-sampled parts of the iAOS can be achieved. The experience from the Disko Bay study will help to expand ecological modeling into new areas along the Greenland coastline as support for management and research.

Preparing multinet for zooplankton sampling, on RV Sanna in, Disko Bay. Photo Eva Friis Møller AU.

4 Extension of ecosystem management systems to other parts of the Arctic

4.1 Evaluation of existing and future iAOS to support models

Before applying ecosystem models for the first time to a regional ecosystem, a consideration on what data would be needed and where they can be obtained is necessary. In this report, most of the modelling was done before the data base of INTAROS iAOS were fully operational, and iAOS was therefore not applied as planned. Also, for some regionally relevant biological data within particular Arctic regions, some of these data series cannot be expected to be included in the iAOS. These need to be found within other data sources. For future models and analyses, the selection of data availability is important, and the following chapter is a discussion on data requirements, relevance and implications of models.

4.1.1 Data requirements (minimum)

The Greenland case was chosen to test how a data-poor region still may benefit from ecosystem modelling, if a minimum of data requirements is met. For the extension of the coastal Greenland modelling to new areas, the main identified obstacle is to get good forcing data, especially for the ecology. The Copernicus MEMS products have horizontal resolution of 12 km for physics but could only provide daily means (and not instantaneous values) from 1992 to 2016. For ecology, the CMEMS model product could provide data on a 25 km grid, but for few simulated years (2007-2010) and few variables (Chl *a*, nitrate and phosphate) (Table 3.1). In the Disko Bay set-up, it was possible to obtain open boundary data with higher temporal and spatial resolution for physics, more ecological variables and more years through personal contacts within the INTAROS project, but those data are not yet open access. Further, there are few spatio-temporal observations of ecological variables and the available data was compiled into a monthly climatology for model validation. The newly established GEM program in Disko Bay will probably help to resolve this problem and it is expected that there will be a good synergy between the developed ecosystem model FlexSem-ERGOM and the GEM in closing existing data gaps. The Greenland meltwater run-off from PROMICE data was used to provide freshwater input to the marine model and was provided by GEUS as part of the iAOS. Essential data needed for model forcing and validation is listed in Table 4.1.1.

Remote sensing data have been collected by most Arctic countries, and the aim of INTAROS is to assemble such data in an accessible database. Data assimilation of several satellite/in situ data products of the Arctic Ocean biogeochemistry will be implemented using state-of-art algorithmic approaches and used to conduct OSSE design studies to optimize future observational deployment as support to the Greenland Ecosystem Monitoring.

Table 4.1.1. Essential data for biogeophysical and ecological models

Variable	Area (long/latt)	Period year	Season	Depth (interval)	Unit	Comment
Temperature	Barents Atlantic[1] & Barents Arctic[2] Greenland Coastal waters	2000-2019	Monthly	0-50m, 50-200m	Degree C	Time series of monthly means pr. area
Temperature and salinity	Greenland waters	2000-2019	Hourly all year	All depths	Degree C	Time series instantaneous data (not means) to force open boundaries
pH	Barents Atlantic & Barents Arctic Greenland Coastal waters	2000-2019	Monthly	Surface	NA	Time series of monthly means pr. area
Freshwater input	Greenland waters	2000-2019	Daily all year	surface	m3/s	PROMICE data from GEUS
Current velocities	Greenland waters	2000-2019	Hourly all year	All depths	m/s	Time series of instantaneous data (not means) to force open boundaries
Chl a	Barents Atlantic & Barents Arctic Greenland waters	2000-2019	Monthly	0-20m	mg/m3	Time series of monthly means pr. area
Net primary production	Barents Atlantic & Barents Arctic Greenland waters	2000-2019	Monthly	Depth integrated	gC/m2	Time series of monthly means pr. area
Phytoplankton biomass, nutrients, detritus and zooplankton biomass	Greenland waters	2000-2019	Weekly means all year	All depth intervals	mmol-N/m^3	Time series to force open boundaries
Zooplankton biomass	Barents Atlantic & Barents Arctic Greenland waters	2000-2019	Monthly	0-200m	Gram dry weight / m2	Time series of monthly means pr. area and pr. size interval: 0-200mu, 200-1000 mu, >1000 mu
Biomass of key pelagic fish	Barents Atlantic & Barents Arctic	2000-2019	Yearly	All depth intervals	Tons/kg	Time series
Biomass of key demersal fish	Barents Atlantic & Barents Arctic	2000-2019	Yearly	All depth intervals	Tons/kg	Time series
Biomass, benthic species	Barents Atlantic & Barents Arctic	2000-2019	Yearly	All depth intervals	Tons/kg	Time series

[1] Polygon long: (3.10,18.4,54.8,58.6,43.1,16.6,3.1), polygon latt: (80.8,74.1,70.2,69.8,66.7,69.9,80.8)
[2] Polygon long: (3.10,65.5,54.8,18.4,3.1), polygon latt: (80.8,80.2,70.2,74.1,80.8)

4.1.2 Relevant data

As one of the most data-rich Arctic regions, The Barents Sea has extensive amount of, and for some cases, very long data series. Since 2004, an annual joint ecosystem-based survey by Norway and Russia, monitor practically all aspects of the ecosystem in a grid net of stations (see https://framsenteret.no/blog/2018/11/29/sixty-years-of-norwegian-russian-marine-research-cooperation/ . Based on these data, and the data from earlier and other surveys, a holistic management plan has been running since 2008, where the state and trends of the ecosystem are presented by a selection of indicators (St.meld. 2006 (2005-2006). These indicators are mainly simple components data series (see fig. 2.4.1). No previous tests have been done to study how these components perform as indicators. In 2019, a new approach for assessment of the state of marine ecosystems in Norway was launched, with new complex indicators suggested for to improve on the sensitivity for the indicators and look for signals on trends from pressures like climate change and human impacts (Jebsen at al. 2019)(fig 2.4.1). This report presents the first results on how the management plan selection of both the simple and some of the suggested the complex indicators perform in ecosystem models, laid out with fixed polygons. The results show that the performance improve when distributing the effort between polygons and months instead of using all resources in one polygon or one month (Ch. 2.6.3). The low response to different harvest strategies found in the complex biomass-dependent indicators shows the importance of a suite of indicators. Since increased ecosystem vulnerability (Hansen et al., 2019b) are not evident from the suggested indicators, further work to make this clearer is needed. Although handled separately in Norway, the different sectors have very different impact on the ecosystem. The cumulative effect of them is important to evaluate, hence including at least indicators on fisheries is important.

In the Disko Bay, less data are available for describing and monitoring the ecosystem. The extensive set of data series in the Barents Sea management plan may be less relevant, and the suggestion that a redundant set of polygons or data collection may still be enough to support management plans for sustainable management of the region. The experience from the Disko Bay study will help to expand ecological modeling into new areas along the Greenland coastline as support for management and research (Ch. 3.5).

4.1.3 Implementations and Extension to other parts of the Arctic

Common data components for all Arctic regions will be from the physical environment. In this climatic extreme region, with huge natural variations and a dramatic increase in long-term heating, climate is a major driver. The iAOS have an important role as provider of such data.

To select other relevant components, the ecosystem of each region should be studied and described. The relations between trophic levels and the key species for driving the ecosystem processes should be known. Having this knowledge, existing and running regional ecosystem management systems should be studied and compared for similarities and differences. In this report the Norwegian Sea has not been included, being a very different ecosystem from the two cases presented. Further on, we will consider if running similar models as for the Barents Sea case, also for the Norwegian Sea. If this will add new insights in extending existing models to new areas, and improve on the information on how to adapt local fisheries management to these model analyses, it will be added to the D 6.13 report.

To select components for ecosystem assessments, to support appropriate management measures, a minimum of knowledge and information is needed. Longer data time series of systematic observations is valuable. However, in the Arctic, such data series are a limiting factor. The satellite observation systems are rather new, and the land-based observation stations are few and far between. How to provide appropriate information to ecosystem management systems is challenging. The design should not be imported uncritically from one region to another, even within the Arctic region. Selection and availability of data series and component performance should be considered particularly for the plan in progress. A first step will have to be to set up a list of relevant components, based on existing monitoring and data series, while the next step is to identify gaps where data are needed. We show that ecosystem models perform and provide heightened ecosystem knowledge, even in relatively data-poor regions. Such models could be used to assess the needed level of information, on monitoring in time and space, to avoid extensive investments in monitoring and survey.

4.2 The role of ecosystem models in existing and future iAOS

The applied ecosystem models in the case studies have different structural complexity and spatial resolutions. The NoBa model, applied to the Nordic Seas and Barents Sea, is the most complex model with many trophic levels and is including human dimensions. It is highly suitable to make management scenarios and indices of higher trophic levels but is more coarsely resolved in time and space than the other two models. NORWECOM.E2E is a well-established model system with high temporal-spatial resolution for the Nordic Seas and Barents Sea and is ideal to make OSSEs. It has also the carbon cycle and key fish species included. FlexSem-ERGOM is a relatively new model for lower tropic levels with the highest spatial resolution among the three models, but with focus on smaller coastal systems and environmental changes. It has the advantage of being very flexible and can easily be adapted to a wide range of local ecosystems in the Arctic (Larsen et al. 2020). The applied ecosystem models of the Arctic environment can have different roles in supporting the existing and future iAOS and some examples are given below.

4.2.1 OSSE in the designs of observational networks

Models can support the local monitoring programs by identifying monitoring stations that are representative for a larger area. The quality of monitoring observations is largely affected by the sampling scheme. Numerical models can contribute to the efficient design and optimization of observing systems for science and operational uses (e.g. Arnold and Dey (1986)). OSSE have been used to optimize monitoring programs and design observational networks in both coastal (Mey-Fremaux et al., 2019) and open oceans (Fu et al., 2011; Majkut et al., 2014; Charria et al., 2016; Garcıa-Garcıa et al., 2019). By correcting the station positions for advection by adding the mean flow from a circulation model, McGillicuddy Jr. et al., (2001) also used an OSSE approach to reconstruct observations to give a synoptic map. Observations are often pre-processed before use, and even inter-annual variability might not be preserved after interpolation (Rufino et al., 2019). This needs also to be taken into consideration when defining indices and designing observational systems. Such efforts will increase the value of observations and enable new applications by connecting and synthesizing sparse observations. The design of an observational network therefore requires some existing knowledge to become a robust basis for a set of indices to be used for management purposes. Such a design should rely both on observations (e.g. from another network) and models (through an OSSE). Therefore, such design can be considered a two-way and reciprocal problem (Fu et al., 2011). OSSE have successfully been conducted for the Barents Sea monitoring program but should be further elaborated through an analysis of available data from WP5 and a proposed revision of existing monitoring programs. In the future, the plan is to do a similar OSSE for the Disko Bay as support to the newly established monitoring program GEM, but the approach can be applied to all areas with existing or planned sampling programs.

4.2.2 Model results as supporting data to the iAOS

Marine ecosystem data from the iAOS is often scarcely resolved and may not cover the whole seasonal cycle, year-to-year variability or the whole 3D spatial domain, because they often are based on few data points or transects from monitoring cruises conducted during a limited time period. Continues sampling devices can provide data with high temporal resolution, but not spatially, and have problems during periods with ice cover. Models can on the other hand provide intelligent interpolation between monitoring data points and extrapolation to larger areas and periods (Skogen et al. subm.).

Models can further quantify biogeochemical processes that are difficult to measure. Monitoring programs are often focused on measuring concentrations (e.g. nutrient concentrations, plankton biomass, fish stocks) rather than food web fluxes. The only rate that is routinely measured in some areas is primary production, whereas research cruises also provide sporadic data on e.g. copepod egg production, grazing rates, growth rates and sedimentation rates. However, it is not possible to measure all fluxes in a food web and to fully and more realistically resolve the emergence of trophic responses in the plankton community, coupled hydrodynamic-biogeochemical models are required (Sailley et al. 2015, Maar et al. 2018). The models can e.g. be used to evaluate feeding strategies (e.g. prey selection and food quality) and how this affects nutrient cycles (Sailley et al. 2015), to estimate the fate (respiration or burial) of carbon sequestration in the food web (Polimene et al. 2016, Ducklow et al. 2015), to estimate the controlling factors for productivity (Stock and Dunne 2009) and to estimate cascading effects in the food web due to changes in mortality of higher trophic levels (Maar et al. 2018). Therefore, models and observations should be just closer together to generate synergies, and to allow a better support for science and management (Skogen et al., submitted).

4.2.3 Application of models to ecosystem-based management

More and more modelling products are being generated and made available for free download, for example through the Copernicus Marine Environment Monitoring Service home page. However, the modelling products are often big data sets and not suitable for stakeholders, and it is mainly the scientific community using the data. An important part of the modelling work is to translate model results into useful tools for stakeholders. Model components can be used to evaluate the status of the ecosystem and detect changes in ecosystem components, which is useful for ecosystem-based management of marine areas.
Models can perform scenarios of environmental and climate changes in order to predict the future conditions of the marine ecosystem processes (e.g. productivity) and key components (e.g. fish species). If the model results are aggregated into maps, time-series or other easily understandable products or services, it can be used to interact with stakeholders and local populations in order to increase awareness and support management decisions. For example the FlexSem-ERGOM model is the first biogeochemical model for Greenlandic coastal waters and since these ecosystems to a large extent are unexplored, the modelling can give insight into the functioning and potential future changes of the different types of ecosystems with respect to e.g. productivity, zooplankton migration, carbon removal, pollution and biodiversity. The NORWECOM.E2E model combines the physics and lower trophic with detailed models of key species, and can be used to e.g. quantify food web fluxes and processes that are hard or impossible to measure, and through a module for fishing, to investigate ecosystem effects of a zooplankton fishery. NoBa Atlantis takes it one step up, including the links between the physics and all the way to the higher trophic levels. It provides the opportunities to explore the cumulative effects of climate and fisheries, and to evaluate processes that are difficult to assess, such as indirect predator-prey relationships.

5 Final remarks

So far, no ecosystem models have been incorporated in ecosystem management systems for the Arctic region. This report shows that it would be a useful addition to the extensive use of a range of data for indicator data in the Norwegian management system, and even in local regions, as Disko Bay in Greenland. The modelling work will gain from involvement from people with local knowledge, stakeholders and policy makers, to improve on how they can be fitted to meet for sustainable use and long-time protection of the marine resources in a changing climate.
When tasks 6.2 and 6.8 move forward, making contacts and getting in dialogue with local communities, stakeholders, managers and policymakers will be important in show the

benefits of cross-fertilizing local and scientific observation systems. Further on, the results presented here will also be in dialogue with task 6.6 and task 6.3. Furthermore tasks 6.2 and 6.8 aims to contribute to the WP 1 roadmap for the future Arctic observing system.

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