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Multispecies management: Species interactions and trade-offs, environmental changes and multiple pressures

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Preface:

The 19th Norwegian-Russian Symposium, entitled “Multispecies management: species interactions and trade-offs, environmental changes and multiple pressures”, was held as a fully remote digital meeting 4-5 June 2024. The Symposium had participation from several Russian and Norwegian institutions and was considered very successful.

Multispecies management is a key concept in ecosystem-based fishery management, with consideration of ecological processes integrated so that management of a stock is seen in conjunction with other associated (or interacted) stocks. The concept was developed in the 1980s for the North and Barents Seas. Initially the focus was on understanding and quantifying interrelations between stocks and their relations to highly variable environmental conditions, and development of multispecies and ecosystem models. A related topic is management of mixed fisheries where different stocks are caught in the same fishery and where the effort on one stock practically affects the level of bycatch of other co-caught stocks. Trade-offs associated with setting optimal harvest levels for interacting stocks is another key aspect of multispecies management. More broadly the marine ecosystems are impacted by a range of different stressors, and a major challenge presently is understanding the cumulative effects of human pressures acting on harvested stocks and marine ecosystems under recent climatic changes. This again relates to management and trade-offs across economic sectors (such as fisheries, aquaculture, petroleum, etc.).

The Symposium program included 4 theme sessions with 33 presentations. The theme sessions were coordinated by the nominees from the Russian and Norwegian parties:

Session 1: Predation and competition. (Tore Haug / Andrey Dolgov)

Session 2: Mixed fisheries and bycatch. (Bjarte Bogstad / Konstantin Sokolov)

Session 3: Pressures on environment and ecosystems. (Harald Gjøsæter / Andrei Krovnin)

Session 4: Multispecies and ecosystem modelling. (Elena Eriksen / Yury Kovalev)

The Proceedings contain contributions in a mixture of formats. Some contributions were based on articles already published. For these, the submissions to Proceedings only include the abstract plus a link to the electronic version of the published article. Other contributions, based on new, unpublished data and meant for discussions at the Symposium, is included in the Proceedings in the format of a standard scientific article and contain totally up to 10 printed pages including text, figures and tables. In addition, good contributions based on new data and due to be published in scientific journals in the near future are represented with an extended abstract (1-2 pages) in the Proceedings.

Bergen/Moscow/Murmansk/Tromsø, January 2025

The editors

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1 - THEME SESSION I: PREDATION AND COMPETITION

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1.1 - Trophic relations of commercially important fishes and invertebrates: can we really consider them in multispecies management of fisheries in the Barents Sea?

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Short communication

Abstract

Various aspects of fish, seabirds and marine mammal predation on commercially important fish and invertebrates in the Barents Sea and possible food competition among pelagic and demersal fishes and other predators are considered. Using of data on predation and competition in multispecies models and in multispecies fisheries management in the Barents Sea as well as its reliability and value for management goals are discussed. Possible rational objectives of fisheries on target species from different trophic levels in the Barents Sea are also discussed.

Key words: Barents Sea, diet, trophic relations, fish, sea birds, marine mammals, predation, fisheries management

Introduction

The Barents Sea is the important area of commercial fisheries for Russia and Norway. Recently Russian and Norwegian c ommercial fisheries target on 13-15 pelagic and demersal fish species (and more 10-15 species can be considered as commercially important), on 3 species of invertebrates (and more 5-10 species can be considered as commercially important) and on 2 species of marine mammals (Shevelev et al., 2011; Nedreaas et al., 2009).

The management and regulation of fisheries in the Barents Sea is conducted by the Bilateral Russian-Norwegian Fisheries Commission based on scientific recommendations of scientists of Russia and Norway on main pelagic and demersal fish stocks (cod, haddock etc.) developed on the ICES Arctic Fisheries working group (AFWG), since 2022 – on the Russian Norwegian Arctic Fisheries Working Group (RN-AFWG). Stock assessment of some groups/species (shrimp, red king and snow crabs, marine mammals) are conducted by other working groups in ICES (Kovalev and Bogstad, 2011).

Recently the ecosystem approach became one of the most important tools for management of separate stocks and marine ecosystems in general (The ecosystem approach to fisheries, 2008; Morishita, 2008). To implement this approach to the Barents Sea commercially important stocks, Russian-Norwegian cooperation was started in mid-1980s (Mehl and Yaragina, 1992; Dolgov et al., 2007). The main goal of these researches was to understanding of interrelations between these stocks and in perspective to use data on their diet in fisheries management in the Barents Sea. Therefore it is necessary to sum up some results of these researches and review what has been done and what can/should be done further.

Main goals of this review were the following: 1) to review available information on diet and trophic relations in the Barents Sea ecosystem; 2) to consider recent using of this information in the multispecies management of fisheries in the Barents Sea and 3) to evaluate if recent fisheries management in the Barents Sea can be improved based on the information on trophic relations in the Barents Sea.

Results and discussion

Review of available information on diet of the most important species/groups and trophic relations in the Barents Sea ecosystem

For estimation of predation of various predators on commercially important fish and invertebrates to incorporate knowledge on trophic relations in stock assessment and fisheries management we need recent and long-term information on 1) abundance/biomass and their interannual variations, 2) diet composition (including ontogenetic, seasonal and year-to-year variations), 3) feeding ration (daily, seasonal or yearly) and 4) annual food consumption (separately for length/age groups of commercially important prey species).

For these goals the joint Russian-Norwegian research program on investigations of trophic interrelations between commercially important hydrobionts in the Barents Sea ecosystem was started since mid-1980 s by PINRO and IMR. Under this program annual monitoring of feeding of the most abundant fish species was conducted – cod (since 1984), haddock (since 1986 and then since 1991), capelin (since 2005) and polar cod (since 2006). Since 1993 PINRO also conducted such investigations of other both commercially important and non-target fishes (40-50 species).

It should be noted that similar research on diet an trophic relations of fish, sea birds and marine mammals in the Barents Sea were also conducted by other Russian and Norwegian academic institutes.

Fish

More than 220 fish species inhabit the Barents Sea (Dolgov, 2016), approximately 100 species regularly occur in the research surveys (Wienerroither et al., 2011, 2013). Abundance and biomass of the most abundant species estimated based on the data from the joint Russian-Norwegian winter and ecosystem surveys.

Long-term monitoring of diet and feeding conditions is conducted only for small number of the most important species (cod, haddock, capelin, polar cod and partly Greenland halibut, long rough dab). For the most other 50-60 fish species, only general diet composition for some years is available (e.g. Dolgov, 2016; Eriksen et al., 2020). Most commercially important fish are planctivorous (capelin, Atlantic herring, polar cod), benthivorous (haddock, wolffishes, plaice), predators (cod, Greenland halibut) or species with mixed diet (saithe, redfishes).

Daily feeding rations were investigated in aquarium conditions only for cod, haddock, saithe, polar cod, plaice, European flounder, long rough dab, golden redfish, Atlantic and spotted wolffishes and thorny skate (e.g. Berestovsky, 2005 and references therein; Karamushko, 2007). Various methods for calculation of feeding rations were developed for cod (e.g. Orlova, 1991; Jobling, 1981; dos Santos and Jobling, 1995 and other). For other species only similar values of feeding rations can be used.

Total food consumption (including commercially important fish and invertebrates) regularly estimated only for cod (). Similar preliminary calculations were done also for haddock, Greenland halibut, thorny skate, long rough dab (Dolgov, 2016).

Atlantic cod is key predator in the Barents Sea ecosystem due to its very wide diet composition, wide distribution and high stock biomass. However, complicative trophic relations between fishes are known in the ecosystem. Many fish predators feed on commercially important species – pelagic fish (capelin, herring, polar cod), juveniles of demersal fish (cod, haddock, redfish, long rough dab) and invertebrates (northern shrimp, snow crab and red king crab. Even pelagic species like capelin and polar cod can prey on larvae and juveniles each other (Dolgov, 2016 and references in). Also some authors consider that predation of herring on capelin larva and juveniles can be crucial for capelin recruitment in the Barents Sea (Huse and Toresen, 2000; Gjøsæter and Bogstad, 1998), but this statement can be rather contradictory (Dolgov et al., 2019).

Food competition is observed between both pelagic (capelin-polar cod, herring-capelin etc.) and demersal (cod-haddock, cod-long rough dab, haddock-long rough dab, haddock-plaice etc.) species (Dolgov, 2016 and references in). Such competition can be high due to feeding on the most abundant prey species (euphausiids, hyperiids, shrimp, pelagic fishes). Cannibalism was registered not inly in cod (Bogstad et al., 1994), but also in pelagic (herring, capelin, polar cod) and other demersal (haddock, saithe, redfish, polar sculpin, gelatinous snailfish, long rough dab, Greenland halibut) species (Dolgov, 2016).

Sea birds

33 species of sea birds occur and breed regularly in the Barents Sea (Strøm et al., 2009; Fauchald et al., 2011). The pelagic feeding species dominate the Barents Sea seabird community, comprised both of diving (e.g. Brünnich‘s guillemot, Atlantic puffin and little auk), and surface feeding species (e.g. northern fulmar and black-legged kittiwake). Coastal species can feed on benthos (e.g. ducks, eiders) and fish (e.g. great cormorant and European shag) (Strøm et al., 2009; Fauchald et al., 2011). In the north and east of the Barents Sea along the marginal ice-zone (capelin, polar cod and zooplankton are important prey items for sea birds, while on south and west sea birds prey on juvenile gadoids, juvenile herring, sandeel and capelin.

Abundance of most sea birds species are known separately for various regions of the Barents Sea (Strøm et al., 2009; Fauchald et al., 2011). However these estimates are also available for some periods, not for long-term periods and not for each year.

Data on diet composition are also available for the most sea birds. However long-term monitoring of their diet even for the most abundant species practically is not conducted due to serious difficulties in such researches.

Concumption of fish and crustaceans by sea birds in the Barents Sea were conducted (Mehlum and Gabrielsen, 1995; Barrett et al., 2002). The estimations were based on data on energy consumption, food assimilation efficiency and caloric content of prey items.

However available data on diet composition and food consumption in sea birds in the Barents Sea are rather general and cannot to consider interannual variations.

Marine mammals

Approximately 25 species of marine mammals inhabit the Barents Sea. 13 species (polar bear, 7 pinniped species and 5 cetacean species) are live here, other 12 species (9 whales species and 3 dolphin species) are seasonal migrants and occur in the Barents Sea only during the summer season for feeding (Kovach et al., 2009; Haug et al, 2011a).

Trophic role of marine mammals in the Barents Sea varied from planctivores (baleen whales) and bentivores (bearded seal, walrus) through fish predators (thoothed whales, most pinnipeds) to top predators (polar bear and killer whale) (Haug et al, 2011a).

Abundance estimates for most species of marine mammals exist for the Barents Sea or for the North-East Atlantic (Haug et al, 2011a), however regular long-term monitoring is conducted mainly for species distributed in the open sea. Evaluation of coastal species is more difficult and only occasional.

Despite wide experience in keeping of some marine mammals in captivity, feeding rations were estimated only for two species harp seal and minke whale (Nilssen et al., 2000; Folkow et al., 2000) based on bioenergetic models used energy requirements of these species. Food consumption estimations were conducted only for two the most abundant species in the Barents Sea – harp seal and minke whale (Nilssen et al., 2000; Folkow et al., 2000). However these estimates were calculated only for two periods with high and low level of capelin stocks and cannot provide interannual dynamics of predation of these species.

Generally trophic relations and food competition between fish, sea birds and marine mammals in the Barents Sea ecosystem are very complicative and related to their stock state as well as state of plankton, benthos and fish communities (e.g. Bogstad et a., 2000, 2015; Haug et al., 2011b; Durant et al., 2014; Dolgov, 2016).

Review of recent considerations of available information on diet and trophic relations in the stock assessment and TAC recommendation for the commercially important species in the Barents Sea

How recently are these data on diet of fish, sea birds and marine mammals as well as their trophic relations (predation and food competition) used in stock assessment and fisheries management?

Data on cod predation on some commercially important species are used in a number of single- and multispecies mathematical models both Russian (VPA, XSA, MS VPA, CONCOD, STRAFICOD, STOCOBAR, ISVPA) and Norwegian (MULTSPEC, AGGMULT, CAPSEX, BIFROST, SYSTMOD, Fleksibest, BORMICON, SeaStar, GADGET, SAM) (Filin, 2006; Bogstad and Filin, 2011). In addition, these data together with literature data on lists of prey for other species/groups from different trophic levels (Planque et al, 2016) were used for developing of ecosystem models (e.g. Ecopath/Ecosim, Atlantis). However most these models cannot to estimate stock abundance and biomass and forecast their dynamics in forthcoming years.

The models recently used for stock assessment are mainly single- or two-species models, which estimate predation of one predator species on one prey species. So, data on consumption of most important prey species (euphausiids, hyperiids, shrimp, snow crab (since 2003), herring, capelin, polar cod, cod, haddock, blue whiting, Norway pout, redfish, Greenland halibut and long rough dab) by cod are presented to the ICES Arctic Fisheries Working Group (since 2022 to RN-AFWG) since 1995. In addition, consumption of juvenile cod and haddock at age 1-6 calculated and presented (as additional catch), and then these data used for estimation of their mortality and then for the stock assessment. So, only data on cod predation on juvenile cod and juvenile haddock as well as on capelin are used for its stock assessment. Similarly data on predation of other abundant fishes (e.g. haddock, Greenland halibut etc.) and marine mammals (harp seal and minke whale) don’t used in the assessment on this group.

At the same time data on predation of other predators on their prey species recently don’t used for stock assessment procedure, at the best only short description of feeding peculiarities or predation impact can be provided. So, despite available long-term information on consumption of other prey by cod these data are not used for stock assessment of Atlantic herring on the Working Group on Widely Distributed Stocks (WGWIDE), northern shrimp on the Pandalus Assessment Working Group (WGPAND) (later Joint NAFO\ICES Pandalus Assessment Working Group (NIPAG) and snow crab on Working Group on the Biology and Life History of Crabs (WGCRAB).

Similarly data on predation of harp seal on zooplankton and fish are not used for estimation the harp seal stock in the Joint ICES/NAFO/NAMMCO Working Group on Harp and Hooded Seals (WGHARP).

Can recent management practice be improved by the information on predators diet and trophic relations?

Now in the Barents Sea fisheries targets on invertebrates (shrimp, red king crab and snow crab), pelagic planktivorous fishes (capelin, sometime also polar cod), demersal benthivorous fishes (haddock, plaice, wolffishes), predatory fishes (cod, Greenland halibut) and fishes with mixed diet (saithe, long rough dab, redfishes). Also limited hunting targets on marine mammals (harp seal and minke whale). Species from other ecological groups from different trophic levels (e.g. krill, copepods, molluscs et.c.) practically don't used by fisheries. At the same time no any balance between stock biomass of predators and their prey evaluated or considered under fisheries management practice.

Taking into account this fact, should we change objectives of fisheries and consequently target species? In such case some approaches can be applied to develop such new objectives. To increase the total catch volume, fisheries should target on the most abundant species with the highest biomass (e.g. capelin) with no or limited catch of predatory fishes (e.g. cod). To increase the financial profit of catch, fisheries should target in species with the highest prices (e.g. Greenland halibut, cod) with no fisheries of their forage fish (capelin, polar cod). To keep ecosystem of the Barents Sea in more or less health state, fisheries should keep more or less proportional withdrawal of species from all trophic levels, including plankton (copepods and euphausiids) and benthos (molluscs, holothurians etc.). If principal approach to fisheries in the Barents Sea will changed, using of data on trophic relations will be much more important.

Conclusions and perspectives

Recently we have got long-term and reliable data on cod diet, long-term but not completely satisfactory data on diet of other demersal and pelagic fish and occasional and fragmentary data on diet of sea birds and marine mammals. But only data on cod predation are used in stock assessment and fisheries management in the Barents Sea until now.

What can we do further? Should we continue to conduct recent practice of annual monitoring research of feeding only for the most abundant predator species (cod, harp seal, minke whale etc.) or also include in this monitoring some other abundant predators? Should we continue to use only single species models for stock assessment and forecasting or develop better assessment tools taking into account predation or real multispecies models?

Diet composition and trophic relations between commercially important fish and invertebrates, as well as most sea birds and marine mammals in the Barents Sea ecosystem were studied rather well, especially under PINRO-IMR cooperation since mid-1980s.

Recently only some aspects of trophic relations (mainly predation by cod) are used in the stock assessment and TAC recommendation for small number of commercially important species (capelin, cod and haddock). Unfortunately most other available information on trophic relations in the Barents Sea ecosystem didn't used in fisheries management until now.

So, the main question is the following – will we be able to principally improve using of data on trophic relations in stock assessment and in fisheries management in the Barents Sea?

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1.2 - A food-web assessment model for marine mammals, fish, and fisheries in the Norwegian and Barents Seas

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Abstract

The purpose of this work is to develop a food-web model of intermediate complexity and perform a quantitative assessment of the interactions between marine mammals, fish, and fisheries in the Norwegian and Barents Sea ecosystems in the period 1988-2021. For this purpose, we use the modelling framework of Chance and Necessity (CaN). The model construction follows an iterative process that allows to confront, discuss, and resolve multiple issues as well as to recognise uncertainties in expert knowledge, data, and input parameters. We show that it is possible to reconstruct the past dynamics of the food-web only if recognising that some data and assumptions are more uncertain than originally thought. According to this assessment, consumption by commercial fish and catch by fisheries jointly increased until the early 2010s, after which consumption by fish declined and catches by fisheries stabilised. On an annual basis, fish have consumed an average of 135.5 million tonnes of resources (including 9.5 million tonnes of fish), marine mammals have consumed an average of 22 million tonnes of which 50 % (11 million tonnes) were fish. Fisheries and hunting have captured an average of 4.4 million tonnes of fish and 7 thousand tonnes of marine mammals. The food-web assessment outputs are further used to quantify how variations in the biomass of marine mammal populations have affected the biomass of commercial fish and vice-versa.

Related publication

Planque, B., Bas, L., Biuw, M., Blanchet, M., Bogstad, B., Eriksen, E., Drouineau, H., *et al.* 2024. A food-web assessment model for marine mammals, fish, and fisheries in the Norwegian and Barents Seas. Progress in Oceanography, 229: 103361. https://doi.org/10.1016/j.pocean.2024.103361

1.3 - Intra- and interspecies trophic relations in fish communities in the Barents Sea

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Abstract

The Barents Sea has a long history of fish diet research, primarily focused on commercially important species. In 2015, a large-scale stomach sampling program was carried out on the routine Barents Sea monitoring surveys, supplemented with samples collected from Russian commercial fisheries. A total of 27,657 stomachs from 70 fish species (including two genera) were analysed, providing a baseline on fish diet in the Barents Sea and establishing a reference for future studies related to climate change (Eriksen et al. 2020). Cluster analysis grouped the fishes in nine trophic groups based on similarities in diet among fish species, while principal component analyses revealed the position of the species and trophic groups along axes reflecting degrees of piscivory, planktivory, and benthivory. Planktivores were further divided into Atlantic-origin species feeding on copepods and euphausiids, and Arctic-origin species feeding on hyperiid amphipods.

We also analysed spatial and seasonal variations in fish diet of 34 selected fish species (Eriksen et al. 2021). Seasonal variations were most evident among planktivores, which take advantage of seasonal 'pulse' of the new generations (e.g. of Calanus finmarchicus), in spring and summer. Piscivores also showed seasonal patterns, feeding on migratory prey like capelin and polar cod during their spawning and feeding migrations. The overall trophic structure - planktivores, piscivores and benthivores - remained stable throughout the year despite these seasonal differences.

Spatial variations were influenced by biogeographic affiliation, distinguishing Arctic from boreal species, and by habitat associations that reduced competition within trophic groups (e.g., between species in shallow versus deep waters). This work improves our knowledge of seasonal and spatial variations in the trophic interactions of the Barents Sea fish community and provides a basis for further studies of energy flow in the Barents Sea ecosystem.

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1.4 - Feeding dynamics of capelin and polar cod in the Barents Sea in a warming era

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Abstract

Capelin (*Mallotus villosus*) and polar cod (*Boreogadus saida*) hold a fundamental position in the Barents Sea ecosystem as consumers of zooplankton while serving as forage fish for the commercial and ecological key species Atlantic cod (*Gadus morhua*). The ongoing warming and Atlantification of the Barents Sea, along with increasing net primary production, makes previously inaccessible northern areas available as feeding grounds for capelin. The opposite effect is anticipated for the ice-dependent polar cod. The transport of Atlantic water with boreal plankton from the Norwegian Sea is important for sustaining biodiversity and production in the Barents Sea. A decline of the medium-sized mesozooplankton biomass to a low level during 2016 to 2022 coincided with a strongly decreasing summer volume transport with the Atlantic Current. The low biomass of medium-sized zooplankton observed in later years raises concern about the feeding conditions now experienced by the higher trophic levels.

Both capelin and polar cod feed predominantly on lipid rich sub-Arctic and Arctic zooplankton species. We found a significant inverse relationship between capelin and mesozooplankton biomass and a clear dietary shift from smaller to larger predator size. Smaller capelin (<12 cm) contained a comparatively higher proportion of copepods, dominated by *Calanus glacialis,* followed by *C. finmarchicus and Metridia longa* (copepodite stages IV-VI). As the capelin grow, their diet switches towards larger zooplankton, primarily euphausiids (mainly *Thysanoessa inermis*). All age groups of polar cod fed heavily on pelagic amphipods (mostly *Themisto libellula*) in addition to copepods and euphausiids, and to some degree also on fish, thus displaying a higher trophic position than capelin. Capelin growth from age 1 to 2 was negatively associated with their abundance at age 2, but positively related to stomach fullness for 2-year-old fish, indicating density-dependent growth. While our study reveals interactions between capelin and zooplankton, such signals between polar cod and their prey were not evident.

Link to the published article:

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1.5 - Northern expansion of Atlantic cod and its effect on native arctic fish fauna in the Barents Sea

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Abstract

In recent decades, many boreal fish species have expanded or shifted their distributions from temperate to subarctic or arctic regions, while native arctic species have contracted their range in response to higher water temperatures and less sea ice. Expanding species have the potential to alter existing food webs by acting as predators and competitors to native fauna. In the North Atlantic, the Atlantic cod has expanded into arctic parts of the Barents Sea around the same time as declines in native fish species have been observed. Here we use the most comprehensive database on Atlantic cod diet, the joint Norwegian-Russian stomach content database, to estimate cod's consumption of arctic fish species over 15 years encompassing a period with a stable cod population, a period when the population increased and expanded into the arctic habitat, and a period when the population declined. Next, we estimate biomass indices of arctic native fish species using data from the same trawl monitoring surveys that sample cod stomachs and use statistical models to evaluate the impact of cod predation and water temperature on arctic fishes. We find that polar cod and small demersal arctic fishes constituted 40-50% of the total daily consumption by cod during the study period. Our findings confirm earlier studies showing that small fishes, including arctic species, constitute a large portion of the cod diet in the northern BS, which is an important feeding area for cod. Cod consumption of arctic fishes considerably increased in the years of expansion and likely contributed to a decline of liparids in the arctic Barents Sea. We also find multidirectional effects of temperature on polar cod biomass and prickleback biomass that may have counteracted or masked predation effects. The most recent years have seen a decline and partial retraction of cod from the arctic area, but consumption has not been fully reduced to pre-expansion levels as the cod population now consists of relatively more older individuals that consume more prey.

1.6 - Ontogenetic, seasonal and interannual variation in diet of North East Arctic haddock

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Extended abstract

Haddock is the second most abundant (in term of biomass) and the only benthivores gadoid species in the Barents Sea. Trophic investigations of haddock in the Barents Sea began in the 1930s and continued through the 1960s-1980s.

Since the 1980s, the Institute of Marine Research (IMR, Bergen, Norway) and the Polar Research Institute of Marine Fisheries and Oceanography (PINRO, Murmansk, Russia; since 2019, the Polar Branch of VNIRO) have been investigating the diet and feeding conditions of haddock in the Barents Sea. IMR conducted such investigations from 1984 to 1991 and later in 2009 and 2015 (593-2510 stomachs per year). PINRO carried out these studies in 1988-1989 and has continued them annually since 1993 (400-8500 stomachs per year).

Based on quantitative analysis of 114,156 stomach contents, the diet composition and feeding habits of haddock from 1984 to 2023 were examined.

Benthic organisms dominated the haddock diet during this period, accounting for 46.3% of the total weight. The main benthic groups were echinoderms, primarily ophiurids, (20.6%), polychaetes and other worms (13.5%) and molluscs, mainly bivalves, (12.2%) (Figure 1). Planktonic organisms, euphausiids (13.0 %) and hyperiids (1.5 %), played a minor role, accounting for 13.5% of the diet by weight. Fish made up 17% of the haddock diet by weight. Among 36 fish species identified in haddock stomachs, capelin was dominant (10.8%). Other commercially important fish species such as herring, polar cod, cod, haddock, blue whiting, saithe, Norway pout, redfish, wolffish, Greenland halibut and long rough dab were also present in their diet. Additionally, jellyfish (Ctenophora) accounted for up to 10% by weight, while fisheries waste contributed minimally (0.9%).

Ontogenetic changes in haddock diet were generally small. Plankton dominated the diet of juvenile fish (age 0+ to 1, length up to 16-20 cm) and regained importance in fish aged 3-7 years and 36-55 cm in length. The proportion of benthic organisms increased in larger and older fish, while the importance of fish prey remained relatively consistent across all age and length groups. A more detailed analysis revealed variations among different prey taxa. The importance of most benthic groups (actinians, molluscs, echinoderms (except ophiurids), Eupagurus) and fisheries waste was higher for larger haddock. The proportion of gammarids, shrimps, and juvenile redfish decreased with haddock size. The proportion of other prey items (comb jellies, polychaetes, ophiurids, and all fish species) remained relatively consistent across all length/age groups. Hyperiids and euphausiids were more prevalent in the diets of juvenile and medium-sized haddock.

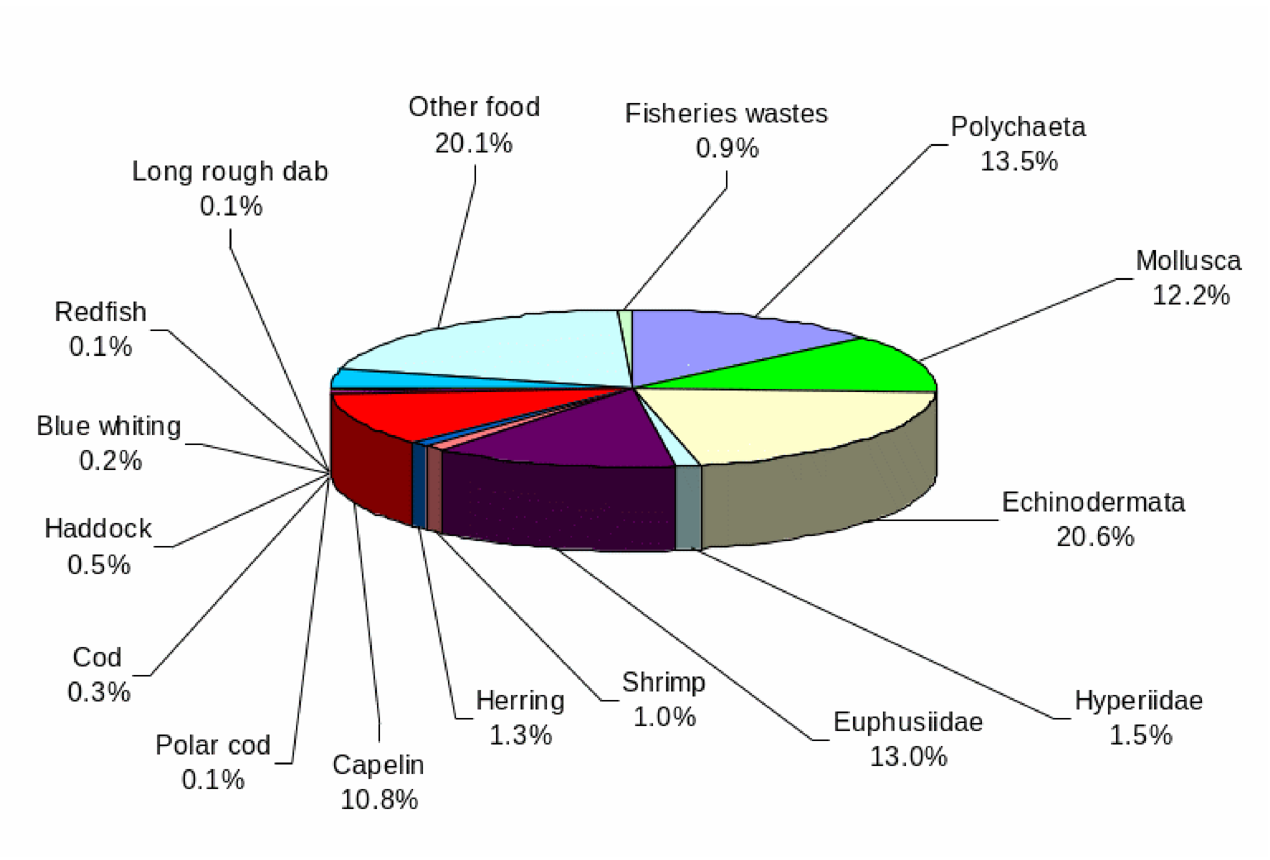

Figure 1. Diet composition of haddock in 1984-2023, % by weight.

Strong seasonal variations in feeding intensity and diet composition of haddock were observed from 1993 to 2023. Generally, the lowest feeding intensity (characterized by a low mean fullness index (MFI) and a high percentage of empty stomachs) occurred during winter when haddock primarily fed on comb jellies and benthos. In spring, haddock intensively fed on pre-spawning and spawning capelin. Summer and autumn were characterized by moderate feeding on various benthic organisms, with increased consumption of post-spawning euphausiids in summer.

Long-term analysis of diet composition (1984-2023) revealed significant variations in the importance of capelin and euphausiids (Figure 2). The weight proportion of capelin in the haddock diet correlated with capelin stock biomass until 2005 (coinciding with the third collapse of the capelin stock). However, this relationship weakened during 2006-2023. Interannual variations in the importance of benthos (polychaetes, molluscs, and echinoderms) had been relatively small after 2005 and their weight proportions has remained stable. From 1993 until present, the general trend has been an overall increase in benthic prey and decrease in plankton and fish prey (Figure 3). Parts of this variation might be due to differences in sampling (area and season) as well as changes in the haddock stock structure and distribution.

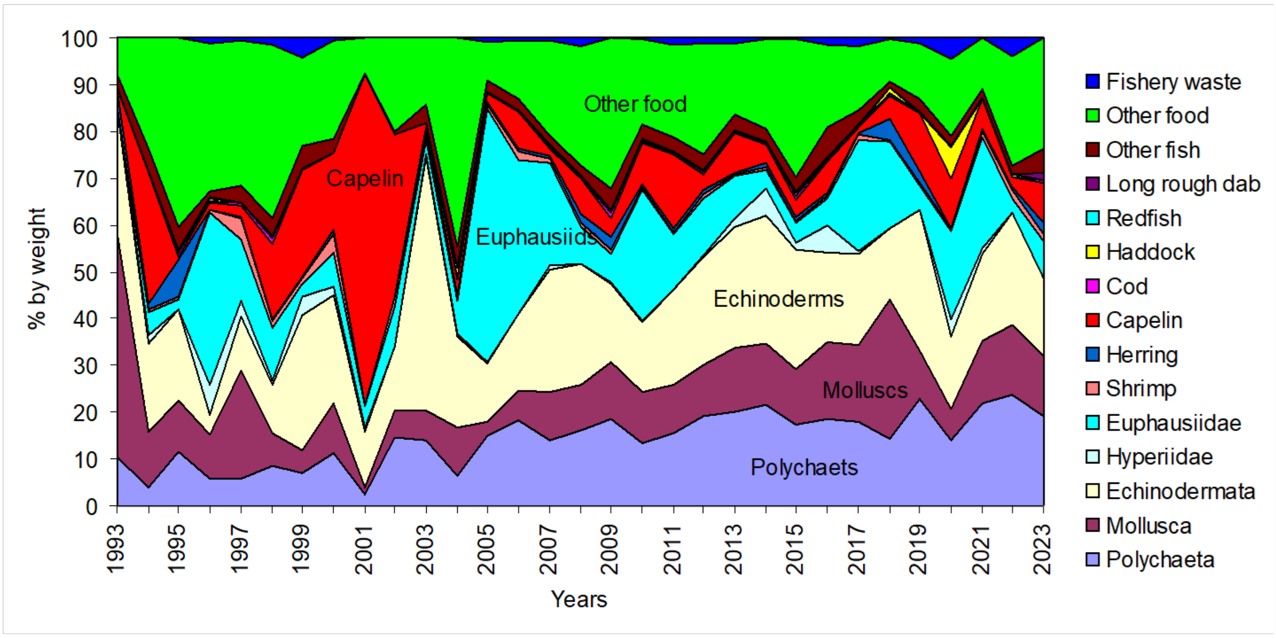

Figure 2. Interannual variation of main prey groups in haddock diet in 1993-2023, % by weight

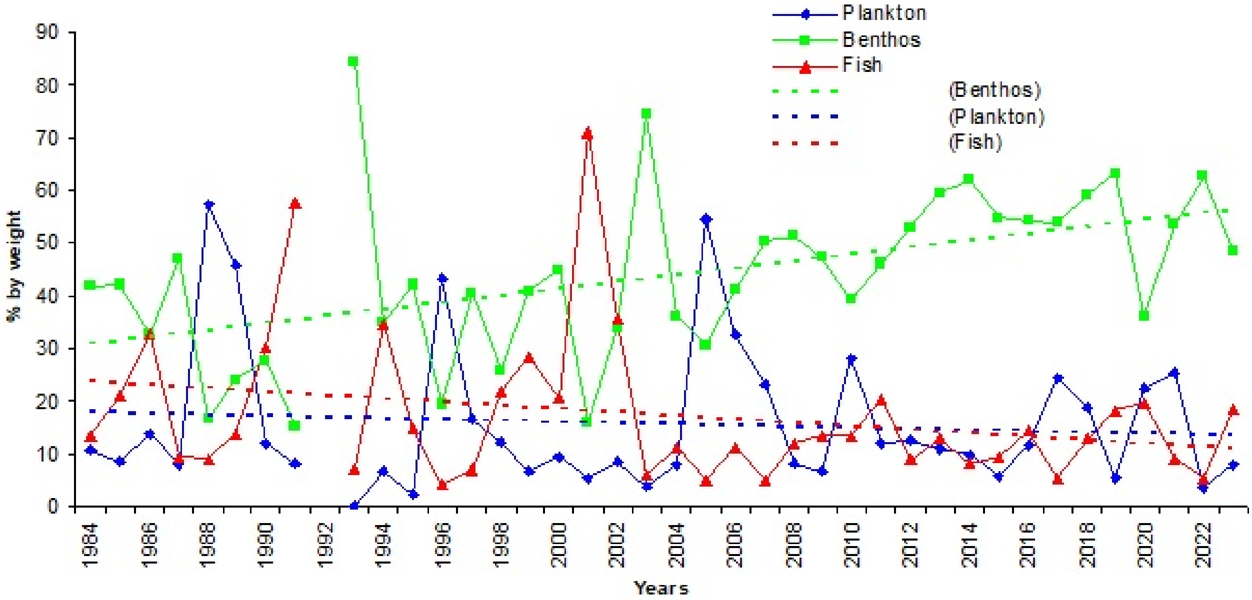

Figure 3. Interannual variations of benthos, plankton and fish in haddock diet in 1984-2023, % by weight.

Haddock is primarily a benthivores species, but macroplankton (such as euphausiids) and fish (like capelin) become important food sources in certain seasons. While haddock feed on various commercially important fish and invertebrates, their predation impact on these species is relatively low compared to other fish predators in the Barents Sea

1.7 - Predator-prey interactions in response to changing prey abundance: The case of Barents Sea cod (*Gadus morhua*) and capelin (*Mallotus villosus)*

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Abstract

The ecological relationship between predators and prey is complex, dependent on several factors, including, their relative abundances, spatial overlap, competition, density dependence and environmental conditions, which can, for example influence the ability of predators and prey to detect one another. Furthermore, individual body size and the bioenergetic needs of the predator can also have consequences for predator-prey dynamics. Additionally, predators, including generalists, can also have apparent preferred sources of prey which dominate their diets. Apparent prey preference is defined as the likelihood that a certain prey will be selected over another. If the abundance of an apparent preferred prey species becomes low it may considerably change predator-prey interactions, having consequences for food-web dynamics and ecosystem structure.

We present a novel investigation of predator-prey dynamics when apparent preferred prey is low using a major North Atlantic predator, Barents Sea cod (*Gadus morhua*), as predator, and capelin (*Mallotus villosus*) as 'apparent preferred' prey. We ask the question: *what do you do if you can't forage on your apparent preferred prey?* We explore whether diet is reflective of main prey availability, as well as apparent prey preference over time. We further examine the relationship between cannibalism and the abundance of apparent preferred prey.

Studying predator-prey dynamics and apparent prey preference in real-time, in the wild is inherently difficult, it often requires information on prey abundance, and prey availability. A commonly used solution however is by using diet data. High-resolution stomach contents sampled on a regular long-term basis can provide information on the long-term variability of species diet, allowing apparent prey preferences to be quantified and, if the spatio-temporal resolution of the data is high, provide information on the relationship between predators and prey.

For this study we use one of the most spatio-temporally comprehensive and diverse stomach content datasets existing. It spans 4 decades and encompasses over 380 000 stomachs for the economically and ecologically important Atlantic cod (*Gadus morhua*) stock in the Barents Sea (Mehl and Yaragina 1992; Dolgov et al. 2007; Holt et al. 2019; Townhill et al. 2020).

Manly-Chesson's selectivity index was used to quantity apparent prey preference over time and across different cod size classes. Stomach fullness indexes were used to quantify temporal prey importance and linear models were used to examine the relationship between the abundance of apparent preferred prey and cannibalism.

In response to low capelin density, we find evidence of prey-switching. Apparent prey preference is complex for Barents Sea cod, with differences observed between size-classes. We find no significant relationship between capelin biomass and cannibalism using stomach content data, refuting hypotheses to the contrary. We find that Barents Sea cod can be specialist foragers, but when apparent preferred sources of prey are low, they switch to more opportunistic foraging.

The complexities of Barents Sea cod predator-prey dynamics are likely paralleled to other predators in the Barents Sea and beyond, and detailed diet information should not be overlooked when studying predator-prey interactions in response to changing prey availability.

Keywords: Cannibalism · Cod · Predator-prey interactions · Preference · Prey availability

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1.8 - Long-term dynamics of liver condition indices of gadoid fish in the Barents and adjacent seas: influence of forage and climatic conditions

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Extended abstract

Long-term series of hepatosomatic indices (HSI) of arctic and boreal gadoid fishes inhabiting the Barents and adjacent seas are considered. Seasonal and interannual fluctuations of HSI in fish of different sizes/ages are shown. The HSI have been compared with the indicators of fish feeding conditions (frequency of occurrence and weight portions of capelin and herring in the diet of cod, haddock and saithe, as well as of copepods and euphausiids in the diet of polar cod and blue whiting) to find out their synchrony during cold and warm oceanographic periods. A gradual decrease in the HSI for cod, haddock, saithe, blue whiting and polar cod in the 2000s – 2020s has been observed, which is opposite to the heat content of water masses trend in the Barents Sea.

Keywords: cod, haddock, saithe, blue whiting, polar cod, nawaga, the Barents Sea, hepatosomatic index

The Barents Sea and adjacent waters are regions where great climatic changes have taken place in recent years (Trofimov , Ivshin, this issue). These changes may have affected the ecosystem of the Barents Sea and, in particular, gadoid fish populations. Several species of gadoid fish inhabit this area, and some of them, like cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), saithe (*Pollachius virens*), blue whiting (*Micromesistius poutassou*), polar cod (*Boreogadus saida*) and nawaga (*Eleginus nawaga*) are target species of traditional commercial fisheries. A number of biological features of fish (e.g. size, length, condition etc.) can be indicative of the state or “health” of their stocks. Gadoid fish are known to store their energy resources mostly in the liver (Lloret et al., 2013) and the hepatosomatic index, HSI (or liver condition index), can be used as an indicator of both physiological state of fish (Eliassen, Vahl, 1982; Hemre et al., 1993; Lambert, Dutil, 1997) and the influence of environmental conditions on them (Yaragina, Marshall, 2000).

The database of PINRO has long-term time series of the liver condition index for a number of gadoid fish, however, with different temporal resolution. Most of the data available are for cod and haddock, while the data for nawaga are scarce. The investigated species belong to different zoogeographic groups. Their depth and temperature preferences are different as well as those of diet composition and habitats, migration cycles and life histories. However, all of them are neighbors residing in the Barents Sea and adjacent waters and possibly, they undergo the same changes of global climatic conditions.

HSI is calculated as the ratio of the liver weight to the fish body weight in percent. As for the species studied, this index proved to be the highest for polar cod and blue whiting, whereas it was the lowest for nawaga and haddock (Table 1).

Table 1. Minimal, maximal and mean values of HSI of the Barents Sea gadoids

Species	**Maximal fish size, cm**	**Average HSI, %**	**Min HSI, %**	**Max HSI, %**
Cod	~140-150	5.2	3.5	7.1
Haddock	100-110	4.4	3.0	6.4

Saithe	120-130	6.2	2.4	9.1
Blue whiting	50-55	5.6	1.2	10.2
Polar cod	35-40	7.5	2.3	11.7
Nawaga	37-42	3.4	2.5	4.1

A tendency towards HSI changing by fish age/size is approximately the same for all the species investigated. The mean index has been found to grow with the age of a specimen or with the increase in its length and weight. The most pronounced tendency towards HSI increasing was observed for cod and haddock, whereas for saithe and nawaga it was less marked (Figure 1).

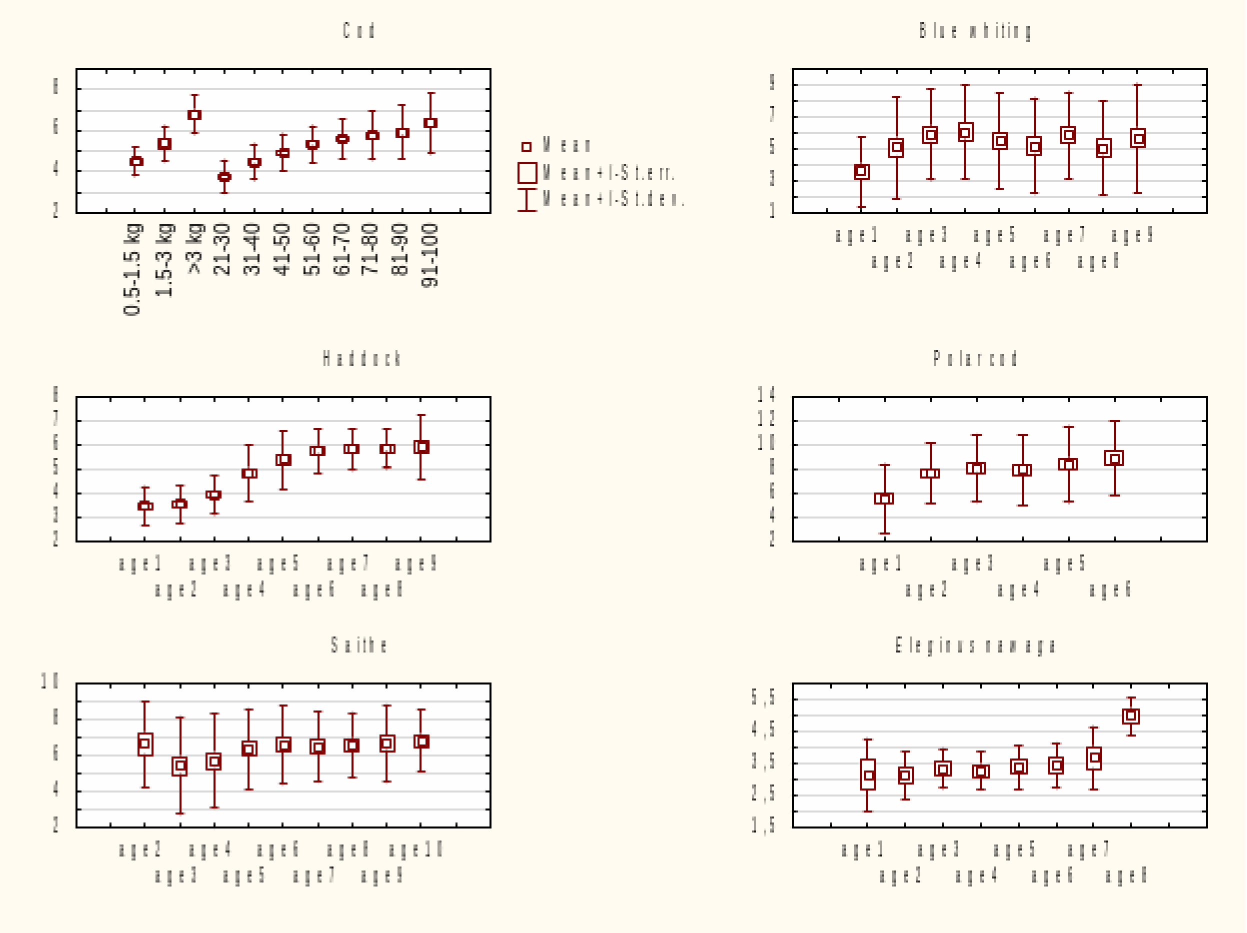

Figure 1. Mean HSI (with standard errors and standard deviations) for the Barents Sea gadoids by size/age in 1927-2020 (the cod data for the 1920s-1940s by weight are taken from Sobolev, Bulashevich, 1952)

A gradual decrease in the HSI indices for all investigated species, except nawaga, was observed in the 2000s – 2020s (Figure 2).

Figure 2. Interannual dynamics of mean HSI values (%) for gadoids in 2000-2020 and its linear trends

No evident similarities in the long-term HSI dynamics of the investigated gadoids species from various zoogeographic or trophic groups were observed. This may result from the peculiarities of their ontogenetic and migration cycles that can affect their energy storage strategies. It can also be an indicator of trophic and/or ecological differentiation among these gadoid fish in the Barents Sea in the course of an evolutionary process.

At the same time, a tendency towards the decline of HSI is similar for the most of considered species. It is opposite to the heat content trend of water masses in the Barents Sea, which may be related to a greater expenditure for maintaining energy balance of fish at the increasing temperature. Also, longer distances of feeding/spawning migrations observed in recent years (Trofimov et al., 2023) could contribute to further expending of energy reserves.

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1.9 - Feeding ecology of harbour porpoises in Norwegian coastal communities

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Abstract

The diet of harbour porpoises in Norwegian coastal waters was studied by analyzing stomach contents and stable isotope samples of 134 animals by-caught in gillnets in 2016 and 2017. Results suggest that harbour porpoises display ontogenetic shifts in feeding, both short-term (stomach contents) and long-term (stable isotopes). The diet of the calves differs from the juveniles and adults, and the lower δ13 C may suggest that they use different habitats than the juveniles and adults. Also, the study showed some spatial heterogeneity in diets but in contrast to the 1980s, where their diets were dominated by capelin, haddock, herring and saithe, the diets in this study was completely dominated by saithe. With a total abundance north of N62 ^{o} of 39751 and a daily energy consumption of 7.1% of their body mass, the total annual prey consumption was estimated to 41,000 tonnes (CI $_{95}$:18-68,000) where 64% (26,000 tonnes) was saithe and 9% herring (~4,000 tonnes). As such, it is concluded that harbour porposes may be regarded as an intermediate important predator along the coast and as such may play an important role structuring coastal ecosystems.

1.10 - Inference for causal relationships among balaenopterids and their prey using categorical data analyses

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Abstract

Several balaenopterid whale species migrate annually to high latitudes during spring and summer to utilize the increased seasonal productivity. Recent climate change in the polar regions have affected spatial distributions of both zooplankton and fish species known to be potential prey for baleen whales. Investigating the directional association among balaenopterids and their prey is important for assessing causality in their trophic interactions in the ecosystem. For this purpose, a relevant and practical statistical method is required to assess spatial overlapping of whales and prey concentrations. Multivariate observational data are often collected over too short a period for time series analysis, or too sparse for applying spatial statistical models. To meet this challenge, we provide an approach based on applying categorical data analysis to present/absent observations and data based on the real-numbers observed. Such real-number data used as explanatory variables for the present/absent response variable are discretized based on the optimal detection of thresholds without any prior biological/ecological information. This approach is implemented in the previous statistical method called CATDAP developed by Sakamoto and Akaike in 1979. Our proposed approach consists of a two-step procedure for categorical data analysis: (1) finding the appropriate threshold to discretize the real-number data for applying an independent test; and (2) identifying the best conditional probability model to investigate the possible associations among the data based on a statistical information criterion. We perform a simulation study to validate our proposed approach and investigate whether the method's observation includes many zeros (zero-inflated data), which can often occur in practical situations.

The approach is applied to the data sets collected during the SI-ARCTIC surveys (https://www2.whoi.edu/staff/pwiebe/projects/si-arctic/) to the west and north of Svalbard in 2014-2017 to investigate directional associations among common minke whales, the predatory fish Atlantic cod, and their main prey groups (zooplankton, 0-group fish). Consequently, the best model for minke whale includes zooplankton and Atlantic cod; the best model for zooplankton includes minke whale and Atlantic cod; the best model for Atlantic cod includes zooplankton and 0-group fish; and the best model for 0-group fish includes zooplankton and Atlantic cod. Our approach supports the idea that zooplankton and Atlantic cod are associated with 0-group fish. The 0-group is normally associated with the epipelagic zone, where they consume zooplankton, and the 0-group includes cod as well as redfish, haddock, capelin, and herring. For minke whale, while a relationship with zooplankton is not directly shown, the directional relationship from zooplankton to 0-group fish has already been shown. Results from proposed approach also support the existence of a link between cod abundance and feeding conditions, such as food competition, for other top predators.

Link to the electronic version of the published article:

[Categorical data analysis using discretization of continuous variables to investigate associations in marine ecosystems - Solvang - 2024 - Environmetrics - Wiley Online Library]

2 - THEME SESSION II: MIXED FISHERIES AND BYCATCH

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2.1 - Mixed fisheries and bycatch

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Extended abstract

In order to discuss the reasons behind bycatch, definition of this and related concepts are needed. Bycatch is the unwanted fish, crustaceans and other marine creatures such as marine mammals caught during commercial fishing targeting other species (could be both wanted and unwanted by fishermen). Wanted bycatch is bycatch of commercially valuable species/stock, allowed to fish (in some cases the bycatch may be even more valuable, at least as price per kg, than the target species) (e.g. bycatch of Greenland halibut, crabs). Unwanted bycatch is bycatch of a species/stock which either has no or negligible value (e.g. of juvenile fish in shrimp fishery in the Barents Sea), or of a protected/endangered species/stock (e.g. marine mammals).

Fish, clams and crustaceans below minimum landing size of a target species could also be considered as bycatch in direct fishery for these species. Mixed fishery is fishery where more than single species/stock is targeted (e.g. cod/haddock in the Barents Sea). Bycatch occurs because species of same size are found in the same area and due to low selectivity of fishing gears. In some cases fish of the same species or with very similar appearance are caught together, and when the stock status is different for the involved species, bycatch of one of them should be minimized (e.g. Sebastes species, Northeast arctic cod vs. coastal cod).

Bycatch in many instances causes discards of both commercial and non-commercial species. It leads to loss of possible future catch, wrong fishery statistics, in some cases – to ecosystem disturbances.

Among the types of restrictions introduced to minimize bycatch are minimum size, % bycatch limit, closed areas, gear restrictions, spatial and temporal restrictions.

Sorting grids with 55 mm between bars are mandatory in the bottom trawl fishery for cod, haddock, gr. halibut and saithe in the Barents Sea. In the shrimp fishery 19 mm grid size is used.

In the Barents Sea, there are minimum landing size and mesh size regulations for most large fish stocks. Also, there are limitations on % of undersized fish allowed, bycatch regulations for juvenile fish in the shrimp fishery, and permanent as well as temporal/seasonal area closures.

A brief history of regulation measures for the bottom trawl fishery for gadoids and shrimp in the Barents Sea is given in the table below:

Year	Fishery regulation measures

1946	Restriction of min. allowed mesh size for trawls 80/90 mm
1961	Restriction of min. allowed mesh size for trawls 110 mm
1963	Restriction of min. allowed mesh size for trawls 120/130 mm
1978	Limitation of annual TAC* (trawl fishery only)
1981	Restriction of min. allowed mesh size for trawls 125 mm
1982	Restriction of min. allowed mesh size for trawls 135 mm**
1983	Limitation of annual TAC (all fishing gears)
1984	Limitation of juvenile cod bycatch during shrimp fishery
1992	Limitation of juvenile cod bycatch during capelin fishery
1993	Obligatory use of sorting grid during shrimp trawl fishery
1997	Obligatory use of sorting grid during cod trawl fishery
2011	Unified regulations of min. allowed mesh size for trawls 130 mm

- * cod only
- **Norwegian EEZ only

2.2 - Morphological evidence supports splitting of species in the North Atlantic *Sebastes* spp. complex

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Abstract

The redfishes (genus *Sebastes*) are long-lived, commercial species in the North Atlantic. Excessive harvest through decades has led to a decline in the mature population of golden redfish (*Sebastes norvegicus*) in Norwegian waters, which is currently considered severely depleted. Accumulating genetic evidence suggests a more complex structure within this genus in the North Atlantic, which has recently inspired the hypotheses of cryptic species within *S. norvegicus.* Despite apparent genetic divergence between two types, they have yet to be verified morphologically. The morphology of genetically assigned fishes from Norwegian and Greenland waters was investigated using traditional morphometric methods, applying Linear Discriminant Analysis and Random Forest classification procedures to identify and evaluate the performance of descriptive characters. Combined with non-parametric meristic analysis, the results show that features such as beak length and eye diameter provide sufficient discrimination between the proposed cryptic species as well as separating them from the sympatric species *S. mentella* and *S. viviparus* . These findings support the presence of an additional redfish species in the North Atlantic, distinguishable both by morphological and genetic characters. This needs to be taken into consideration in future monitoring and management strategies for North Atlantic redfish.

2.3 - Impact of mixed fishery on the stock dynamics of the Norwegian-Barents Sea golden redfish (*Sebastes norvegicus*)

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Short communication

Abstract

The aim of the study was to evaluate the impact of changes in mixed fishery of bottom fish on bycatch of golden redfish of the Norwegian-Barents Sea population. The study shows the dynamics of golden redfish bycatches in the Russian fishery of bottom fish in the Barents Sea and adjacent waters in 2001-2020. Spatial distribution, size and species composition of catches containing golden redfish were considered. The study provides the analysis of length distribution of the golden redfish in commercial catches and fishing effort. The study suggests that the increase of golden redfish yields in 2016-2020 was primarily due to greater fishing effort rather than stock recovery. This was caused by the reopening of direct fishery for beaked redfish that form mixed concentrations with golden redfish. Bycatches of golden redfish in recent years increased also due to shorter feeding migrations of cod to the northern and north-eastern Barents Sea. This led to an increased overlap of cod fishery areas with distribution of golden redfish.

Key words: golden redfish *Sebastes norvegicus* , mixed fishery, fishing mortality, bycatch, fishery management, Barents Sea.

The golden redfish (*Sebastes norvegicus*) of the Norwegian-Barents Sea population inhabit the area along Norway's northwest coast and the continental slope to the Spitsbergen archipelago. In the eastern Barents Sea its distribution extends to the Kanin Bank, Goose Bank, and Novozemelskaya Bank (Zakharov et al., 1977; Drevetnyak et al., 2011). Its distribution area may change depending on water temperatures. The golden redfish is a bentho-pelagic species characterized by daily vertical migrations. It inhabits depths to 300-350 metres (Zakharov et al., 1977; Barsukov et al., 1986). Mature individuals undertake feeding, spawning, and wintering migrations (Barsukov et al., 1986; Drevetnyak et al., 2011). The golden redfish is a slow-growing and long-lived species. It becomes mature at approximately 10 years old at 30-35 cm length (Zakharov et al., 1977).

By ICES estimates, the total biomass of the golden redfish stock has decreased from 120.0 to 40.0 thousand tonnes since the early 1990s (ICES, 2020) as a result of a long period of poor recruitment combined with excessive fishing mortality. Since 2003, due to the depressive state of the stock, direct fishery for golden redfish has been prohibited. It is allowed to be caught only as a bycatch.

In recent years, despite the ban on direct fishery of golden redfish, an increase in its catch was observed. From 2015 to 2020, the international catch increased from 3.6 thousand tonnes to 9.0 thousand tonnes, and the Russian catch, from 0.7 thousand tonnes to 2.6 thousand tonens (ICES, 2020). For the evaluation of the stock recovery strategy it is crucial to reveal the reasons behind the increased catches of golden redfish despite the ban on direct fishery. This may be a consequence of positive trends in the stock dynamics and changes in mixed fishery, leading to a concomitant rise in bycatch of golden redfish. In the latter case, the increase in the golden redfish catch could be associated with an increased fishing pressure.

The aim of this study is to investigate the effects of changes in mixed demersal fishery on the bycatch dynamics of golden redfish in the Norwegian and Barents Seas.

Material and methods

The study applies the Russian fisheries statistics for 2001-2020. We analyzed the distribution, size, and species composition of catches that contained golden redfish. The quantity and duration of fishing operations were also examined. Catches in which beaked redfish and golden redfish were not separated were not analyzed. Bycatches of golden redfish were classified into two categories: less than 5% and more or equal to 5% of the total catch biomass.

Data on the length composition of golden redfish in commercial catches were collected by PINRO observers. Total length, including the spread caudal fin (zoological length), was measured with an accuracy of 1 cm. Approximately 300 golden redfish were randomly selected from catches for length measurement. A total of 79090 specimens of golden redfish from commercial catches were measured in 2001-2020. These data were combined by five-year periods.

Results and discussion

During 2001-2020, golden redfish was by-caught by Russian commercial vessels in trawl and longline fisheries of demersal fish. Catches were mainly taken by bottom trawls. Cod constituted the majority of catches containing golden redfish. The second most significant target was haddock. At the same time, the proportion of haddock increased if not all catches containing golden redfish were considered, but only those where its bycatch made up 5% or more of the total catch biomass (Table 1).This suggests that areas with a higher density of golden redfish distribution demonstrated larger overlap with haddock fishing areas in comparison with its general distribution. For cod, no such trend was identified. The share of beaked redfish in catches containing golden redfish had been insignificant until 2015. However, after the re-opening of direct fishery for beaked redfish, its share in catches containing golden redfish increased sharply (Table 1).

Table 1. Species composition of catches (%) with golden redfish bycatch averaged by 5-year periods*

Species / Period	2001-2005	2006-2010	2011-2015	2016-2020
Cod	68.9 (53.4)	59.1 (45.1)	65.5 (47.5)	68.5 (58.3)
Haddock	15.1 (21.4)	25.5 (34.3)	23.7 (26.6)	18.7 (22.8)
Saithe	3.6 (4.6)	6.0 (4.8)	3.5 (12.1)	5.2 (4.6)
Beaked redfish	0.1 (0.2)	0.2 (0.1)	0.2 (0.3)	2.0 (0.8)
Golden redfish	3.6 (12.1)	3.5 (10.6)	1.6 (9.2)	2.1 (9.9)
Other	8.7 (8.5)	5.9 (5.3)	5.8 (4.7)	5.6 (4.5)

*– catches with the portion of golden redfish of 5% or more by weight are shown in parentheses.

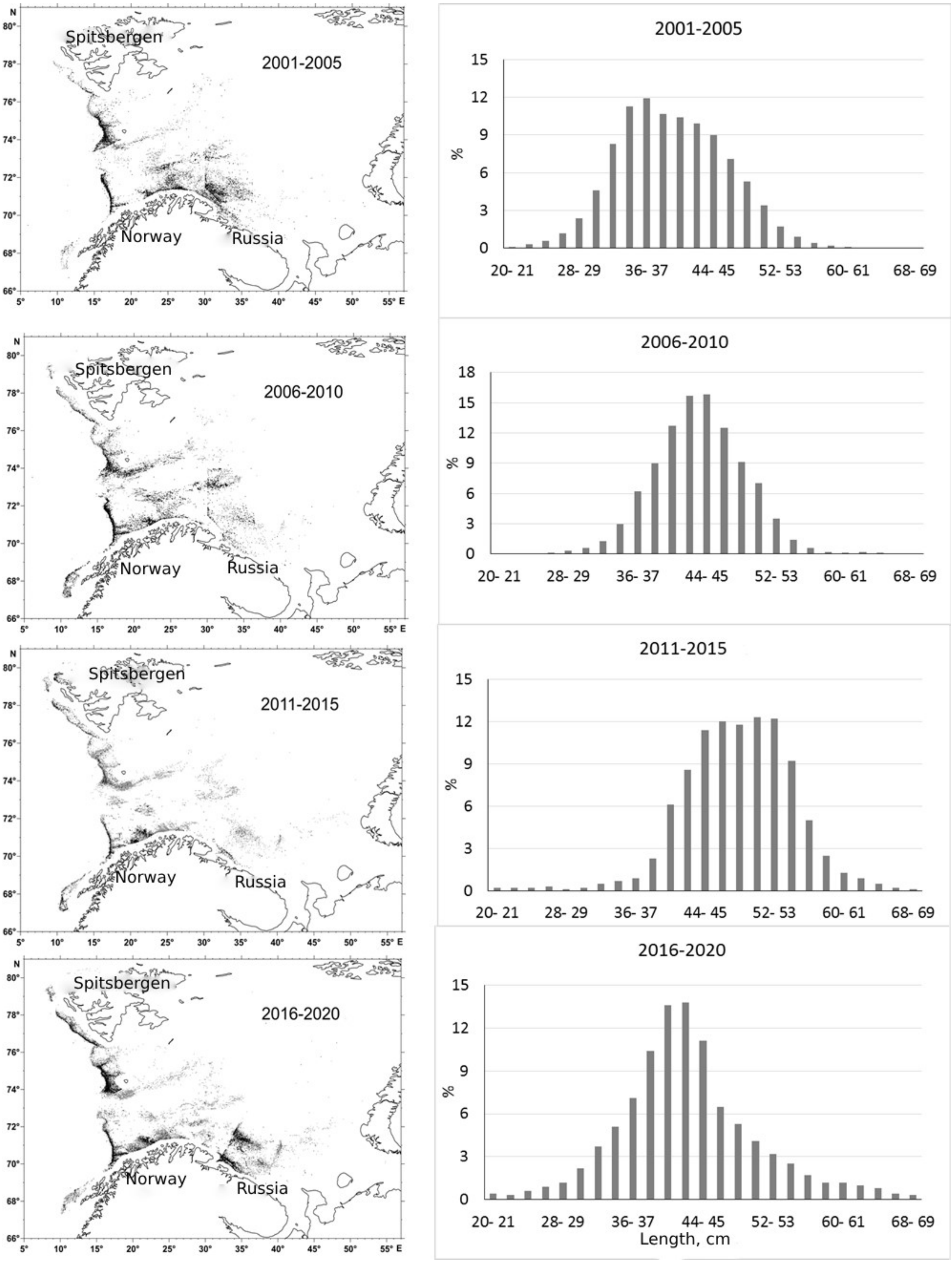

Figure 1. Distribution of golden redfish catches and its length composition in different periods.

The area where golden redfish bycatches were taken did not change in 2001-2020 (Figure 1). However, in 2001-2005 and 2016-2020, the frequency of golden redfish occurrence in catches of fishing vessels in the southeastern part of its distribution area was higher than in 2006-2015. This was apparently caused by a change in the length composition of golden redfish in catches. In 2006-2015 the portion of young fish was less than in 2001-2005 and 2016-2020 (Figure 1). Aggregations of young fish occur primarily in the southeast of the distribution range, while large mature fish migrate to longer distances in the northwest. Larger portion of young individuals in 2001-2005 and 2016-2020 as compared to 2006-2015 made an impact on the spatial distribution of golden redfish bycatch.

The number and duration of fishing operations with golden redfish bycatch varied throughout the years. The lowest fishing effort was observed in 2003, and the highest, in 2020 (Figure 2). The increase in the fishing effort from 2015 to 2020 coincided with a rise in the catch of golden redfish. Changes in the fishing effort generally depended on the Russian cod and haddock quotas and harvesting rates, as well as on the overlap of golden redfish distribution with cod fisheries areas.

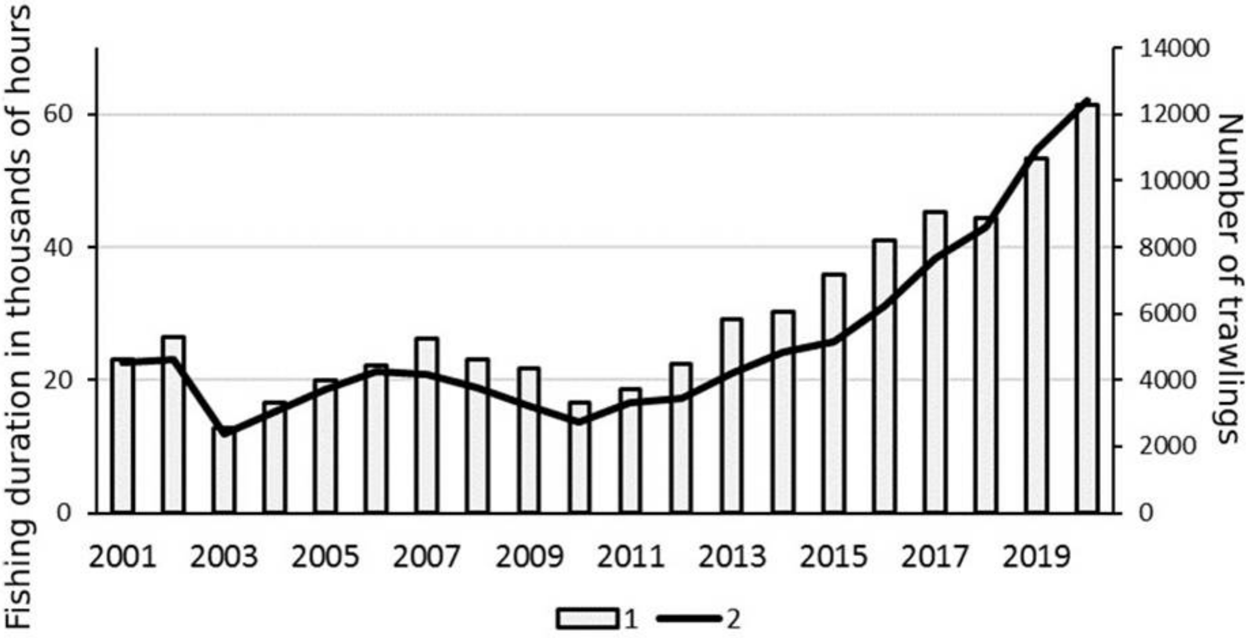

Figure 2 . Fishing effort in golden redfish fishery by Russian commercial vessels in 2001-2020: 1 — duration of fishing activities, 2 — number of fishing operations.

In 2001-2016, a correlation between the interannual changes in Russian annual catches of golden redfish and cod with the portion of these species in joint catches was found (Figure 3). This relationship, however, was not observed in the subsequent years. In recent years, the catch of golden redfish demonstrated a relative increase compared to the total catch of cod, which did not affect the ratio of these species in joint catches. This is because since 2017 the increase in the golden redfish catch was accompanied by an increase in the portion of cod catches with golden redfish bycatch (Figure 4). Therefore, the portion of cod in mixed catches did not decrease despite the declining total cod catches.

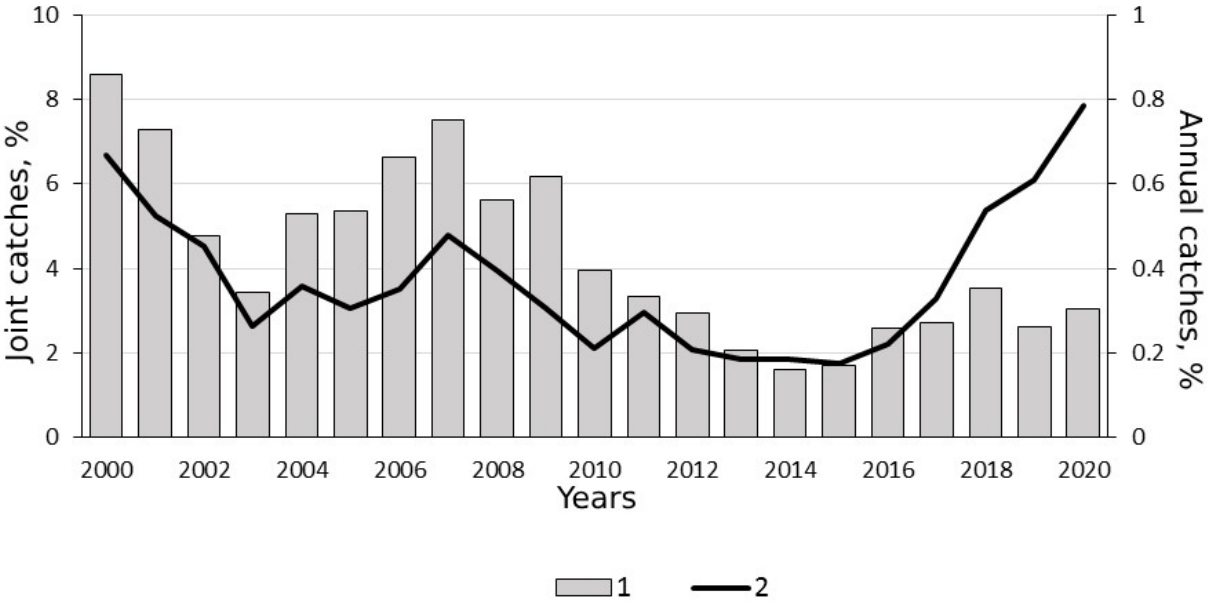

Figure 3. Portion of golden redfish and cod in Russian catches: 1 — in mixed catches of cod and golden redfish, 2 — annual catches of cod in comparison with golden redfish.

The increased occurrence of golden redfish in cod catches in 2017–2020 was also due to the increased overlap of its distribution areas with cod fishing grounds. This resulted from changes in the feeding migration patterns caused by the cod stock decline, with a shorter duration and smaller extent of cod migrations to the north and northeast of the feeding area, where golden redfish do not occur (ICES, 2021).

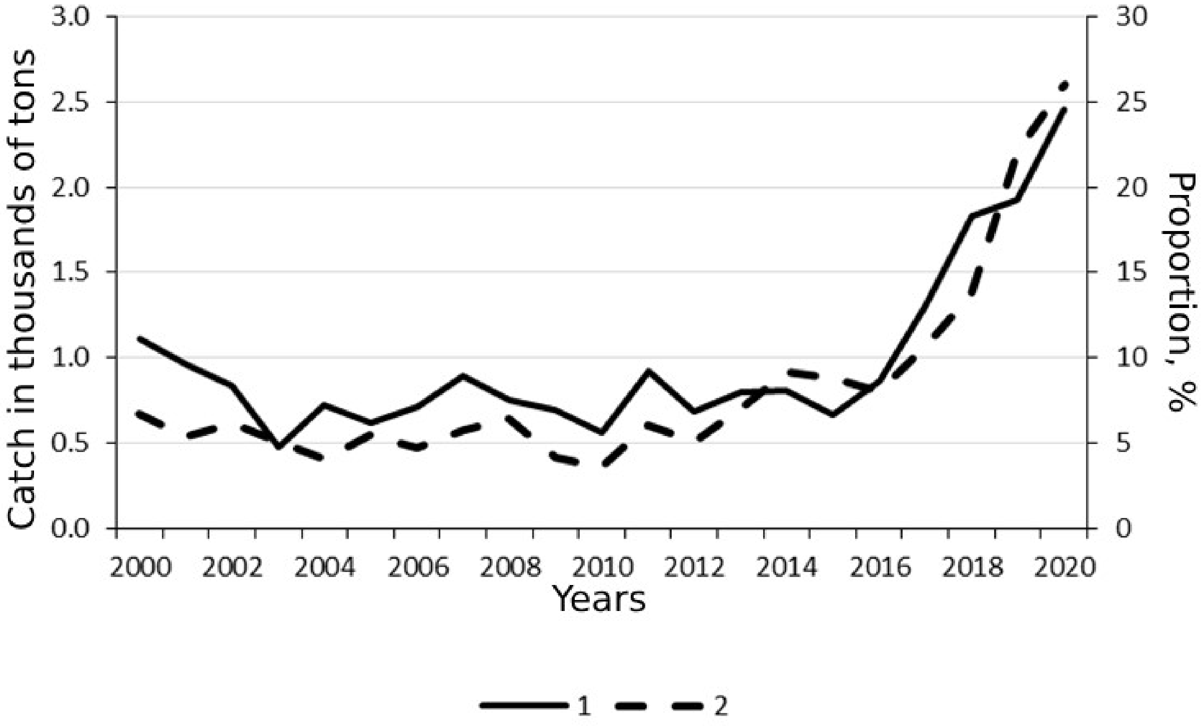

Figure 4. Catch of golden redfish compared to the frequency of its occurrence in cod catches: 1 — Russian catch of golden redfish; 2 — portion of cod catches containing golden redfish bycatch.

However, the main reason for the sharp increase in the golden redfish bycatch in 2017–2020 was apparently the reopening of the beaked redfish fishery due to the stock recovery. It was confirmed by the multiple increase of the beaked redfish portion in catches containing bycatches of golden redfish in 2016–2020 (see Table 1). Spatial distribution of both species is largely the same (Barsukov et al., 1986). The beaked redfish prefers greater depths than the golden redfish, but in the cod fishing areas on the slopes of the Spitsbergen archipelago and in the Norwegian Economic Zone, both species occur together.

Conclusion

The multispecies approach to the analysis of golden redfish catches used in the study allows to conclude that the increase in its bycatch in mixed fishery of bottom fish in 2016-2020 was primarily due to an increased fishing effort rather than stock recovery. Shorter extent of cod feeding migrations to the northern and eastern Barents Sea following the reduction in the stock size contributed to the increased fishing pressure on golden redfish in 2016-2020. This resulted in a larger overlap between cod fishing areas and the distribution of golden redfish. However, the growth of golden redfish bycatch in 2016-2020 was mainly caused by changes in the multispecies fisheries management rather than by natural factors. The re-opening of the directed fishery for beaked redfish permitted the fishing vessels with a quota for that species not only to increase the fishing time for golden redfish, but also to fish on the densest concentrations, because the limitation of redfish bycatch (20% for both species, beaked and golden) in the gadoid fishery started to apply to golden redfish only.

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2.4 - Gaussian mixture models reveal highly diverse targeting tactics in a coastal fishing fleet

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Abstract

Fishermen make repeated choices with respect to when, where, and how to catch their target species. While these targeting tactics—and the factors shaping them—are known to fishers and some experts, knowledge about them is largely informal and not well utilized for management purposes. To formalize information on targeting tactics, we propose a set of methods combining model-based classification of target species with generalized linear models. We apply these methods to Norwegian coastal fishing vessels that caught Atlantic cod (*Gadus morhua*) as a part of their catch portfolio in 2019. The data contains nearly 32 000 fishing trips by 761 vessels. Gaussian mixture models identify eight latent targeting tactics. Cod contributes significantly to three of the tactics. The Herfindahl–Hirschman Index, a measure of vessel-level diversity of tactics, shows that one quarter of the vessels had a specialized strategy (targeting cod plus at most one additional tactic). While cod is often studied as a single-species fishery, we show that cod-catching vessels can be engaged in relatively pure fisheries during some fishing trips but switch to different, often more mixed targets during other trips. We term this as “sequential mixed fisheries”. This is both a challenge and an opportunity for the fisheries management.

Keywords: cluster analysis, finite mixture model, fisher behaviour, fishing tactics, generalized linear model, métier choices, mixed fisheries management.

Published as

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2.5 - Species composition and length distribution in Norwegian catches fished with small-meshed trawl for the target species Norway pout (*Trisopterus esmarkii*) and blue whiting (*Micromesistius poutassou*) in the North Sea during 2014-2019

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Directorate of Fisheries, Bergen, Norway

Abstract

The Directorate of Fisheries (FDir) carried out 9 cruises on board 9 different vessels during 2014-2019 in order to investigate the species composition and length distribution in the Norwegian industrial fishery with small-meshed trawl for the target species Norway pout (*Trisopterus esmarkii*) and blue whiting (*Micromesistius poutassou*). Six of the vessels fished with small-meshed trawl without grid and were also rigged to produce fish for human consumption. The remaining vessels fished with small-meshed trawl with grid. Seven cruises were carried out in Norway's economic zone south of 62 □ N whereas two cruises were carried out in the EU-zone in the North Sea. Data from the electronic catch reporting (ERS) and sales notes were also used in the further data analyses.

A total of 73 different species/categories were registered on all the cruises, while only 22 species/categories were given on the nine sales notes from the cruises. In each of the 9 cruises, between 0.5 and 11.3% (0.8-36 tonnes) of the quantity in storage tanks was assigned to an incorrect species in the ERS, and on the sales notes between 1.1 and 12.8% (3.4-41 tonnes) of the quantity was assigned to an incorrect species.

The main difference between catches fished with small-meshed trawls with and without grid was that the maximum length of saithe (*Pollachius virens*) and European hake (*Merluccius merluccius*) in the catches was lower in small-meshed trawls with grid than without grid. The maximum lengths of saithe and European hake were 47 and 48 cm with grid and 65 and 62 cm without grid, respectively.

2.6 - The importance of accurate conversion factors for fish landings and catch statistics: achievements from the joint Norwegian-Russian cooperation on measurements and calculations of conversion factors from 1993 to 2021

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Extended abstract

One of the most important measures in fisheries regulation for jointly managed stocks of marine species within the framework of the Joint Russian-Norwegian Fisheries Commission (JRNFC) is to establish joint conversion factors when making products of marine biological resources (MBR). There is a strong relation between accurate conversion factors and reliable estimates of actual catches of marine species. Today, the Joint Russian-Norwegian Fisheries Commission includes the Permanent Russian-Norwegian Committee on Fisheries Management and Control, which, in its turn, consists of a Subcommittee and four Working Groups, including the Working Group on conversion factors that was established in 1993.

In 1993, the Working Group (WG) on conversion factors was established as one of the bodies of the Permanent Russian-Norwegian Committee for Fisheries Management and Control (the Permanent Committee). The WG aimed to develop Russian-Norwegian joint conversion factors for products made of the jointly managed stocks of marine species in the Barents and Norwegian seas. In nearly 30-year period of the WG’s activities, Russian and Norwegian scientists have conducted studies that aimed to develop and establish joint conversion factors for use onboard fishing vessels (more than 20 research cruises) and at fish processing plants and factories on land.

One of the key WG's activities was to develop “The joint Russian-Norwegian method of measuring and calculation of conversion factors for fish products produced on board fishing vessels”. The Permanent Committee adopted this method in 2013, and its implementation allowed the scientists to unify the requirements and approaches to the joint Russian-Norwegian studies on technological standardization and to obtain agreed data that satisfy both Parties.

According to the method’s requirements, a data sample obtained for a representative fishing period (for three recent calendar years) served as a basis to calculate the portion of fish caught in the main fishing areas in different seasons of the fishing year with a particular fishing gear.

The scheme for measuring and calculation of conversion factors is shown in Figure 1.

The objects of these studies were marine species from the Barents and Norwegian Seas as follows: cod (*Gadus morhua*) , haddock (*Melanogrammus aeglefinus*), Greenland halibut (*Reinhardtius hippoglossoides*) and beaked redfish (*Sebastes mentella*). The subject of these studies was the conversion factors for different types of edible fish products made of the above listed marine species.

This paper summarizes the results from Russian-Norwegian joint studies on measurements and calculations of joint conversion factors when making various types of products from the jointly managed stocks in the Barents and Norwegian seas from 1993 to 2021.

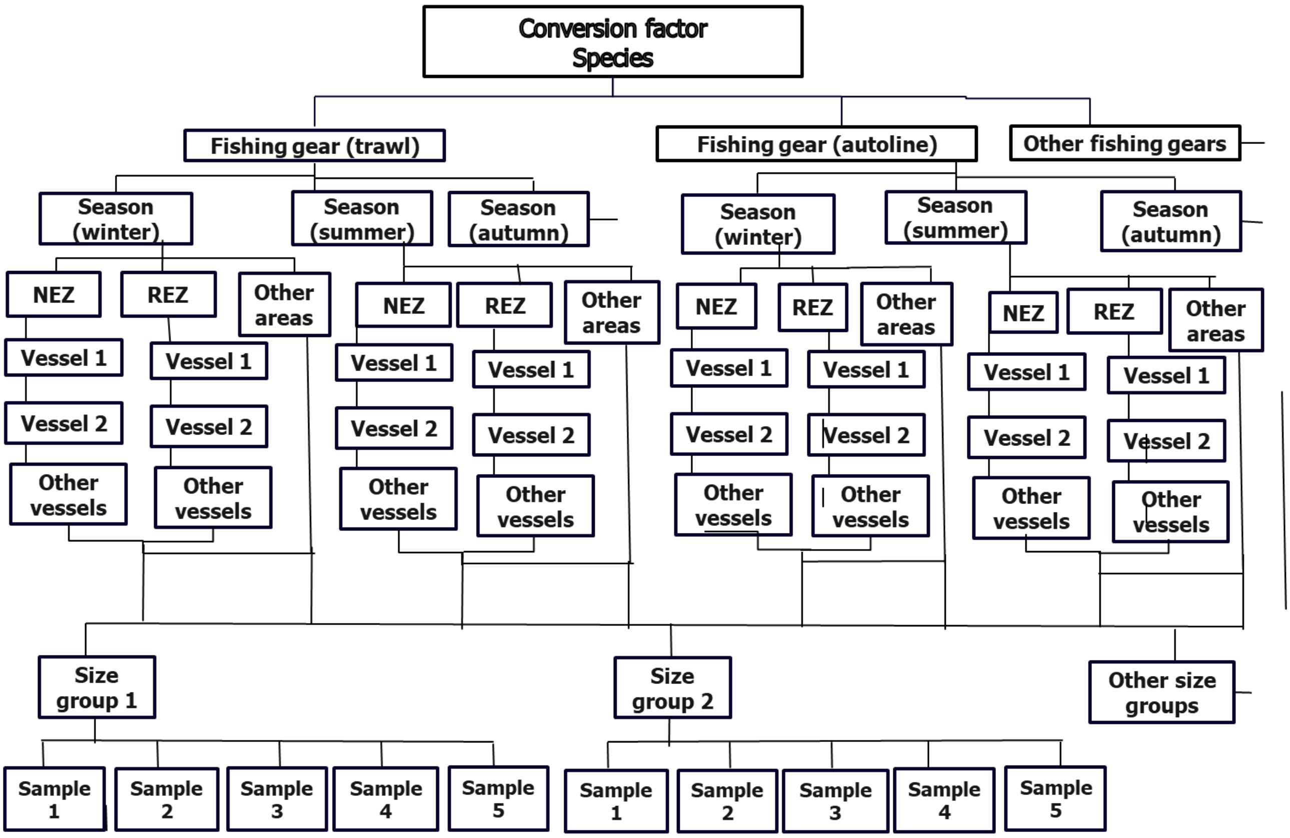

Figure 1. Scheme of measurement and calculation of conversion factors.

Joint research cruises conducted in different seasons of the fishing year in the Norwegian Economic Zone, the Exclusive Economic Zone of the Russian Federation, the water areas of Spitsbergen, the “Grey” zone and international waters of the Barents Sea, as well as joint studies at coastal fish processing plants and factories allowed the scientists to collect a unique statistical material and calculate conversion factors for various types of frozen products made of cod, haddock, Greenland halibut and beaked redfish. As research data was accumulated, the JRNFC adopted valid conversion factors, which are applied for the vessels from the Russian Federation, the Kingdom of Norway and third countries, and they contribute to an objective assessment of the removal of marine biological resources.

The disagreements between the Parties on understanding the degree and depth of processing of marine biological resources, which arose during their joint studies, resulted in the development of the Joint Russian-Norwegian Technical Descriptions for Products of Joint Stocks in the Barents Sea and Norwegian Sea. The document contains descriptions in three languages (Russian, English and Norwegian) of various types of cuts of frozen products made of cod, haddock, Greenland halibut and beaked redfish, as well as their pictures taken

during the studies.

Key words: Working group, cod, haddock, Greenland halibut, beaked redfish, joint conversion factors, products, jointly managed stock of marine species, fisheries regulation, the Barents and Norwegian Seas.

2.7 - On the red king crab bycatch and survival within bottom trawl fishery in the Russian part of the Barents Sea

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Short communication

Abstract

The red king crab (*Paralithodes camtschaticus* (Tilesius, 1815) is one of the bycatch species in the bottom-trawl fishery in the Barents Sea. *Paralithodes camtschaticus* was introduced into the Barents Sea in the 1960s (Orlov, 1978). At present it is widespread in the southeastern part of the Barents Sea, in the coastal waters of the Kola Peninsula, the Scandinavian Peninsula, in the White Sea Funnel and the White Sea Throat.

The densest aggregations of red king crab in the Russian part of the Barents Sea are located in the southern waters of the Barents Sea, where a large area has been closed for bottom trawling since 2006, but was reduced since 2021 due to crab aggregations shifted to the East and the North-East. In nearby areas where the bottom trawl fishery is allowed, the sea flounder (*Pleuronectes platessa*) and haddock (*Melanogrammus aeglefinus*) are the main target species. Crabs caught by bottom trawl will able to be damaged or die. Assessment of the crab bycatch in the bottom-trawl fishery and finding relevant crab stock protective measures are quite problematic. Another problem are survival characteristics of bycaught crab, i.e. how many crabs will die after being caught and released back to the sea.

The present work is aimed to assess the red king crab bycatch quantity in the southern part of the Russian EEZ in the Barents Sea and to discuss its survival peculiarities using experimental data.

This work provides updated bycatch data and uses data of experiments in 2020 to estimate how many crabs could die due to the bycatch by bottom trawl fishery. It consists of two parts: bycatch rate estimations and survival peculiarities discussion. Some preliminary results have already been published in 2021 (based on the data from 2017-2019) [Stesko, Bakanev, 2021] and in 2022 (based on the results of experimental work carried in the summer of 2020-2021) [Stesko, 2022].

Methods

Calculations of bycatch done by our methods [Stesko, Bakanev, 2021].

To assess the red king crab bycatch the effort method was used [Walmsley et al., 2007].

(1)

B_c - annual crab’s bycatch, t;

M $cpue_i$ - fishery effort per polygon, hours of trawling;

E_i - crab’s bycatch in each survey point, t / hour

Each polygon has size 10` in latitude x 10` in longitude. The data are based on the results of the red king crab trawl surveys in August-September 2017-2023.

In the survival experiments instant and delayed mortality assessed [Stevens, 1990]. Firstly, after catching, alive crabs were kept on the deck from 1 to 8 hours and then their vitality condition were checked. This condition considered in three grades (statuses): normal, depressed, dead. The exact status was confirmed through the analysis of the crab' movement patterns. After the first stage of experiment crabs were put in the pot and lifted down to the sea bottom. After 3-5 hours the pot was lifted up and crabs vitality status were re-checked.

Results

According to our estimations, from 1.7 to 8.7 thousand tons of the red king crab were annually bycaught during Russian bottom trawl fishery, which is from 0.6 to 2.9% relative to the total biomass of the red king crab in the Russian EEZ. The catches of commercial crab males in the bottom-trawl fishery range from 1.1 to 5.8 thousand tons, which is from 0.6% to 3.2% of the crab' stock.

These results of the red king crab survival experiments within the bottom trawl fishery indicate that a relatively small proportion of crabs were died or got injured after towing. In accordance with results of the experiments of crab survival there were almost no mortality until 3 hours and up to 40 % were dead within keeping on the deck just in 3-5 hours with average 5.4 % , and up to 59 % during 5 hours and even more. Delayed mortality after crabs released in marine water was up to 15 % with average 11 %.

We estimated that only 0.4-3.3 thousand tonnes of crabs could die after discarding, if they were released harmless to the sea.

However, it should be noted that our survival investigations were provided on a scientific vessel with small-sized research gear and after 15 minutes trawl towing. Assessment could be improved if same approach as on fishery vessel is used. These results are preliminary as they do not consist all results of survival experiments, which had been held until 2024. Additionally, main king crab aggregation are spread, and we have plans to access a larger area of the Barents Sea.

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2.8 - Incidental catches of harbour porpoise, Phocoena phocoena, by the Norwegian offshore gillnet fleet

André Moan, Arne Bjørge and Martin Biuw

Institute of Marine Research

Abstract

Harbour porpoise (*Phocoena phocoena*) bycatch for Norwegian commercial gillnet fisheries from 2006 to 2018 was estimated using a traditional ratio estimator and generalized additive linear mixed models, with weight of fish landed and number of gillnet hauls as proxies for fishing effort. Estimates were derived from data collected with a contracted reference fleet of small coastal vessels and scaled up to the whole fleet using data from landing statistics. Bycatch estimates exhibited large yearly variations, ranging from 1151 to 6144 porpoises per year. Bycatch estimates in 4 of the last 5 years were significantly less than in the preceding 2 years. The best ratio-based and model-based yearly bycatch estimates were 1580 porpoises [coefficient of variation, (*C.V.*) 0.10, 95% confidence interval (*CI*) 1302–1902] and 1642 porpoises (*C.V.* 0.15, 95% *CI* 1165–2142), respectively. About 75% of bycaught porpoises were taken in the cod (*Gadus morhua*) and monkfish (*Lophius piscatorius*) fisheries, while the rest were taken in a variety of different gillnet fisheries. Our results suggest that bycatch of harbour porpoise in Norwegian gillnet fisheries has been unsustainable for several of the last 13 years but are currently within international bycatch limits due to a recent reduction in monkfish fishing effort.

Based on published paper

André Moan, Mette Skern-Mauritzen, Jon Helge Vølstad, Arne Bjørge, Assessing the impact of fisheries-related mortality of harbour porpoise (*Phocoena phocoena*) caused by incidental bycatch in the dynamic Norwegian gillnet fisheries, *ICES Journal of Marine Science* , Volume 77, Issue 7-8, December 2020, Pages 3039–3049, https://doi.org/10.1093/icesjms/fsaa186

3 - THEME SESSION III: PRESSURES ON ENVIRONMENT AND ECOSYSTEMS

Author(s): (IMR), Alexander G. Trofimov (VNIRO, Viktor A. Ivshin (VNIRO), Alexey L. Karsakov (VNIRO), Mikhail Yu. Antsiferov (VNIRO), Maxim A. Gubanishchev (VNIRO), A. Sumkina (VNIRO), A. Krovnin (VNIRO), K. Kivva (VNIRO), V. Ivanov (MUS/AARI), Evgeniy Sentyabov (VNIRO), Cecilie Thorsen Broms (IMR), Eva Chamorro (UiT), Kanchana Bandara (Fram centre), Kaja balazy (IOPAS), Malin Daase (UiT/UNIS), Eilif Gaard (FMR), N. Sören Häfker(AWI), Xabier Irigoien (AZTI), Slawomir Kwasniewski (IOPS), Martin Lindegren (DTU), Anders Mosbech (AU), Bettina Meyer(AWI/UO/ICBM/HIFMB), Emilia Trudnowska (IOPAS), Espen Bagøien (IMR), Sünnje L Basedow (UiT), Irina P. Prokopchuk (VNIRO), A. Mikhina (VNIRO), Lis lindal Jørgensen, Anne Kari Sveistrup (IMR), K. Zaytseva (VNIRO), N. Strelkova (VNIRO), I. Manushin (VNIRO), A. Kudryasheva (VNIRO), K. Rolskaia (VNIRO), D. Zakharov (ZIN RAS), Viyaznikova, V.S. (VNIRO), Blinova, D. Yu. (VNIRO), Paolo Cipriani, Miguel Bao-Dominguez, Lucilla Giulietti, and Arne Levsen (IMR)

3.1 - A sensitivity study of climate exposures on different stocks in the North, Norwegian, and Barents Seas.

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Institute of Marine Research, Bergen

Abstract

Globally, impacts of climate change display an increasingly negative development of marine biomass, but there is large regional variability. In this analysis of future climate change exposures on stock productivity proxies for the North Sea, the Norwegian Sea, and the Barents Sea, we have provided calculations of accumulated directional effects as a function of climate exposure and sensitivity attributes. Based on modelled changes in physical and biogeochemical variables from three scenarios and knowledge of 13 different stocks' habitats and response to climate variations, climate exposures have been weighted, and corresponding directions these have on the stocks have been decided. SSP1-2.6 gives mostly a weak cooling in all regions with almost negligible impacts on all stocks. SSP2-4.5 and SSP5-8.5 both provide warmer conditions in the long term but are significantly different in the last 30 years of the century when the SSP5-8.5 warming is much stronger. The results show that it is the current stocks of cod and *Calanus finmarchicus* in the North Sea, and polar cod and capelin in the Barents Sea that will be most negatively affected by strong warming. Stocks that can migrate north into the northern seas such as hake in the Norwegian Sea, or stocks that are near the middle of the preferred temperature range such as mackerel and herring in the Norwegian Sea and cod and *Calanus finmarchicus* in the Barents Sea, are the winners in a warmer climate. The highly different impacts between the three scenarios show that multiple scenario studies of this kind matter.

Link to the published article

Sandø, A. B., Hjøllo, S. S., Hansen, C., Skogen, M. D., Hordoir, R., and Sundby, S. 2024.

A multi-scenario analysis of climate impacts on plankton and fish stocks in northern

seas. Fish and Fisheries. URL https://api.semanticscholar.org/CorpusID:269905657.

3.2 - The current trends in the Barents Sea climate

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Extended abstract

The Barents Sea plays a key role in water exchange between the North Atlantic and the Arctic Basin. Atlantic waters enter the Arctic Basin through the Barents Sea and the Fram Strait. Variations in volume flux, temperature and salinity of Atlantic waters influence hydrographic conditions in both the Barents Sea and the Arctic Ocean. This paper analyses meteorological and hydrographic conditions in the Barents Sea over the past four decades.

W arming in the Barents Sea has been observed since the early 1980s, accompanied with increasing storm activity and a northeastward drift in thermal frontal zones (Fig. 1). Strong trends ($R^2 > 0.5$) were found: increasing ones in the climate index, storm activity, air and water temperatures in the Barents Sea, and decreasing ones in the Arctic and Barents Sea ice extent, as well as in areas occupied by cold waters. Since 2000, the steady warm period was recorded in the sea. Since 2005, high air and water temperatures, intensive storm activity, large areas of warm waters and northernmost position of thermal frontal zone centroids as well as low ice coverage, small areas of cold waters and weak thermal frontal zones were observed.

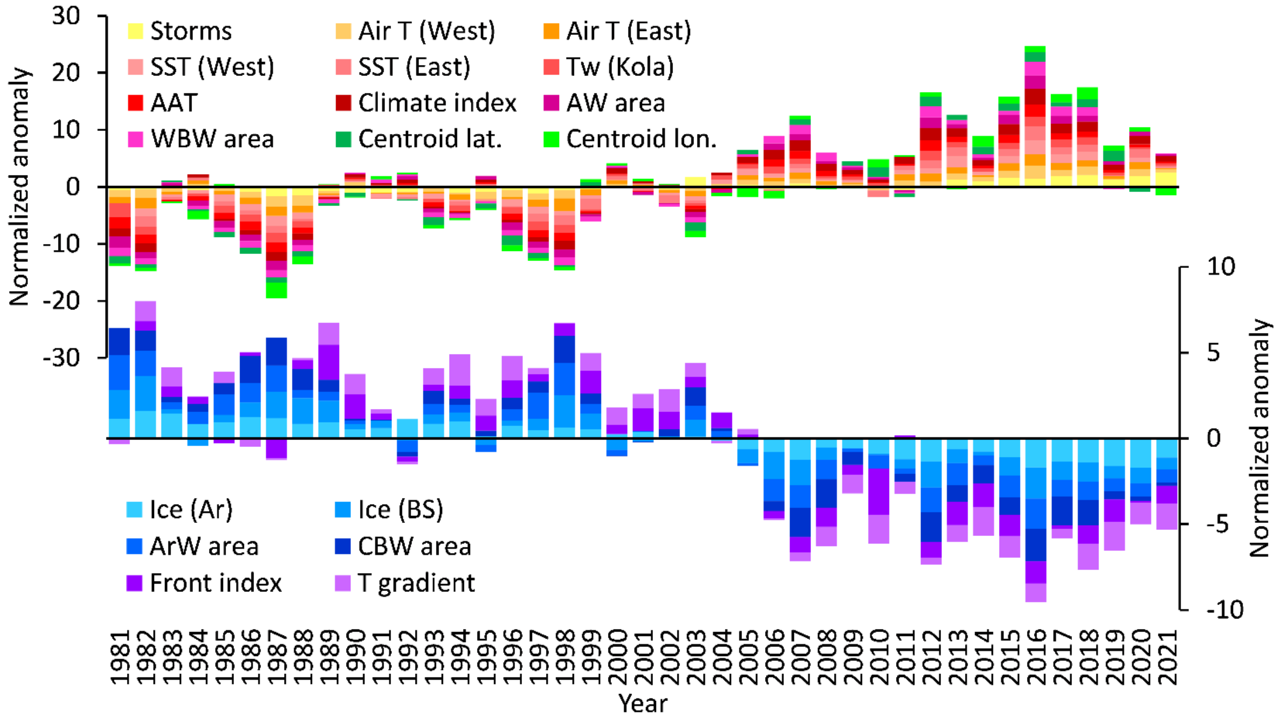

Figure 1. Normalized anomalies of meteorological and hydrographic variables in the Barents Sea in 1981–2021: storm activity (Storms), air temperature (Air T) in the west and east of the sea; ice extent in the Barents Sea (BS) and Arctic (Ar) ; sea surface temperature (SST) in the west and east of the sea; Atlantic water temperature (Tw) in the Kola Section (0–200 m); area-averaged temperature (AAT) at 100 m depth; areas covered by different waters (ArW – Arctic waters, <0°C; AW – A tlantic waters, >3°C; CBW – cold bottom waters, <0°C; WBW – warm bottom waters, >1°C) ; length index of thermal frontal zones at 50 m depth (Front index); mean temperature gradient in the zones (T gradient); geographical centroids (longitude and latitude) of the zones; climate index of the Barents Sea (the average of normalized anomalies of ice-free area, air and water temperatures).

Extent and sharpness of thermal frontal zones in the Barents Sea decreased significantly in the 2000s and reached record-low values in 2010. The decadal mean centroid of the zones shifted northeast by 86 km from the 1980s to the 2010s.

The warming peaked in 2016 with record-high air temperatures of 3.3°C (compared to the long-term average of 1.5°C; here and further in this paragraph, the 1981–2020 averages a re given in brackets) in the west and 1.1°C (−2.0°C) in the east, sea surface temperatures of 6.6°C (5.3°C) in the west and 4.8°C (2.9°C) in the east, Atlantic water temperature of 5.32°C (4.40°C) – second maximum after 5.36°C in 2012, and Atlantic water area of 402×10^{3} km^{2} (255×10^{3} km^{2}). In 2016, the Barents Sea ice extent and Arctic water area reached record-low values of 14.5 % (31.3 %) and 91×10^{3} km^{2} (258×10^{3} km^{2}) respectively.

Since 2016, despite still warm, low-ice and stormy conditions, there has been a cooling trend in the Barents Sea: a decrease in air and water temperatures, Atlantic water area, and an increase in sea ice extent, Arctic and cold bottom water areas. In recent years, the storm activity has remained at a high level of 142–172 days per year (average of 113 days), whereas the length index and mean temperature gradient of thermal frontal zones have remained at a low level.

Advection plays a key role in the Barents Sea climate and the environmental parameters within the sea are closely interrelated (Fig. 2). Storm activity affects air temperature over the sea and the Arctic ice extent. Air temperature, in its turn, influences ~~on~~ SST, deep-water temperature and ice extent in the Arctic and Barents Sea. SST also affects deep-water temperature and together they influence ~~on~~ the area of ice. Water temperature determines areas of water masses, which affect thermal frontal zones. The larger the area of warm waters and, accordingly, the smaller the area of cold waters, the more northeasterly the frontal zones will shift. The larger the area of cold waters, the more sharpened and extended the frontal zones will be and vice versa. The northward shifting of frontal zones is associated with their weakening.

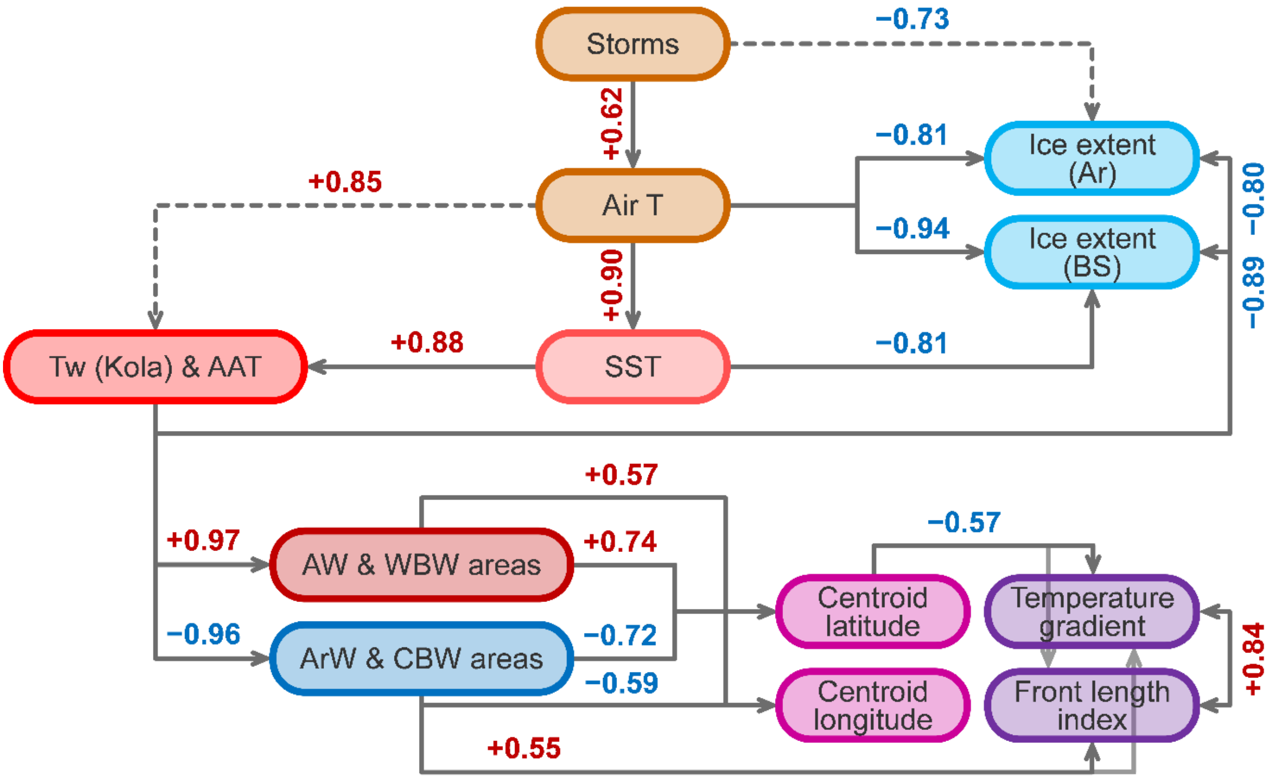

Figure 2. Interactions between environmental parameters of the Barents Sea. Figures show correlation coefficients. All of them are statistically significant at the 95 % confidence level.

Keywords: Barents Sea, meteorological conditions, hydrographic conditions, correlations, climate variability, current trends.

3.3 - 120 years of oceanographic observations along the Kola Section

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Extended abstract

Long-term observations along standard sections are necessary to study seasonal and interannual variability of oceanographic conditions. The Kola Section (along 33°30′E) in the Barents Sea is unique not only in the length of data series – it has been observed since 1900 – but also in the frequency of its observations – 6 to 20 times a year. Over 120 years, it has been observed 1263 times, with 12407 oceanographic stations carried out (Fig. 1). As the section is located in the southern and central parts of the Barents Sea, it crosses coastal and Atlantic waters flowing from the west (the Norwegian Sea) to the east and northeast. The Kola Section is widely used as an indicator of the Barents Sea climate since the temperature from it reflects the thermal state of the entire sea.

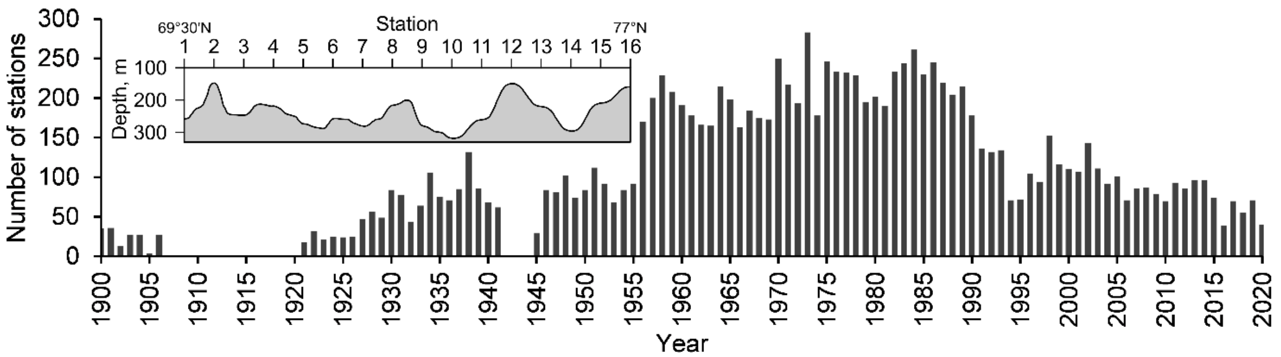

Figure 1. Annual number of oceanographic stations carried out in the Kola Section in 1900–2020. The inset diagram shows the bottom topography along the section.

In this study, we generalized oceanographic data from the Kola Section available since 1900. Long-term (1951–2020) means and standard deviations of water temperature and salinity were updated for each standard depth at each station of the section on a monthly basis. Monthly and yearly temperature and salinity in the 0–50, 0–200, 50–200 and 150–200 m layers in three parts of the section associated with coastal (Murman Coastal Current) and Atlantic (Murman Current and Central branch of the North Cape Current) waters were tabulated for each year of the period 1951–2020.

The seasonal variability of thermohaline conditions in the Kola Section was analyzed. The seasonal cycle in temperature is much better seen than in salinity. Greater annual ranges of both temperature and salinity are observed in the upper 30 m with maximum values in coastal waters. The ranges decrease with depth and northward. The seasonal minimum temperature occurs mainly in April almost at all depths, while the timing of the seasonal maximum lags with depth: in the upper 50 m, it occurs in August–September, and in the 150–200 m layer – about three months later, in November–December. In some years, the timing of temperature extremes may shift by one or two months relative to their long-term averages. As a result, the period of seasonal warming (for example, in the 0–200 m layer) may lengthen to 6–9 months or shorten to four months with the long-term average of 5 months. The seasonal cycle of salinity is most noticeable in the upper 50 m, where the minimum occurs in the warmest months (August–September) and the maximum – in the coldest ones (December–April). The seasonal minimum salinity lags with depth. On moving along the section northward, the lifetime of thermo- and haloclines shortens (from half a year in the southern part of the section to three or four months in its northern part), their lower boundary depths decrease. During the cold season (December–April), temperature and salinity vertical distributions in the section are close to homogeneous.

The interannual variability of thermohaline conditions in the Kola Section was analyzed. Year-to-year changes in temperature make a significant contribution to its overall variability in the intermediate and deep waters of the Murman Current and Central branch of the North Cape Current: the range of interannual fluctuations in the annual mean temperature is 1.5–2.5 times (by 0.8–1.7 °C) greater than the range of seasonal fluctuations (on the basis of long-term mean values). In the Murman Coastal Current (at all depths) and in the upper 50 m (in the entire section), the seasonal changes in temperature plays much more significant role than the year-to-year ones: the interannual range is 0.7–3.2 °C less than the seasonal one. The contribution of interannual fluctuations in salinity to its overall variability in the Kola Section is predominant everywhere: the interannual range is 0.20–0.42 (3–14 times) greater than the range of seasonal fluctuations in all layers and parts of the section.

All the years of the period 1951–2020 were classified by the level of thermal and haline state of the main currents in the Kola Section. As a result, warm/cold and saline/fresh periods were identified, which were in good agreement for different parts of the section. It was noted that the levels of thermal and haline state of waters in different layers and parts of the section were not always identical in the same year. That happened due to different degrees of influence of factors determining the thermohaline conditions in the southern Barents Sea.

Since the late 1980s, a warming has been observed, known as the modern global warming of the Arctic. It is unprecedented in duration and strength. Since the mid-2000s, record-high water temperatures have been observed in the Kola Section (Fig. 2).

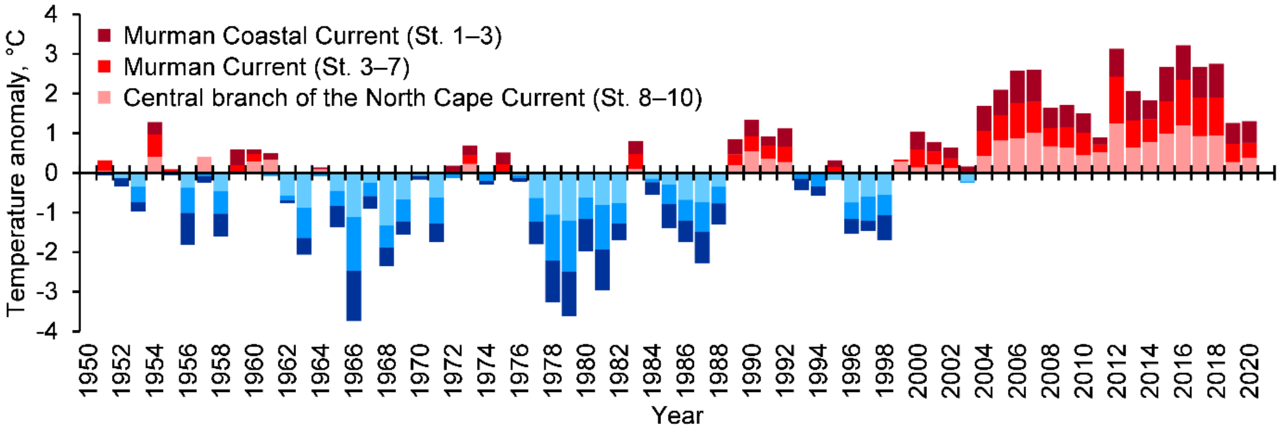

Figure 2. Annual mean temperature anomalies (°C) in the Kola Section (0–200 m) in 1951–2020.

The generalized data on temperature and salinity in the Kola Section presented in the paper can be useful in conducting studies in the field of physical, commercial and biological oceanography of the Barents Sea.

Keywords: Barents Sea, temperature, salinity, seasonality, interannual variability

3.4 - Seasonal ice in the Barents Sea and its variability

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Abstract

The Barents Sea (BS) is one of the key areas in the Arctic for monitoring of climate change. Sea ice is important to the climate system, and it is also one of the main indicators of climate change. In particular, this affects the transportation and production of hydrocarbons, as well as reproduction, distribution and behavior of the main commercial fish species in the BS. In this study, the concentration of sea ice has been analyzed. Ice concentration and the extent of sea ice are considered as key climate indicators and are included in numerous national and international reports assessing climate change. However, ice concentration and sea ice extent provide incomplete information about the variability of sea ice. The date of retreat (DOR) is one of the parameters characterizing changes in sea ice and its evolution. To determine the DOR, a threshold value of ice concentration of 15% is used. The study is based on data from the NOAA/NSIDC Climate Data Record (CDR) for 1979-2019 .

During the analysis of hydrological parameters, periods of cooling (1979 - 1982, 1986 - 1988, 1996 - 1998) and warming (1983 - 1984, 1989 - 1995, 1999 - 2010) were distinguished. An anomalous cooling was observed in 1977 - 1982. The maximal ice edge spread to the south was noted in 1989 - 1998. During the period 1979 - 1988, when the anomalous cooling was registered (1979 to 1982), the sea ice edge was located slightly further north than in 1989 - 1998. The ice concentration values greater than 0.15 for each grid node were calculated from the mean annual values for the 1979-2019 period. The minimum number of years with ice concentration greater than 0.15 was observed in the southern sea, and their maximum in the northern BS. The ice edge extended furthest south during the period from 1989 to 1998. In the years 1979-1988, when an anomalous cooling (from 1979 to 1982) was followed by warming (from 1983 to 1984), the ice edge moved slightly further north. From 1979 to 1998, the ice edge reached the Bear Island in the western sea. The average annual ice concentration over 40 years throughout the Barents Sea is 0.4. In the southern part of the sea, the average concentration does not exceed 0.2, in the central part it is in the range of 0.2–0.6, and in the northern part – 0.6–0.9. In the eastern part of the sea (off the western coast of the Novaya Zemlya archipelago) the concentration is higher than at the same latitude in the central part of the sea. In different grid nodes of the central BS, the ice cover was observed from 15 to 30 years. In the area of the Novozemelskaya Bank, the ice was registered for 25-30 years, while slightly to the west at the same latitude the ice was noted for 35-40 years. It is expected that in the next 2-3 decades, the trend toward an increase in the duration of the ice-free season in the Barents Sea will remain. The trend of increasing duration of the ice-free season in the Barents Sea is one of the manifestations of the growing "Atlantification" of the Atlantic Arctic.

The distribution of DOR across the Barents Sea from 1979 to 2019 is characterized by a zonal pattern. Ice retreat begins in February in the southern part of the sea and gradually moves north, where complete retreat occurs at the end of September. In the main part of the water area, retreat of ice takes place in the period from April to August inclusive. The western part of the sea differs from the eastern part in having earlier dates of DOR. In 2016, ice retreat in the southern part of the sea was observed in April, while in 1979 it was much later,

in May-June. In 2016, ice retreat was observed in January in the northeastern part, but in 1979, ice retreat was observed in January in the northwestern part. A significant negative regression coefficient of DOR is observed throughout the entire sea area. The exception is the region between Franz Josef Land and the Spitsbergen archipelago, where this regression coefficient is close to zero. A negative regression coefficient shows that the DOR is shifted to earlier dates. The region of maximum negative regression coefficients (8–10 days over 40 years) is located in 76 ° N, 35 ° E region. Across the entire Barents Sea area, since 2003, there has been a steady shift in the timing of seasonal ice clearance to earlier dates.

3.5 - Long-term Monitoring of the Lofoten Vortex Based on Field Observations

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Short communication

Abstract

The paper deals with the results of long-term observations of the quasi-stationary Lofoten vortex carried out during the International Ecosystem Surveys of the Nordic Seas (IESNS) in May 2007-2022. The thermohaline parameters in the trawl-acoustic studies of pelagic and deep-sea fishes were measured from the surface to a depth of 1000 m. The study examines the distribution of temperature and salinity at a depth of 800 m as the most appropriate depth to determine the location of the Lofoten vortex for each of the 16 years of the research. Also, the vertical distribution of the thermohaline characteristics on transects, crossing the Lofoten vortex along approximately 69° and 70°N was investigated. An assessment of the inter-annual spatial variability of the location of the stations with the maximum temperature within the vortex and the centroids of areas with temperature above 1 °C is considered. The study briefly presents the results of the long-term TS-analysis of water masses in the central part of the Lofoten vortex and their comparison with the TS-characteristics of waters off the vortex.

Keywords: the Norwegian Sea, the Lofoten vortex, thermohaline characteristic, spatio-temporal changes

Introduction

The Lofoten Basin is the largest reservoir of ocean heat in the Nordic Seas. The Lofoten vortex is a feature of the basin as the most anomalous mesoscale structure of the Norwegian Sea. The vortex is located in one of the main areas of the winter convection in the Norwegian-Greenland basin and has an impact on the formation of dense water in this region. The fact that water from the Atlantic enters great depths of the Norwegian Sea within the Lofoten vortex and retains this position appears to be of much interest for fundamental research in oceanography and hydrophysics.

Many researchers have studied the Lofoten vortex in the last few decades. In general, all their works can be divided into three groups: analysis of rare specialized small-scale deep-sea observations at polygons (Ivanov, Korablev, 1995; Korablev, 2001) , analysis of satellite observations of surface temperature, salinity and sea level (Raj et al., 2015; Zinchenko et al., 2019) sometimes using available data from Argo buoys (Alexeev et al., 2016; Dugstad et al., 2019) , and analysis of results from the hydrodynamic modeling (Belonenko et al., 2014, 2017, 2018; Köhl, 2007; Søiland, Rossby, 2013) .

In contrast to these three types of input data used in the previous studies, we tried to analyze the spatio-temporal changes in the structure of the Lofoten mesoscale vortex in the same season (May) throughout 16 years (2007-2022) using incidental field observations which are not directly aimed at studying this vortex.

Materials and results

Oceanographic data used in the article were obtained during the International Ecosystem Surveys in the Nordic Seas (IESNS) in May 2007-2022. The author of the article took part in most of them on board the Norwegian research vessels "G.O. Sars" and "Johan Hjort" from IMR (Sentyabov, 2018) . Oceanographic data from research vessels of other marine institutes participating in these surveys (in particular the Marine and

Freshwater Research Institute (Iceland) and the DT U Aqua - National Institute of Natural Resources (Denmark)) were also used in this work. In these surveys (ICES, 2015), CTD-stations were covered along with trawl-acoustic observations and so they were not done in the same coordinates in different years. The distance between stations varied from 50 to 90 nautical miles that makes them to be considered only as incidental studies of the Lofoten vortex, but not specialized ones. Temperature and salinity measurements were carried out from the water surface to a depth of 1000 m using the SBE-9Plus profiler produced by Sea Bird Electronics.

The distribution of thermohaline characteristics at a depth of 800 m is considered as the most relevant to locate the vortex under study. This was confirmed also by the earlier works (Ivanov, Korablev, 1995; Søiland, Rossby, 2013 etc.). The paper also presents the attempts to identify the vortex structure based on the distribution of temperature (above 4 °C) and salinity (more than 35.1) in the 500-600 m layer. The attempts, however, were unsuccessful due to the large area of distribution of waters from similar temperatures in the Lofoten Basin and near the Norwegian continental shelf and great inter-annual variability of salinity in this layer. The vertical distribution of temperature and salinity in transects along approximately 69 and 70° N was also studied.

At the chosen depth of 800 m, waters of temperatures above 1°C occupied an area of 115 nautical miles (or 214 km) in diameter and for waters of salinity above 35.0 it was about 100 miles (185 km) on the average for 16 years. The scales of the vortex core according to the data obtained by other researchers using other measuring instruments appear to be significantly smaller. In the paper (Raj et al., 2015), based on satellite altimetry data, it is stated that the average radius of the Lofoten vortex is 37 km. According to Yu et al., (2017), who used glider data, the average radius of the core of the Lofoten vortex is about 18 km. However, the spatial resolution of the stations grid (as mentioned above, 50-90 miles) often disables tracing the vortex “core” area which may be located between stations.

The greatest deepening of waters with temperatures above 3 °C and salinity higher 35.0 (to depths of more than 1000 m) was observed in 2010-2013 and 2017-2020. This phenomenon is well illustrated by the vertical temperature distribution in one of transects (along 70° N) in Figure 1. In some years (2007-2009, 2014-2016 and 2021-2022), warm waters penetrated to great depths only slightly and in the center of the vortex, the temperature at a depth of 800 m rarely went above 2°C.

In ten cases over the 16-year period, in addition to the main vortex, localized in the Lofoten Basin between 69° and 71° N mainly between 1° and 6° E, a “secondary” eddy was observed to the east, usually between 10° and 12° E. above depths less than 3000 m. Examples are given in Figure 2. The "secondary" eddies (detected by deflection of isotherms) were mainly found in the southern transect (along 69° N). In transect along 70° N, “secondary” eddies were identified only in 2008-2010, 2013-2015 and 2017 (see Figure 1). At the same time, the appearance of "secondary" eddy was often accompanied by a weak development of the "main" vortex. These “secondary” eddies occurred along with the greatest development of the Lofoten vortex and deep influx of warm and salty waters only in two cases: in 2010 and 2019.

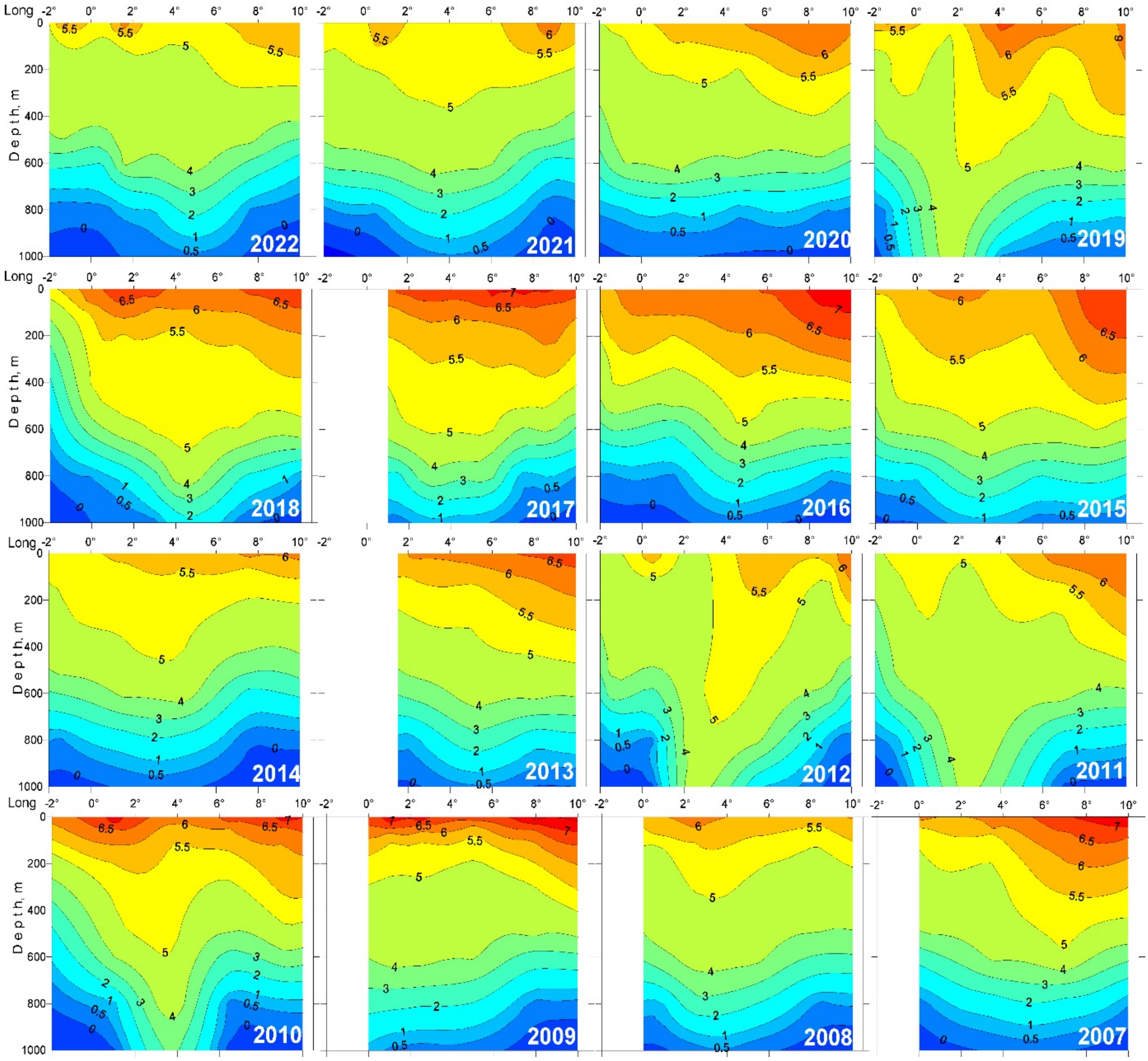

Figure 1. Vertical distribution of temperature in transect along appr. 70° N, May 2007-2022

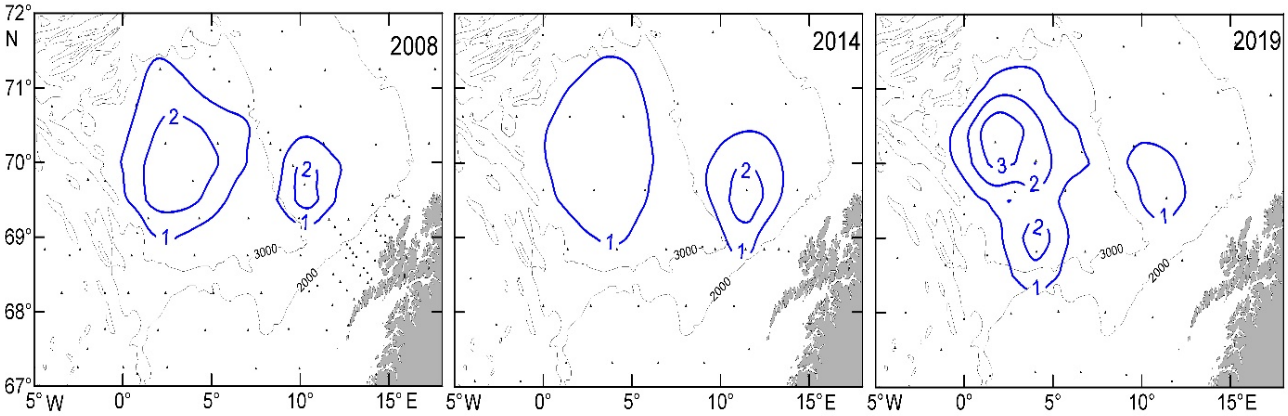

Figure 2. Positions of isotherms (°C) at 800 m in the Lofoten Basin area in May 2008, 2014 and 2019. Dots indicate the position of oceanographic stations and thin lines indicate isobaths

To assess the inter-annual dynamics of the vortex position, data on the position of stations with the highest temperature at a depth of 800 m were used. Since there were no specialized polygon observations, it brought some uncertainty into the assessment. The chart appeared to be quite random (red lines in Figure 3). The centroids of areas with temperatures above 1°C at a depth of 800 m were also calculated using water temperature as a weighting factor. Their spatial dispersion was much smaller, within an ellipse of 33 nautical miles (appr. 60 km) in diameter, with an exception in 2007 (black lines in Figure 3). The movement of the centroids was anticyclonic from 2007 to 2014 and cyclonic from 2015 to 2022. A similar displacement (mostly cyclonic) of the Vortex center, determined by the maximum horizontal anomaly of potential density, with a range of 65-70 km, but with seasonal averaging, was revealed by the results of model calculations (Volkov et al., 2015). Ivanov and Korablev (1995) noted that the distance between the most distant points of the cyclonic trajectory of the displacement of the vortex center was appr. 130 km.

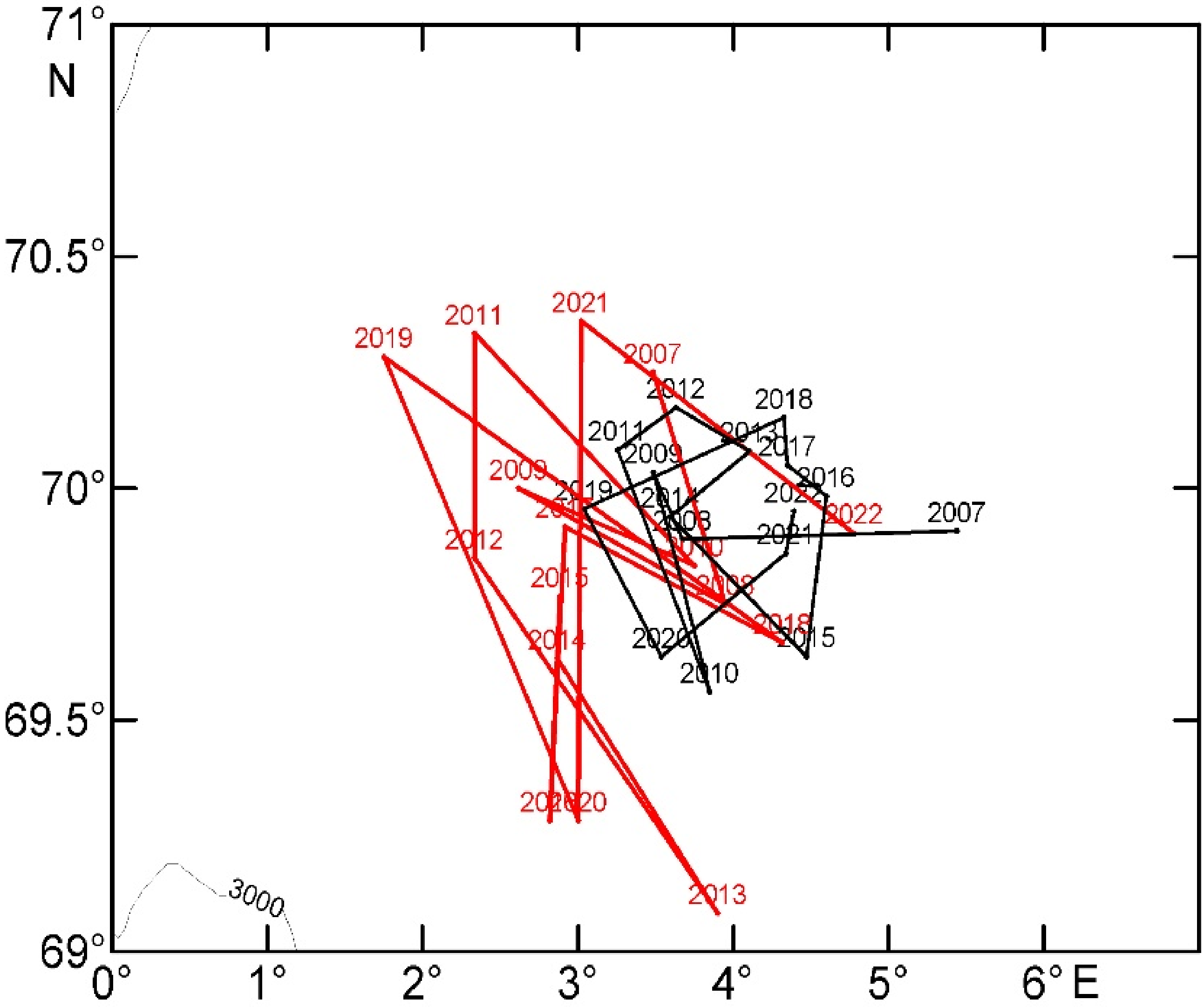

Figure 3. Inter-annual variability of positions of the stations with maximum temperatures (corresponding to the center of the vortex – red lines and numbers) and the centroids of areas with temperatures above 1 °C (black lines and numbers) at 800 m within the Lofoten vortex.

The TS-analysis of water masses in the vortex center revealed a considerable increase in temperature (above 2-3 °C) and salinity (app. 35.0) in the 600-800 m layer compared to the surrounding waters off the vortex (Figure 4), with a very significant inter-annual range of their values in the upper 300 m layer.

Conclusion

Thus, obtained as a result of the analysis of non-specialized observations in the same season (May) for many years (2007-2022), the characteristics of the Lofoten vortex generally agree with the estimates made earlier by other authors who used model calculations, satellite observations, gliders and Argo buoys, as well as data from reanalysis. These results may be of scientific and practical interest. In the future, the incidental field observations can be used both to continue monitoring of the Lofoten vortex and to confirm theoretical estimates and various hypotheses about the spatio-temporal variability of characteristics of the vortex and probably the whole Norwegian Sea as of a distribution area for many commercial pelagic and deep-sea fishes.

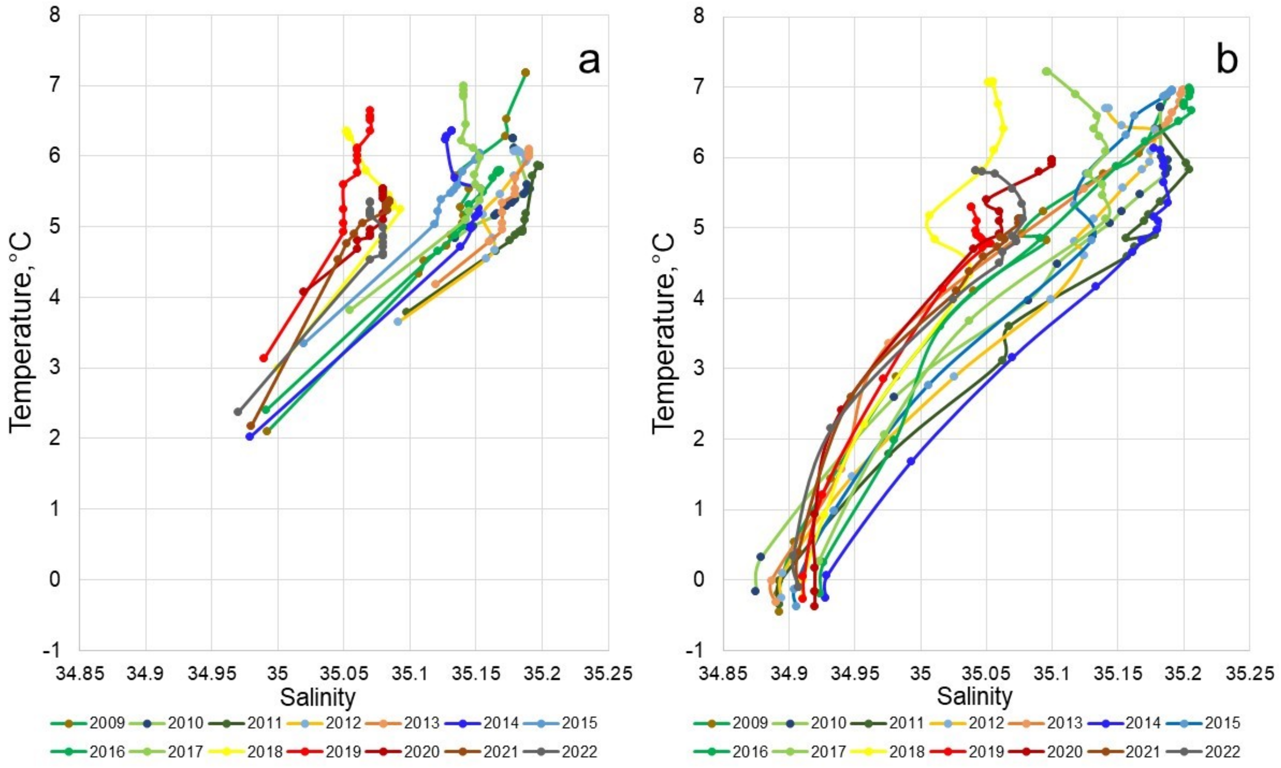

Figure 4. TS-charts based on data (0-800 m) in the center of the Lofoten vortex (a) and in nearest stations off the vortex (b) in May 2009-2022.

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3.6 - Meta-analysis of stage-specific *Calanus finmarchicus* vertical distribution in relation to hydrography and chlorophyll in the North Atlantic

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Abstract

Calanus finmarchicus is an extensively studied zooplankton species in the North Atlantic. While many studies have explored its abundance and life cycle, the relationship between its vertical distribution and environmental variables during the feeding season has not been sufficiently investigated on large spatio-temporal scales. We conducted a meta-analysis of stage-specific *C. finmarchicus* vertical distribution data and its relationships with environmental variables (temperature, salinity, irradiance, chlorophyll) in the epipelagic layer (0-200 m) of the North Atlantic. We aimed to discern common, stage-specific responses to environmental factors. A GAM model was fitted to understand which variables were most important in structuring the vertical distribution of this species. The data were gathered during spring and summer over 47 years, from 1971 to 2018. Early copepodid stages were distributed significantly shallower, and the vertical distribution of all developmental stages was strongly related to seasonal environmental dynamics. The timing of the phytoplankton bloom emerged as a key factor determining vertical distribution, all developmental stages were found shallower during the seasonal surface Chl.- *a* maximum. This suggests that food availability is an important driver of the vertical distribution of *C. finmarchicus* . We also found thresholds in temperature and salinity at which vertical distributions were significantly different.

Key words:

Zooplankton dynamics, habitat selection, environmental variables, North Atlantic, Generalized Additive Model (GAM).

3.7 - Zooplankton biomass trends in subareas of the Barents Sea – recent developments

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Abstract

The Barents Sea has experienced significant warming and reduced ice-cover during the last decades. The spatial distributions of relatively warm Atlantic water versus cold Arctic water, and of the species adapted to each of these environments, have changed rapidly – "borealization". Zooplankton make energy from planktonic primary producers available to organisms on higher trophic levels in the ecosystem and are subjected to bottom-up as well as top-down processes. To study spatial and temporal variability in zooplankton biomass, we divide the Barents Sea into the 15 subregions used in ICES WGIBAR analyses. The zooplankton biomass data from the joint Norwegian/Russian Ecosystem Survey in the Barents Sea are from 2000-2023. The data are based on vertical hauls from near bottom to surface with WP2 and Juday zooplankton nets with mesh-size 180 µm. We assess the temporal trends for spatially consistent subsets of monitoring data covering the extent of the Barents Sea. In the western subareas of the Barents Sea that represent the inflow region for Atlantic water from the Norwegian Sea, the variability has dominated over the trend for total mesozooplankton biomass during the last ~ 20 years. For the shallow bank areas in the central Barents Sea, there has been a decreasing total biomass trend during most of the study period. In two eastern subareas just west of Novaja Zemlja, the biomass levels are primarily characterized by high variability. However, since about 2020 size-fractioned biomass which is available for the western and central subareas reveals some very low levels of the size-class mainly representing medium to large copepods combined with increased levels of the size-class representing the very smallest copepod species or earliest stages. This presentation focuses on the most recent area-specific developments (2018-2023) in zooplankton biomass and represents information essential for evaluating feeding conditions for various fish, sea mammals and birds.

The data presented by Bagøien & Prokopchuk at the 19th Russian-Norwegian Symposium 2024 are partly published in:

Dalpadado P, Prokopchuk IP, Bogstad B, Skaret G, Ingvaldsen RB, Dolgov AV, Boyko A, Rey A, Ono K, Bagøien E, Huse G (2024). Zooplankton link climate to capelin and polar cod in the Barents Sea. *Progress in Oceanography* , https://doi.org/10.1016/j.pocean.2024.103302

Skjoldal HR, Sperfeld E (2024). Size-fractioned zooplankton biomass in the Barents Sea: macroecological patterns across biogeography, climate, and varying ecosystem state (1989–2020). *Marine Ecology Progress Series,* https://doi.org/10.3354/meps14485

Skjoldal HR, Eriksen E, Gjøsæter H. (2022). Size-fractioned zooplankton biomass in the Barents Sea: spatial patterns and temporal variations during three decades of warming and strong fluctuations of the capelin stock (1989–2020). *Progress in Oceanography* , https://doi.org/10.1016/j.pocean.2022.102852

3.8 - Dynamics of distribution and abundance of main macroplankton groups in the Barents Sea based on new time-series

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Short communication

Abstract

Macroplankton is a critical component of the Barents Sea ecosystem, as it serves as a food item for fish, sea birds, and marine mammals. It is difficult to overestimate its significance given the conditions of our latitudes. *Chaetognatha* , *Euphausiacea* , *Hyperiidea* , and *Pteropoda* are the most prevalent macroplankton taxa in the Barents Sea.

From 1953 to 2016, PINRO conducted routine monitoring of the macroplankton community in the Barents Sea from October to December in order to evaluate the feeding area and forecast fattening conditions for commercial fish. The data collected during this multi-year period were utilized to investigate a variety of aspects of the distribution, abundance dynamics, and biology of euphausiids during the autumn and winter periods. The material was unique in terms of observation duration and water area coverage.

In 2016, the macroplankton survey was discontinued and a new time series was implemented for the joint Russian-Norwegian bottom trawl survey in February. This survey also included the euphausiids wintering period and allowed PINRO's macroplankton assessment method to be used again by fishing for wintering near-bottom macroplankton assemblages with a trawl net.

In this context, we were interested in exploring the potential of utilizing a novel time series to evaluate the condition of macroplankton during the winter season. We examined these organisms in terms of their distribution, species structure, and abundance, while also examining the impact of the primary factor, water temperature. The mild and abnormally warm conditions in the Barents Sea during the study period influenced the distribution and abundance of macrozooplankton.

Key words: macroplankton, euphausiids, chaetognaths, hyperiids, pteropods, Barents Sea.

The materials from the annual macroplankton surveys conducted during the joint Russian-Norwegian winter ecosystem survey in February–March of 2015–2023 were used in this study. The survey gear included a trawl net, which was attached to the middle part of the headline of the bottom trawl. Generally 36 - 106 samples were collected per year in the southern Barents Sea covered by Russian research vessel. The net was used to catch macroplankton in the bottom layer and was located 6–10 meters above the bottom surface. The biomass was quantified in grams per 1000 m^3 , and the abundance of different species and groups was quantified in specimens per 1000 m^3 .

From 2015 to 2021, euphausiids comprised the most prevalent macroplankton group, accounting for an average of 61.31% of the total macroplankton abundance. Starting in 2022, there was a noticeable shift in the overall pattern as the *Chaetognatha* group emerged as the dominant species, accounting for 54.19% in 2022 and 53.75% in 2023. The abundance of *Hyperiidea* and *Pteropoda* remained consistently low throughout the study period, with an average of 0.65% and 0.11%, respectively.

Throughout the study period, there has been a noticeable decline in the abundance of euphausiids. However, their biomass continues to hold a significant presence, accounting for 59.13% of the total macroplankton biomass, excluding the year 2020. Interestingly, in 2020, *Chaetognatha* emerged as the dominant group in terms of biomass, comprising 61.23%.

The biomass of *Hyperiidea* and *Pteropoda* remained consistently low, with *Hyperiidea* accounting for 1.03% and *Pteropoda* accounting for 0.24%.

In the period from 2015 to 2023, the distribution of euphausiids exhibited patterns typical of warm years. Notably, the area occupied by the densest euphausiid concentrations experienced a significant expansion during abnormally warm years.

Five species of euphausiids inhabit the Barents Sea. These include the local species *Thysanoessa inermis* and *T. raschii* , as well as the Atlantic species *Meganyctiphanes norvegica* and *T. longicaudata* . In recent years we have also observed the warm-water species *Nematoscelis megalops* .

T . inermis and *T. raschii* , the local Barents Sea euphausiid species, have traditionally been the most abundant in this surveyed area. However, the rise in mean long-term water temperature ~~has~~ had a detrimental impact on these species, particularly *T. raschii* . The eastern areas near Kolguyev Island serve as the primary spawning areas and aggregations for juveniles of this species. Notably, these areas typically exhibit the highest concentration of euphausiids during years with the lowest average annual water temperature.

The euphausiid species composition observed in this study exhibited characteristics commonly associated with warm years. The dominant species were those typically found in the southern Barents Sea, with *T . inermis* being particularly abundant. Notably, the year 2020 documented the highest levels of abundance for this species. *T. raschii* abundance reached maximum values in 2020 and in 2021. In 2019, the observations revealed the highest abundances of *M. norvegica* . The population of *T. longicaudata* reached its peak in 2015, with a maximum abundance of 131 spec/1000 m^3 . In the other years, the population remained relatively stable, with no more than 80 spec/1000 m^3 . During the study period, the coastal parts of the western areas occasionally encountered a rare warm-water species *N . megalops* . This species appears only occasionally in the Barents Sea, and its presence is dependent on the intensity of warm Atlantic water inflow. From 2015 to 2023, the population of *N. megalops* remained consistently low, with no more than 10 spec / 1000 m^3 .

There was a noticeable rise in the population of predatory *Chaetognatha* , specifically the dominant species, *Sagitta elegans* . This increase in abundance can have a detrimental impact on mesoplankton communities. The long-term mean abundance of chaetognaths in 2015-2023 was 731 spec./1000 m^3 . The lowest average abundance was observed in 2016 (388 spec./1000 m^3) and the highest in 2022 (1153 spec./1000 m^3).

During this research, *Chaetognatha* were observed to be present in various locations within the Barents Sea . Our study did not uncover the dependence between their abundance and water temperature. It is plausible that other factors, such as the abundance of mesoplankton, may play a role.

The minimum abundance of hyperiids was observed in 2015. The mean abundance of the boreal *T. abyssorum* was consistently higher every year compared to the Arctic species *T. libellula* , which was observed only in 2018, 2019, and 2021, with a maximum population density of 1.2 spec./1000 m^3 . The maximum abundance of *T. abyssorum* did not exceed 20 spec./1000 m^3 . We found *T. abyssorum* across a vast expanse of the sea, while we predominantly observed *T. libellula* in the northern region.

The pteropods were represented by *Clione limacine* , the most abundant species in the Barents Sea. The average abundance of this species was observed to be consistently low, ranging from 0.5 in 2015 to 2 spec./1000 m ^{3} in 2019. Based on our observations, the average annual abundance of specimens is 2 spec./1000 m ^{3} . The maximum average abundance is recorded in 2023.

Conclusion

Based on the data collected in 2015-2023, it is regrettable to report that the new time series cannot fully replace the previous one for the period from 1959 to 2015. In the February survey, the focus was solely on the southern part of the Barents Sea within the Russian economic zone. This is in contrast to the previous time series, which encompassed a larger part of the Barents Sea water area, excluding only the areas covered by ice.

Due to these factors, it is currently unfeasible to evaluate the effects of warming on cold-water species. Their natural habitat extends beyond the February survey boundaries, making it challenging to determine the northern limits of warm-water species distribution. Assessing mass aggregations of euphausiids near the Spitsbergen archipelago and their contribution to the food base of commercially important fish is currently impossible.

3.9 - Benthos responses to fast climate change in the Barents Sea

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Extended abstract

Megabenthos (called benthos from here) is captured from the seafloor by trawls everywhere in the Barents Sea (Anisimova et al. 2011; Jørgensen et al. 2015; Zimina et al. 2015; Johannesen et al. 2016; Degen et al. 2016; Jørgensen et al. 2019; Zakharov et al. 2020; Jørgensen et al. 2022; Golikov et al. 2024) , and most taxa (and stations) have been recorded between 100-350 m depth. Benthos species are found in the stomachs of a variety of fish, including sharks, and sea mammals and birds are also preying on benthos. Some fish species use complex benthos habitats as nursery and feeding grounds. Shrimps, crabs and bivalves make up commercial stocks of the Barents Sea.

In 2005-2023, 866 species were recorded in the joint Norwegian-Russian database with a mean number of 317 taxa recorded per year. In 2023, 453 species (682 taxa) were recorded across the Barents Sea. In 2023, the mean number of taxa per trawl was 31.

The taxa represent Mollusca, Arthropoda, Cnidaria, Sponges, Echinodermata, worms, Bryozoa and Chordata and several other small groups.

An increased number of species recorded, from 142 in 2005, to 453 in 2023, can most likely be explained by an increase in research effort. The program now includes four research vessels with 12 experts per year, annual training courses and standardized manuals, efficient methods saving time and resources, and exchange of data on an annual basis.

The number of boreal species has increased while the number of arctic species has been stable during the observation period. The mean benthos biomass across the Barents Sea fluctuates from less than 15 kg/nm of trawling in 2005 to a maximum value of almost 90 kg/nm in 2018 and to less than 35 kg/nm in 2023. These fluctuations are highly dependent on years with accidental large sponge, crab, sea star or bristle star catches and years with poor geographical coverage or bad conditions. A possible mean biomass may be 40-50 kg/nm of benthos in a “normal” trawl haul. The largest trawl hauls (more than 100 kg) are frequently taken from the northeastern and southwestern areas of the Barents Sea.

Sponges make up the largest biomass across the Barents Sea followed by arthropods such as crabs and shrimps, and echinoderms such as brittle stars and sea stars.

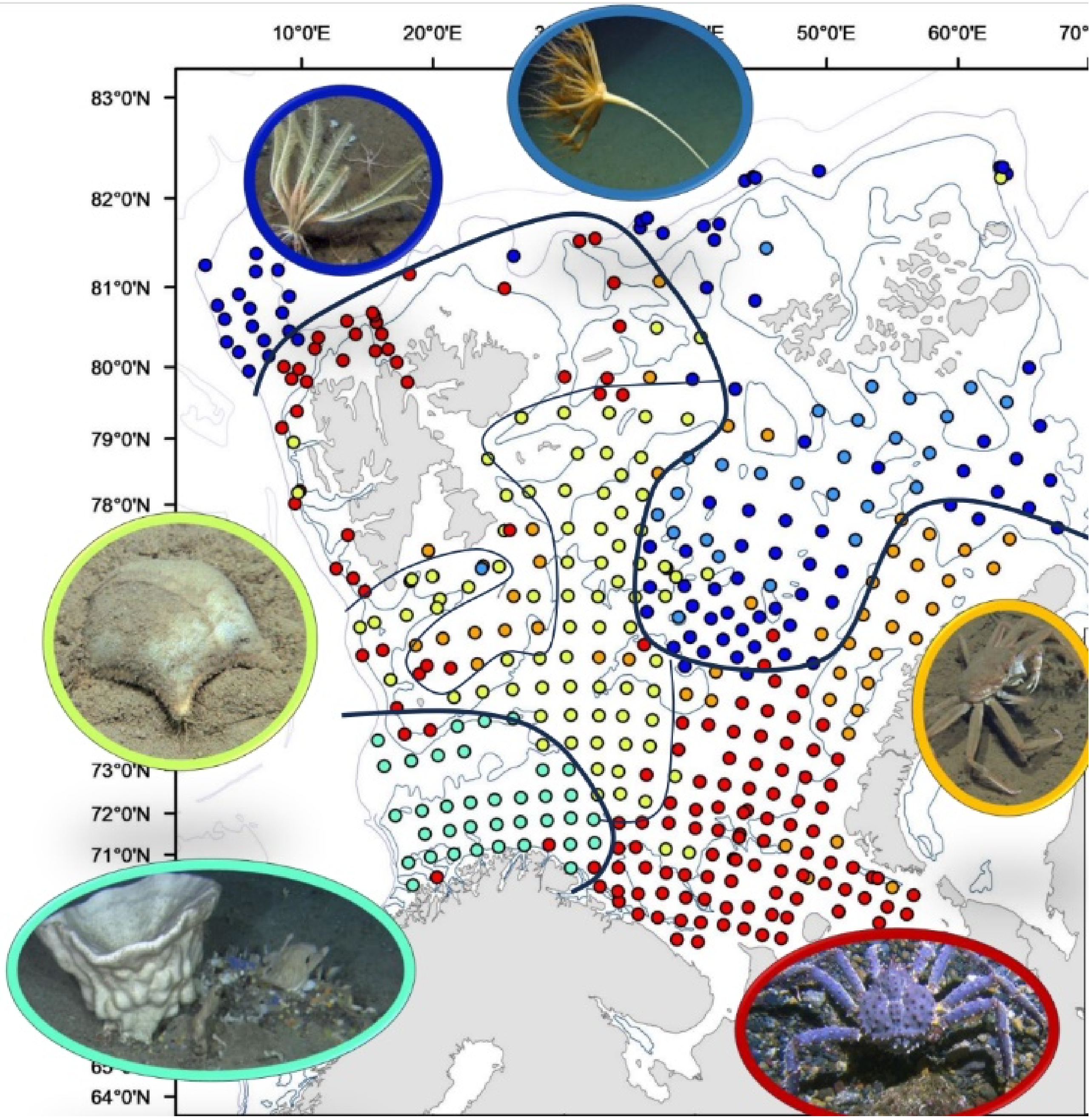

Figure 1: The saline and warm Atlantic water of the southwest (see figure to the right) contain large sponges as Geodia , Thenea and Axinella , the sea cucumber Parastichopus and Molpadia and the lobster Munida sarsi . The relatively warm southeast and northwest areas contain species such as the king crab Paralithodes camtschaticus , the sea cucumber Cucumaria frondosa , and the sponge Geodia . The cold Arctic waters in the northeast and Yermak plateau holds the brittle star Gorgonocephalus and Ophiopleura borealis , the sea-pen Umbellula , the sea-lilies (echinoderm, Crinoidea) Heliometra , and the snow crab Chionoecetes opilio . The relatively cold central Barents Sea is occupied by the sea-star Ctenodiscus crispatus , the brittle-star Gorgonocephalus , and crangonid shrimps such as Sabinea . The relatively cold waters along Novaya Zemlya are characterized by the sea urchin Strongylocentrotus , and the snow crab.

The biomass of boreal benthic species was higher than the biomass of arctic species in the central Barents Sea in 2014-2018, while the biomass of Arctic benthic species dominated in this area before and after this period. When the area coverage of bottom water types is related to these fluctuations, the “boreal period” may be explained by the warm period back in 2007 when warm Atlantic waters occupied 50 % of the Barents Sea. In the “Arctic periods” cold Arctic and mixed bottom water prevailed. We predict that the biomass of Arctic benthos in 2023-2027 will dominate as a consequence of the “cooler” bottom water years of 2020-2022. The “pool” of dominant boreal biomass has expanded north and east from 2009-2013 to 2019-2023.

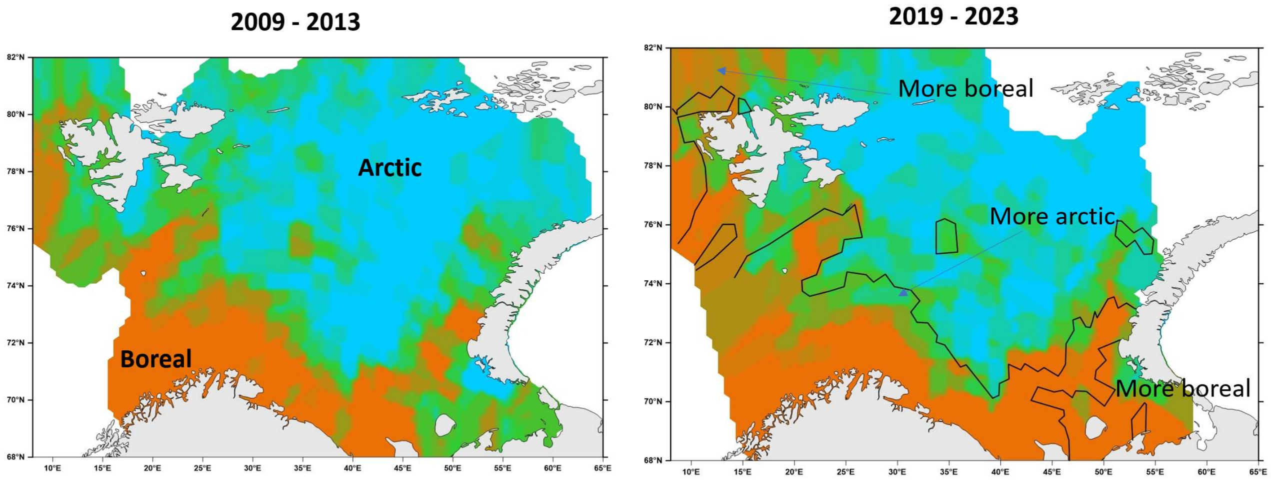

Figure 2: The extrapolated boreal (red) vs arctic (blue) dominance of benthos biomass for the two periods 2009-2013 and 2019-2023.

The years dominated by either arctic or boreal bottom fauna may be an indication of benthos responding to a fast-changing Barents Sea bottom water temperature, but with a time lag of several years due to the slow regeneration periods of many megabenthic species and long lifetimes.

Also, the large interannual biomass (kg/nm) fluctuations (low in 2010, 2015, 2020; maximum in 2012 and 2017 see figure below) may indicate a response to bottom temperatures.

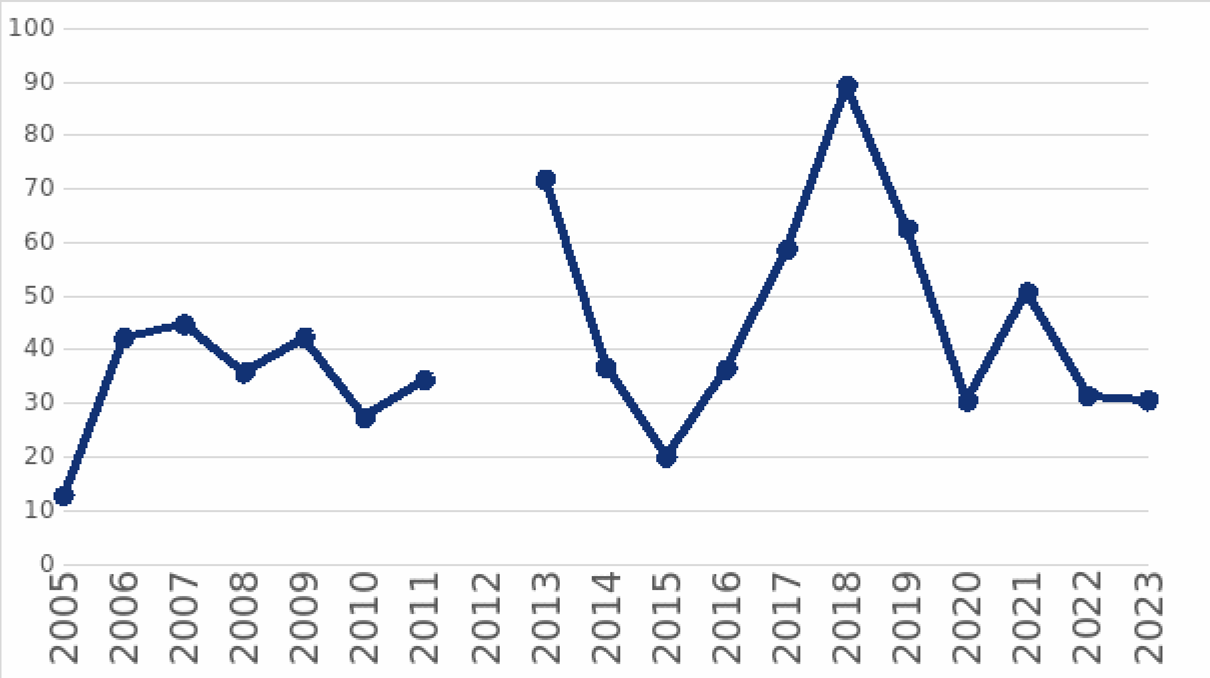

Figure 3: The mean annual Barents Sea benthos biomass (kg/nm) from 2005-2023. Missing data from 2012 due to trawl defect.

Geographically have an area of lower benthos biomass in the Russian areas increased during 2020-2023 (see figure below).

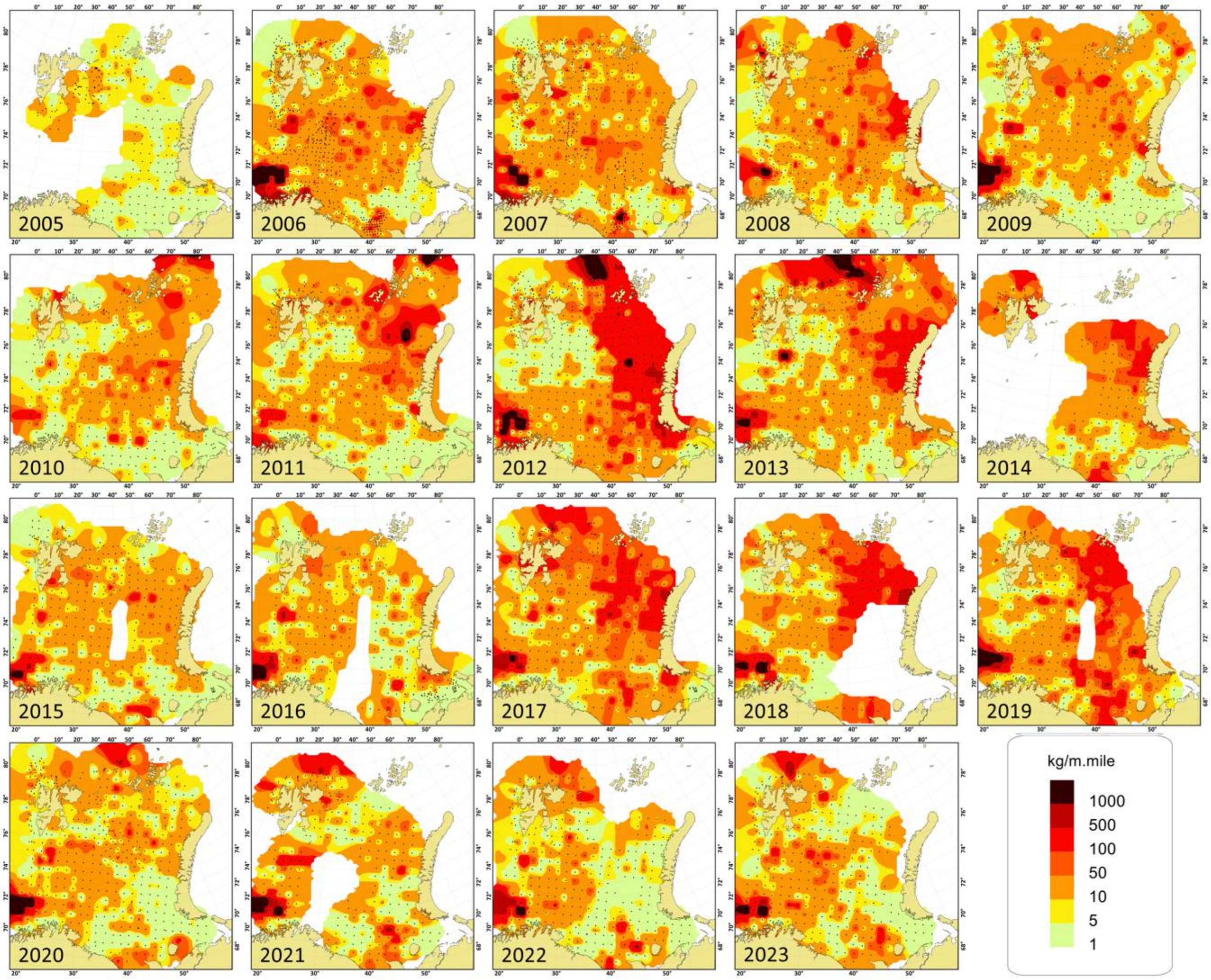

Figure 4: The spatial extrapolated benthos biomass across sampled stations for the period 2005-2023.

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3.10 - Barents Sea megabenthos under impact of red king crab and snow crab

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Extended abstract

Recently, the emergence of new species on the Barents Sea shelf has become fairly common [Zakharov, Jørgensen, 2017]. As a rule, these are single findings, and the impact of such invaders on native communities is mostly local and limited. The exceptions are the red king crab *Paralithodes camtschaticus* (Tilesius, 1815) and the snow crab *Chionoecetes opilio* (Fabricius, 1788). Due to their size, these species can be classified as megabenthos; so the investigation of their bycatch in trawl benthos is of certain interest when studying both their acclimatization and associated dynamics of benthic communities in the Barents Sea.

The introduction of the red king crab into the Barents Sea occurred more than 60 years ago [The Red King Crab, 2021]; the introduction of the snow crab, more than 25 years ago [Kuzmin et al., 1998; Snow Crab Chionoecetes opilio, 2016]. The expansion of the range and increase in the abundance of red king crab since the early 1990s resulted in colonization of a vast area in the southern Barents Sea by this species. The range of the snow crab rose from the Goose Bank (one finding in 1996) to a broad area in the Barents and Kara seas and adjacent waters. The nutrition of the red king crab and snow crab was properly analyzed, and this allowed both to describe their food spectrum in the Barents Sea and identify the most intensively consumed groups of animals [Manushin, 2021; Snow Crab…, 2016; Zakharov et al., 2021]. With bycatch data from ichthyological trawls, one can assess the distribution of invasive crabs, their biomass in new areas, and possible effect on other megabenthic species. In this regard, the aim of this study is to reveal changes in the structure of megabenthic communities that have occurred over the past 15 years under the impact of the red king crab and the snow crab.

Material for this work was sampled during annual Russian–Norwegian ecosystem survey in August– November 2006–2020 (Fig. 1A). The research covered the entire Barents Sea, the northwestern Kara Sea, the eastern sites of the Norwegian and Greenland seas, and adjacent areas of the Arctic Ocean. Trawls were mainly carried out within nodes of the standard grid of stations, with a distance between stations of about 40 nautical miles (Fig. 1B).

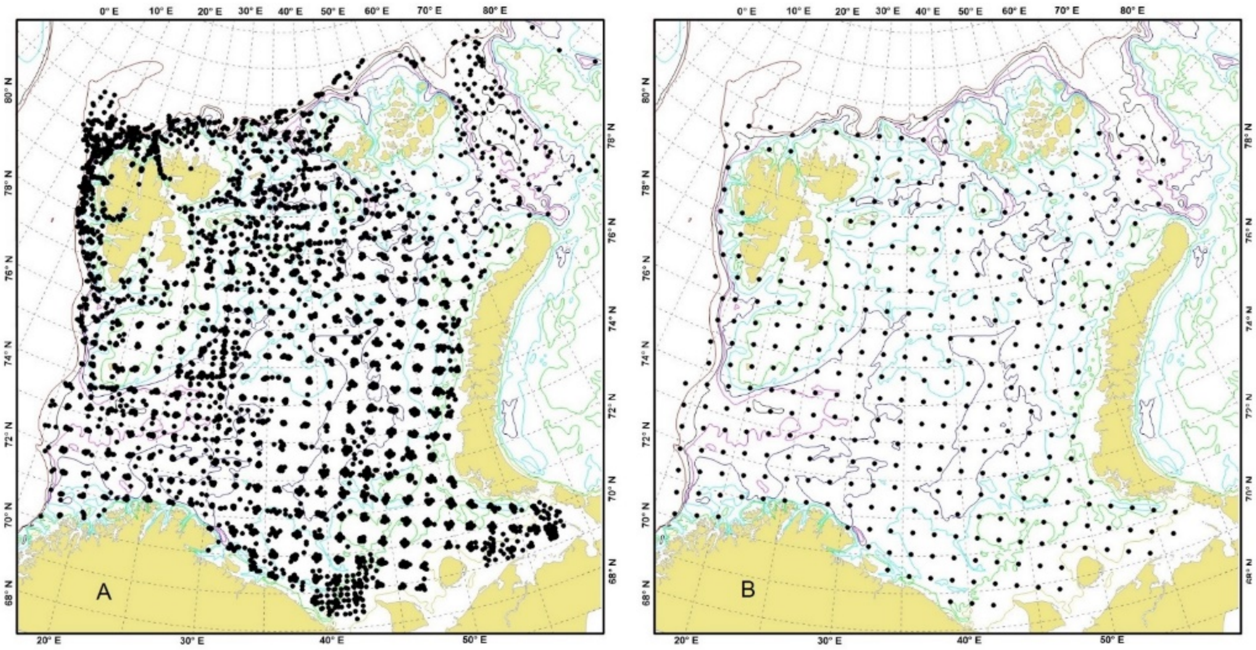

Figure 1. Position of bottom trawls in 2006-2020 (A) and the standard grid of stations (B) in the joint Russian-Norwegian Ecosystem Survey

To estimate the changes in megabenthic communities over 15 years, this period was divided into three ones: 2006–2010, 2011–2015, and 2016–2020. Stations performed during each period and located at a distance of < 35 nautical miles from nodes of the standard grid (Fig. 1B) were combined for subsequent analysis. Stations situated at longer distances and not covered by the standard grid were excluded from the dataset. Each trawl point matched only one node of the standard grid of stations. The variation in depths between stations at nodes of the standard grid for each period averaged about 5 m. The material obtained in different years during cruises of several RV and processed by researchers of various qualifications differed in the detail of taxonomic processing. Accordingly, to standardize the initial data and analyze it properly, part of the material was not used or was taxonomically grouped. Species and taxa recorded only once during the entire study period were excluded from the dataset. Supraspecific identification of widespread and easily identifiable species was ruled out as well [e.g., Hyas sp. against the backdrop of occurrence of two well-recognized species, Hyas araneus and Hyas coarctatus. Animals identified down to the phylum, class, and order levels were excluded from the analysis due to their low abundance or negligible contribution to total biomass. Species with low biomass (bryozoans, hydroids, and amphipods) and difficult to taxonomically identify (sponges and polychaetes) were grouped within family rank. For each group of stations united within nodes of the standard grid of trawling, a total list of taxa was made, and their ratios in the total biomass were determined. The obtained data were processed by k-means clustering using the Bray–Curtis dissimilarity as a station-by-station similarity measure. The number of clusters was determined for each period based on testing their optimal number by various statistical techniques (Zakharov et al., 2024).

Monitoring which we have begun in 2004–2005 showed that snow crab and red king crab were recorded in the survey area at 1% of stations. Then, their occurrence changed. For snow crab, it increased sharply and rose almost by 30 times by 2020. For red king crab, it remained almost at the same level of 2% until 2013, started to increase in 2014, and finally reached the value of 4–5%. This reflects different stages of acclimatization for crab populations during the study period. Specifically, red king crab was at the last stages of naturalization, while snow crab was actively exploring the recipient ecosystem expanding its range and increasing the abundance. In 2004, the distribution area of snow crab was 20 thousand km²; that of red king crab was 28 thousand km². By 2020, the range of snow crab increased by more than 40 times and reached the value of 831 thousand km², while that of red king crab rose only by 6 times, up to 176 thousand km². The rates of increase in both the frequency of occurrence and range for snow crab were significantly higher than those for red king crab.

To analyze the fluctuations in the composition of megabenthos over 15 years, we selected nodes of the standard grid of stations (Fig. 1B) where snow crab and red king crab were encountered during the entire study period. The proportion of snow crab in the total biomass of bycatch in its habitat gradually increased from 0.2% in 2006 to 2% in 2011. In 2012, it rose to 5%; by 2013, the value increased sharply to 15%. In subsequent years, the relative biomass stabilized, varied slightly at one level, and reached 20.6% by 2020. In 2008–2013, the relative biomass of red king crab in the survey area varied at the level of 1–2%; since 2014, it increased sharply; and by 2020, it amounted to 28.9% (Fig. 3). In general, in the distribution area of considered invaders, the proportion of almost all megabenthic groups decreased since 2006: ascidians, from 5 to 0.1% in 2020; cnidarians (mainly, sea anemones), from 7 to 1%; crustaceans (excluding introduced species), from 6 to 3%; and molluscs, from 5.2 to 1.3%. The proportion of echinoderms dropped significantly: from 62% in 2006 to 36% in 2020. No changes were recorded in the relative biomass of polychaetes, nemerteans, priapulids, etc. At the same time, an increase in the proportion of sponges was noted in bycatches: from 5 to 10%.

According to the results of k-means clustering, 11 clusters were identified in the first analyzed period; 11 clusters were revealed in the second one; and 12 were defined in the third one (Fig. 2, Table 1).

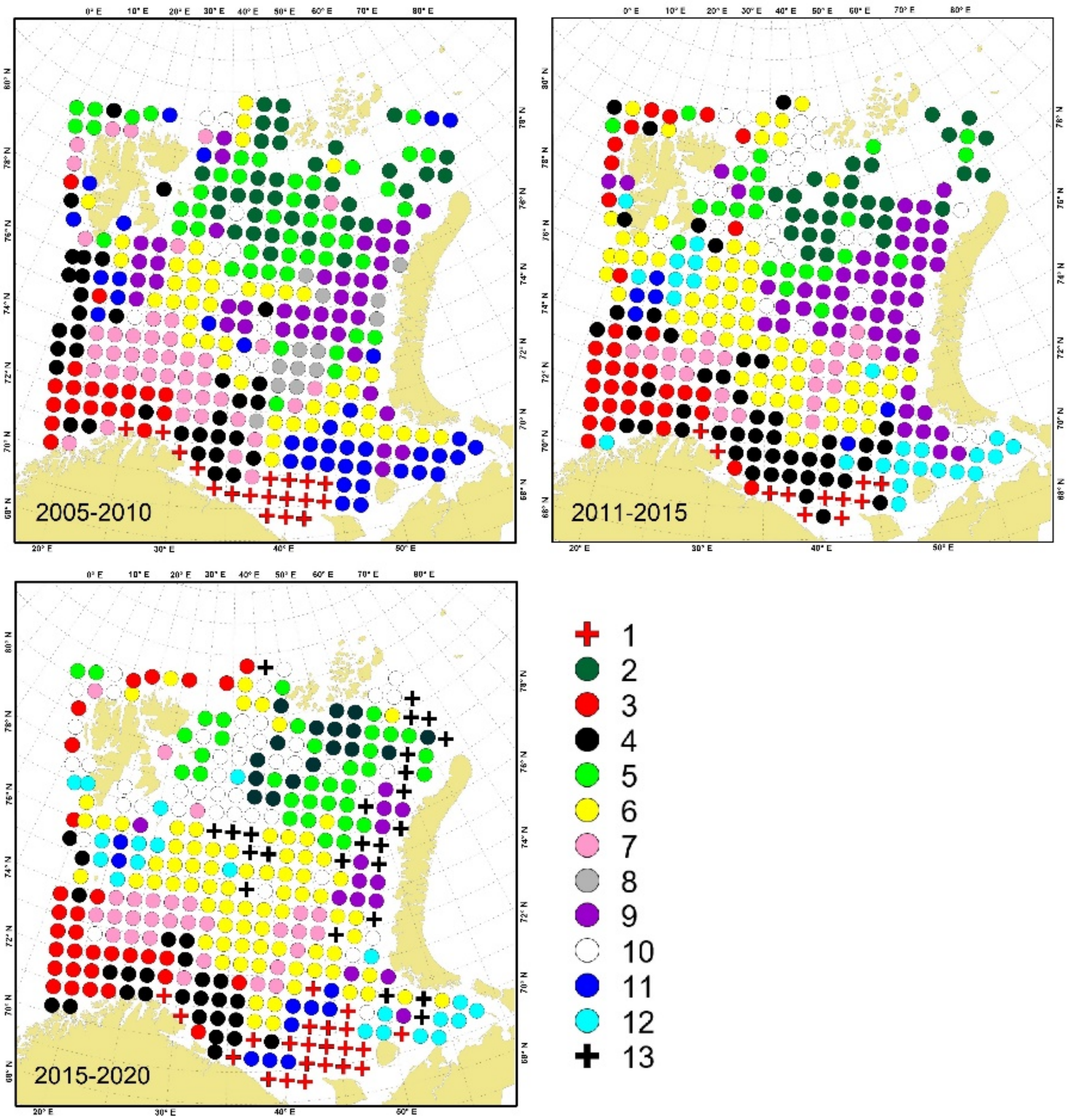

Figure 2. Megabenthos communities in the Barents Sea and adjacent waters based in 2006-2010, 2011-2015 and 2016-2020. The designations and descriptions of the communities are given in Table 1.

In 2006–2010, the biomass of snow crab rapidly increased in the southeastern Barents Sea. This species became a subdominant one [against the backdrop of prevalence of starfish Ctenodiscus crispatus (Bruzelius, 1805)] in soft-soil communities in the Goose Bank area [community No. 6 in Fig. 7 and Table 1]. By 2010, snow crab already locally dominated in the biomass of megabenthic catches in this site [Lyubin et al., 2010].

Table 1. Megabenthos communities in the Barents Sea in 2006-2010, 2011-2015 and 2016-2020. Designation of communities as in fig. 7. Dominants and subdominants are given with indication of relative biomass (%)

2006-2010	**2011-20 15**	**2016-2020**

Communities	Dominants and subdominants	Communities	Dominants and subdominants	Communities	Dominants and subdominants
1 ✚	***Paralithodes camtschaticus*** (55,0) Geodiidae (1,9) *Hippasteria phrygiana* (1,7)	1 ✚	***Paralithodes camtschaticus*** (41,7) Suberitidae (1,8)	1 ✚	***Paralithodes camtschaticus*** (61,2)
2 ●	*Gorgonocephalus* (14,8) *Ophiopleura borealis* (9,7) *Umbellula encrinus* (7,6) *Heliometra glacialis* (7,3) *Ophiacantha bidentata* (5,8)	2 ●	*Ophiopleura borealis* (21,0) *Gorgonocephalus* (12,9) *Molpadia* (6,6) *Ophiacantha bidentata* (5,6) *Ophioscolex glacialis* (4,5)	2 ●	*Ophiopleura borealis* (24,3) ***Chionoecetes opilio*** (4,9) *Molpadia* (4,0) *Gorgonocephalus* (3,7)
3 ●	Geodiidae (75,4) *Parastichopus tremulus* (1,4)	3 ●	Geodiidae (67,2) Ancorinidae (4,9)	3 ●	Geodiidae (70,2) Ancorinidae (4,9)
4 ●	Actiniaria (57,4) Alcyonacea (7,0) Hormathiidae (5,1) *Hippasteria phrygiana* (3,5)	4 ●	Hormathiidae (8,7) Actiniaria (6,5) *Urasterias lincki* (6,2) *Ctenodiscus crispatus* (5,0)	4 ●	*Bolocera tuediae* (10,1) *Hippasteria phrygiana* (10,1) *Parastichopus tremulus* (8,2) Hormathiidae (5,0) *Molpadia* (4,5)
5 ●	*Gorgonocephalus* (48,8) Actiniaria (2,9) *Heliometra glacialis* (2,8) *Ctenodiscus crispatus* (2,5)	5 ●	*Gorgonocephalus* (45,9) *Ctenodiscus crispatus* (4,2) *Sabinea septemcarinata* (3,1) ***Chionoecetes opilio*** (2,1)	5 ●	Gorgonocephalus (37,6) ***Chionoecetes opilio*** (13,0) Ophiopleura borealis (4,2) Ophioscolex glacialis (4,1)
6 ●	*Ctenodiscus crispatus* (23,7) ***Chionoecetes opilio* (7,7)** *Urasterias lincki* (7,0) Icasterias *panopla* (6,7)	6 ●	*Ctenodiscus crispatus* (39,6) *Icasterias panopla* (18,6) *Urasterias lincki* (10,0) *Sabinea septemcarinata* (8,7) Hormathiidae (5,8)	6 ●	*Ctenodiscus crispatus* (23,1) *Urasterias lincki* (9,6) *Icasterias panopla* (6,9) Polymastiidae (5,0) ***Chionoecetes opilio*** (4,4)
7 ●	Polymastiidae (10,6) Actiniaria (8,3) *Molpadia* (7,5) *Ctenodiscus crispatus* (6,2) Theneidae (4,1)	7 ●	*Molpadia* (24,8) *Ctenodiscus cris* patus (11,2) Polymastiidae (3,6) Theneidae (3,6)	7 ●	*Molpadia* (22,9) *Ctenodiscus crispatus* (12,3) *Bathyarca glacialis* (7,6) Polymastiidae (7,1)
8 ●	*Ciona intestinalis* (13,7) *Molpadia* (11,5) *Ctenodiscus crispatus* (4,3) *Strongylocentrotus* (4,3)				
9 ●	*Strongylocentrotus* (35,1) *Sabinea septemcarinata* (5,7) *Gorgonocephalus* (5,5) *Ctenodiscus crispatus* (3,6)	9 ●	*Strongylocentrotus* (34,4) ***Chionoecetes opilio*** (18,0) *Ctenodiscus crispatus* (9,2) *Urasterias lincki* (4,6) *Gorgonocephalus* (3,6)	9 ●	*Strongylocentrotus* (37,9) ***Chionoecetes opilio*** (9,9) *Gorgonocephalus* (1,7)

10 ○	*Heliometra glacialis* (27,6) Actiniaria (6,0) *Sabinea septemcarinata* (3,7)	10 ○	*Gorgonocephalus* (7,9) *Sabinea septemcarinata* (6,4) *Heliometra glacialis* (6,1) *Ophiacantha bidentata* (5,0) *Strongylocentrotus* (4,4) *Ctenodiscus crispatus* (4,1)	1 0 ○	*Heliometra glacialis* (7,6) *Sabinea septemcarinata* (6) *Ctenodiscus crispatus* (5,6) *Chlamys islandica* (5,0) *Ophiacantha bidentata* (4,7) *Gorgonocephalus* (4,5)
11 🔵	*Sabinea septemcarinata* (15,4) *Cucumaria frondosa* (12,7) *Sclerocrangon boreas* (7) *Hyas araneus* (6,4) *Balanus* (5,8) *Strongylocentrotus* (5,4)	11 🔵	*Cucumaria frondosa* (32,0) *Microcosmus glacialis* (4,7) *Balanus* (1,9)	11 🔵	*Cucumaria frondosa* (21,2) ***Paralithodes camtschaticus*** (13,8) Suberitidae (7,0) Hormathiidae (2,3)
		12 ●	*Strongylocentrotus* (13,8) *Balanus* (10,4) *Chlamys islandica* (6,9) *Alcyonidium gelatinosum* (5,6) *Hyas araneus* (4,7)	12 ●	*Strongylocentrotus* (16,2) *Balanus* (9,1) *Chlamys islandica* (6,9)
				13 ✚	***Chionoecetes opilio*** (35,3) *Ctenodiscus crispatus* (4,1) *Gorgonocephalus* (3,3)

In 2011–2015, snow crab became a subdominant species in the Novaya Zemlya shallows (community No. 9 in Fig. 7 and Table 1) and the northern Central Bank (No. 5). During this period, it was a subdominant species in almost all communities of the Novaya Zemlya archipelago. The area of several communities shifted. Specifically, for sea urchins the area decreased (No. 9), and for the mud star C. crispatus (No. 6), it increased. The snow crab populations were unstable (see Fig. 5). Thus, the dense aggregation in the Goose Bank dropped greatly, and this is associated with the redistribution of aggregations in general. The snow crab aggregations that moved to the areas of the Central Bank and the southern Novaya Zemlya Bank were increasing their proportions in communities since 2006, and in the northern Novaya Zemlya shallows, since 2009. In 2016–2020, snow crab prevailed in communities (No. 13 in Fig. 7 and Table 1) between the Novaya Zemlya and Franz Josef Land archipelagos on the border with the Kara Sea, on the slopes of the Novaya Zemlya shallows and in the Central Bank, and in the Southern Novaya Zemlya Trench. The area of communities with the subdominance of this hydrobiont increased and covered the area from the Franz Josef Land and Novaya Zemlya archipelagos to the Perseus Bank, as well as the northern Pechora Sea (No. 2, 5, and 9). To the south of the Franz Josef Land archipelago, snow crab was a subdominant species in the community of brittle star Ophiopleura borealis Danielssen & Koren, 1877 (No. 2). In the Novaya Zemlya Bank, in the community dominated by sea urchins of the genus Strongylocentrotus Brandt, 1835 (No. 9), mainly Strongylocentrotus pallidus (G. O. Sars, 1871), snow crab was the second most dominant species. In the eastern sea, in the community of brittle stars of the genus Gorgonocephalus Leach, 1815 (No. 5) and O. borealis (No. 2), snow crab was on the second position. In 2006–2010, red king crab prevailed among megabenthic organisms in coastal waters of the Kola Peninsula, in the Murman Rise, and in waters off the Kanin Peninsula (community No. 1 in Fig. 7 and Table 1). In the community of sponges (No. 3) in the Eastern Murman and warm-water species (No. 4) in the Western Murman, it was a subdominant species. In 2011–2015, it still dominated in the North Cape area and Eastern Murman waters, but became less common in bycatches in the coastal Western Murman and Murmansk Rise. Dense aggregations of red king crab on the southern slope of the Kaninskaya Bank expanded eastward, to the Kanin Peninsula. In 2016–2020, the area of red king crab dominance expanded noticeably to the northeast: this species prevailed in communities around the entire Kanin Peninsula, north and west of Kolguev Island, off the Kaninskaya Bank, and in the Goose Bank. In the community of the orange-footed sea cucumber Cucumaria frondosa (Gunnerus, 1767) (No. 11 in Fig. 7 and Table 1), red king crab was the first subdominant in the areas of the southern Murmansk Rise, on the slopes of the Kaninskaya Bank, and in the southern Goose Bank. To a limited extent, it was also found in communities of sponges of the genus Geodia Lamarck, 1815 (No. 3), warm-water species (No. 4), and shallow-water species (No. 12) in the Pechora Sea. Moreover, it was recorded in the community of the snow crab (No. 13) at the southern tip of the Novaya Zemlya (see Fig. 1 and Table 1).

As shown, under current climatic conditions, red king crab will remain a part of megabenthic communities in the southeastern Barents Sea. Snow crab will continue to migrate from the east to the western Barents Sea, up to the Spitsbergen archipelago, where similar benthic communities exist; in case of colder conditions, its migration will occur faster. A scenario is possible in which shallow waters of the Spitsbergen archipelago will be a new reproductive center of the snow crab population in the Barents Sea, along with the current center near the Novaya Zemlya archipelago.

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3.11 - Vulnerability of the sponge communities under impacts of bottom trawling activity in the Barents Sea (based on the example of Rybach'ya Bank)

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Keywords: Vulnerable Marine Ecosystems (VMEs), sponges, trawling impact, Barents Sea

Short communication

Introduction

Sponges are one of most important group of the bottom fauna of the Barents Sea. They form the basis of Vulnerable Marine Ecosystems (VMEs) and provide habitat for many living organisms. VMEs are any benthic ecosystems that can be considered within clear spatial boundaries and are characterized by vulnerability to any fishing activities (ICES. 2019). It was shown earlier (Løkkeborg, Fosså, 2011; Lyubin et al., 2011) that a bottom trawl with ground rope have significant adverse impacts on benthic communities. In recent years, such an impact on VMEs in the Barents Sea has been widely discussed (Buhl-Mortensen et al. , 2019).

According to the results of the annual ecosystem surveys in 2005-2023, sponges were evenly distributed in the study area, but the largest aggregations were found in the northern shelf and the southwestern part of the Barents Sea (Atlas…, 2018; Eriksen E. et al., 2023). For instance, in 2023, the share of sponges in the total biomass of the benthic communities was estimated about 71%.

It was speculated that the large forms of epifauna are suffering the most from bottom fishing activities because of ground rope and trawl doors. These are communities of sponges and coral polyps, which are typical environment-forming organisms. Gradual reduction of such settlements finally may causes the collapse of the entire communities.

Figure 1 shows development of bottom trawl fisheries in the Barents Sea since 1960s. It is obvious that nowadays fishery activities have largely increased.

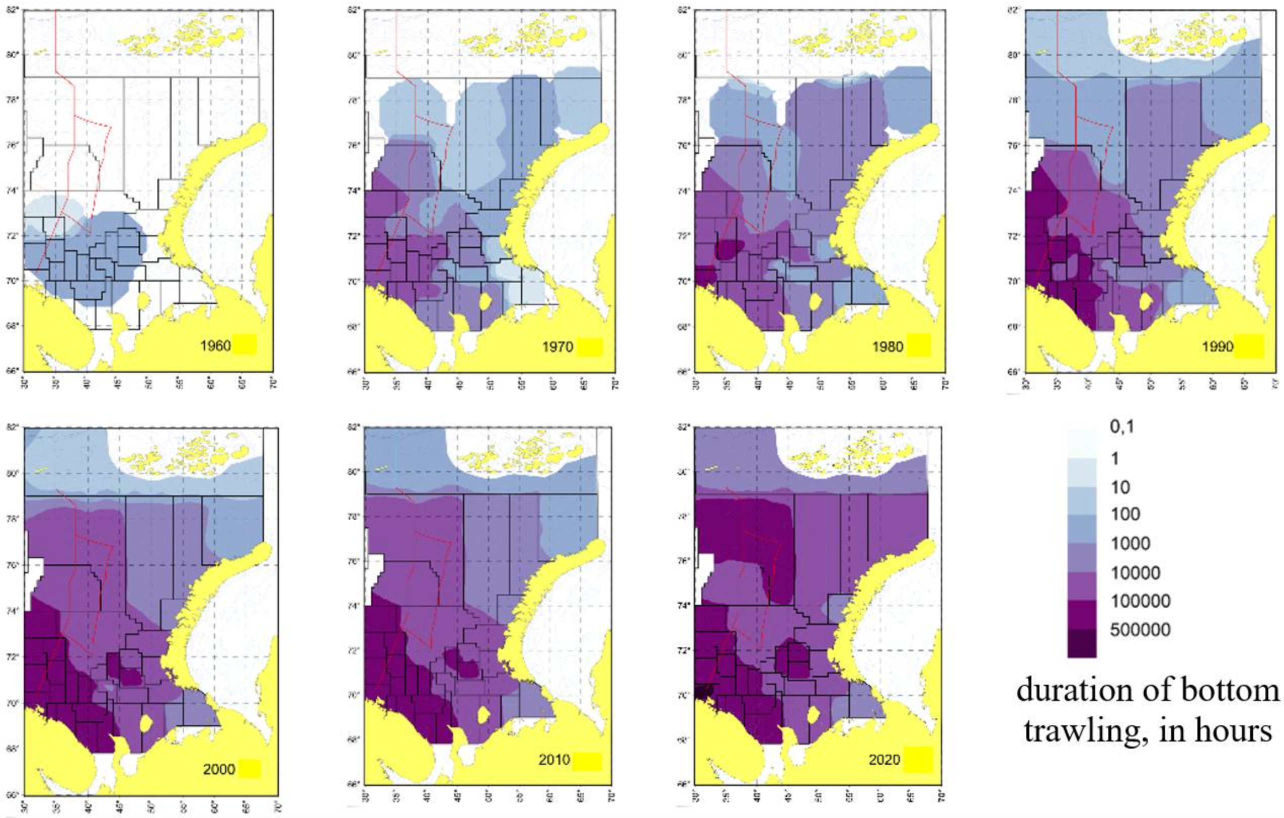

Figure 1. Cumulative trawl load in the Russian economy zone of the Barents Sea from 1960 to 2020

Materials and methods

The biomass data of sponges from station No. 2 (70°00 NN 33°30 EE) of the Kola section was used. The station has the longest time series (since 1930), where the large number of sponges' spicules in bottom sediments was observed. The results of the scientific papers with the data about dense aggregations of sponges on the Rybachaya Bank were also used). The assessment of the state of macrozoobenthos was carried out based on materials collected during the surveys in 1930-2012 (167 stations, more than 400 samples collected by a van Veen dredge with a sampling area of 0.1 m ^{2}) in the Barents Sea.

Results and discussion

Since the beginning of the observation period, the large sponge aggregations were identified in the area of the Rybachaya Bank back to 1938 (Filatova, 1938). But up to 1970s, the share of sponges in the total biomass of benthic organisms at station No. 2 ranged from 55 to 98% with maximum value of more than one kg/m ^{2} . However, nowadays sponges have lost their leading position in benthic communities in this area (fig. 2).

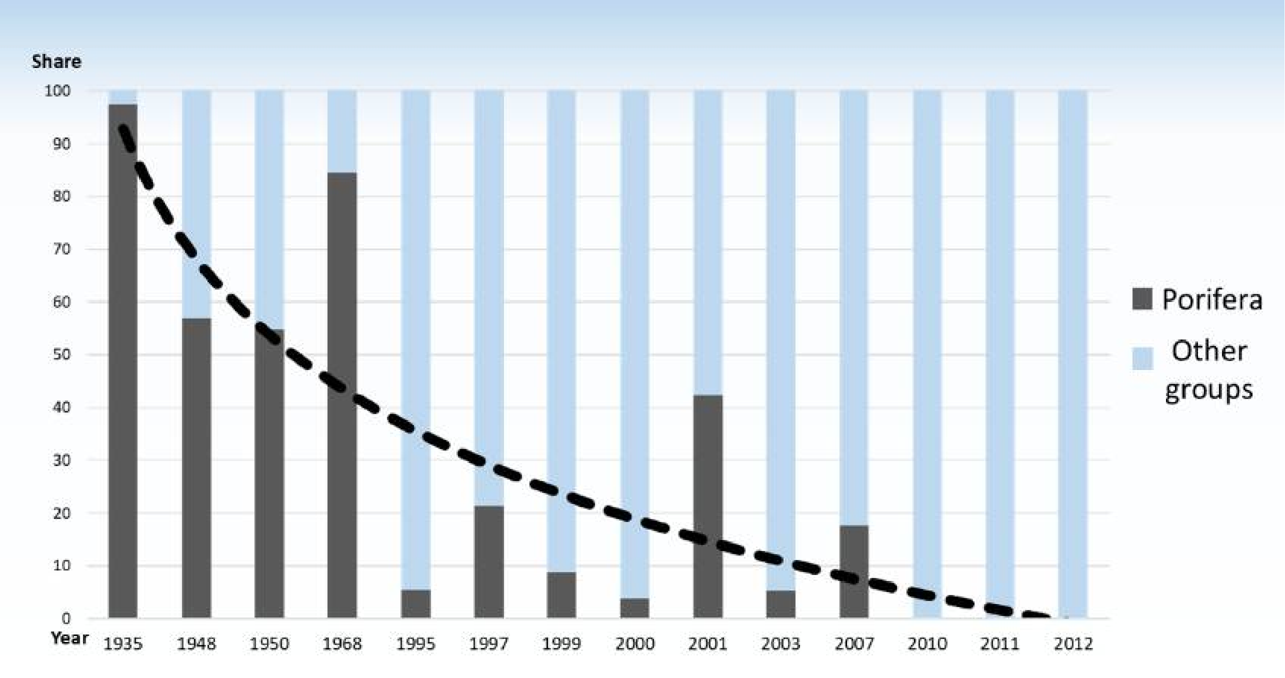

Figure 2. Percentage of sponges in the total biomass of bottom organisms in bottom grab on the station No.2 in 1935 - 2012.

The analysis of ratio of dominant groups of benthic organisms of the other stations of the Kola Meridian shows that the dominant groups of organisms in the whole studied area was Polychaeta (fig. 3).

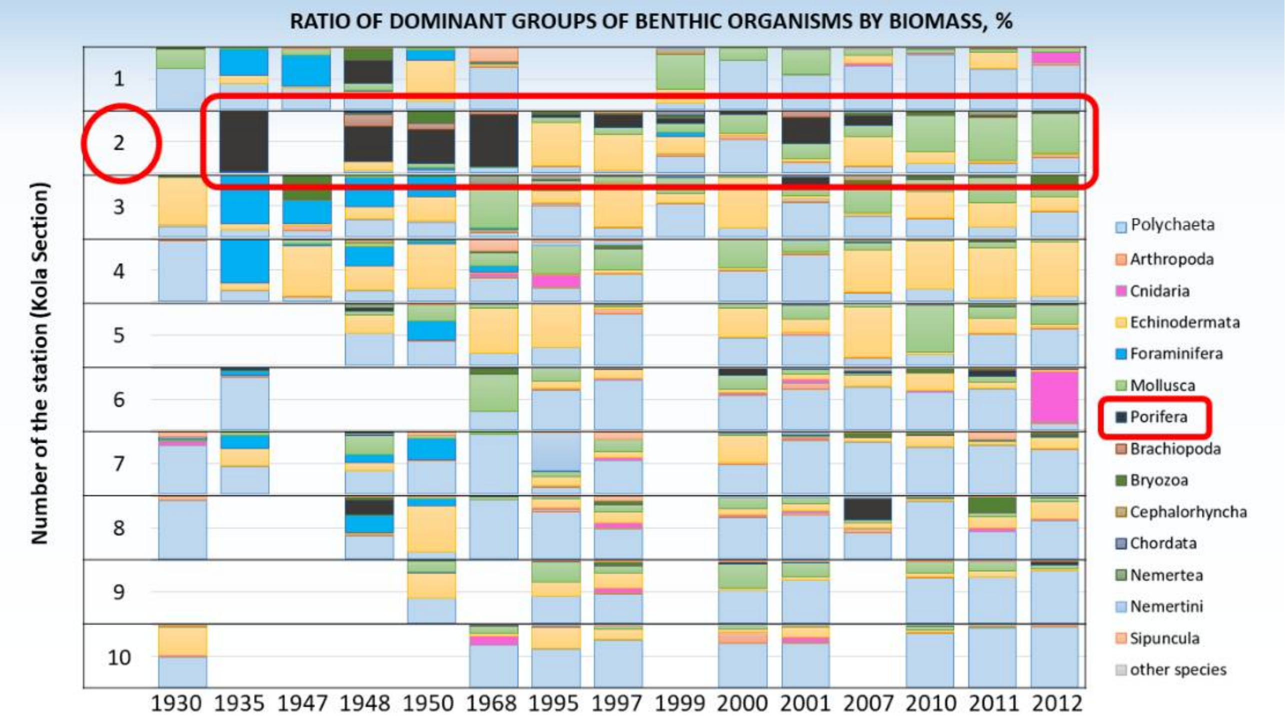

Figure 3. Ratio of dominant groups of benthic organisms by biomass, %.

The southern stations (No. 1 and No. 2) of the Kola Meridian are located in the area of intensive trawl fishing activities. Gradual increase in fishing activities has been observed since early 1960s (fig. 1). It appears that large sponges are much more damaged than the small epifauna and infauna organisms.

Conclusion

The difference in the dynamics of benthos biomass at station No. 2 of the Kola Sections from neighboring stations is clearly demonstrate the adverse impacts of bottom fishing activities on sponges' community. The data obtained can be used as a forecast of the dynamic of the aggregation of sponges in the western and northern parts of the Barents Sea shelf.

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3.12 - A hidden biodiversity in the Northeast Atlantic Ocean: ascaridoid nematodes in the Atlantic cod *Gadus morhua*

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Abstract

Cod is a key demersal species in the Arctic waters of the NE Atlantic, playing a crucial role in the region's marine ecosystem and fisheries. Northeast Arctic cod (locally called "Skrei") is a separate stock of Atlantic cod inhabiting Barents Sea waters. Its members show distinct migratory behavior which involves spawning along the Norwegian coast, sustaining rich fisheries. Parasitic ascaridoids commonly occur in cod in high numbers. This study aimed to examine ascaridoid species diversity and spatial distribution, including potentially zoonotic species, in Arctic populations of Atlantic cod. More than 100 fish were sampled from the Barents and Norwegian Seas during 2019–2020. Fish were inspected for nematodes using the UV-press method (ISO 23036-1:2021). According to morphology, larvae were assigned to *Anisakis* , *Phocanema, Contracaecum* or *Hysterothylacium* . Genetic species identification was performed on a subsample of 150 randomly selected nematodes comprising specimens of the four genera, obtained from different tissues of the studied cod, by sequencing of the mitochondrial cytochrome c oxidase subunit II (mtDNA *cox2*) gene. Genetic identification of subsamples of ascaridoid larvae revealed the presence of 8 species in the examined fish, i.e. *A. simplex* (s.s.), *C. osculatum* A, *C. osculatum* B, *Phocascaris cystophorae, P. decipiens* (s.s.), *P. krabbei* , *P. bulbosa* and *H. aduncu m.* Ascaridoid abundance was significantly positively related to fish length. Parasites were mostly located in viscera. Only *A. simplex* (s. s), *P. krabbei* and *P. decipiens* (s.s.) were found in flesh. *P. decipiens* (s.s.) often occurred in the dorsal and caudal musculature, *A. simplex* (s. s) and *P. krabbei* mostly in belly flaps and *P. bulbosa* in liver. Massive infections by *C. osculatum* sp. B and *A. simplex* (s.s.) were also found in fish caeca. Adult reproductive stages of *H. aduncum* resided in the stomach lumen and intestine. The high ascaridoid diversity observed in cod from Arctic waters is supported by the wide range of cetacean and pinniped hosts inhabiting the northern NE Atlantic, the abundance of intermediate hosts, and ecological conditions that favour the complex life cycles of these nematodes.

Link to the published paper: https://pubmed.ncbi.nlm.nih.gov/36321524/

4 - THEME SESSION IV: MULTISPECIES AND ECOSYSTEM MODELLING

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4.1 - Introduction to multispecies and ecosystem modelling in the Barents Sea

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Abstract

Practical interest in the development of multispecies models for fisheries management in the Barents Sea arose in the 1980s for a number of reasons. This was primarily related to a sharp decline in stocks and catches in the Barents Sea in that period due to overfishing and negative environmental impacts on the recruitment of commercial species. The dramatic consequences of the capelin stock collapse for the cod stock have shown the need to consider trophic interactions between the commercial species. The development of a joint Russian-Norwegian database on cod stomach contents and the calculations of consumption of commercial species by marine mammals provided the required input data for the multi-species models. The development of the MS VPA multispecies model for the North Sea in those years also facilitated the development of multispecies models for the Barents Sea.

At the end of the 20th century, close cooperation was established between Russian and Norwegian scientists in the development of multispecies models for the Barents Sea. Sigurd Tjelmeland played the key role in this cooperation as an organizer of joint IMR-PINRO research on multispecies modelling for the Barents Sea. From the mid-1980s to the mid-1990s, major efforts were focused on complex models involving many species (MULTSPEC, AGGMULT, MSVPA). Since the late 1990s, priority has been given to less complex models involving fewer species and biological processes (Gadget, Bifrost, STOCOBAR), as such models were considered more suitable for direct use in stock assessment. Since the 2010s, there has been an increased interest in ecosystem modelling (ATLANTIS, DSF, EFIBAR).

Ecosystem models describe the structure and function of an ecosystem. These models deal with physical variables (currents, temperature, salinity), chemical variables (acidification, major nutrients) and biological variables (phytoplankton, plankton, benthos, fish and top predators). Ecosystem models can be used both to better understand the functioning of a marine ecosystem, and to provide indications of how an ecosystem is likely to change in response to climate change and to changes in human activities, including fisheries.

A wide variety of available ecosystem models allow us:

- to address different questions on future ecosystem functioning at various levels of details or complexity;
- to evaluate uncertainty and test hypotheses by varying assumptions;
- to gain understanding on the ecosystem now and in the future.

According to a review conducted by WGIBAR in 2017, approximately 20 ecosystem and multispecies models

have been developed for the Barents Sea. These models have been widely used in various theoretical analyses, but none of them has been used as an operational model in stock assessment. The reason for this is the single-species approach to current stock assessments and the complexity of multi-species models, which makes them difficult to use in short-term forecasting.

4.2 - Stable isotopes as a tracer of the marine environment ecosystem studies

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Abstract

The isotopic parameter $\delta^{18}O$ in oceanography is used for the calculation of mixing proportions of the Atlantic, rivers, and melted waters as well as the relative content of ice-forming waters. The isotope parameter $\delta^{18}O$ has unique conservative properties. It does not depend on chemical–biological processes and is an ideal tracer for nutrients balance estimates. This parameter in oceanography is usually used for the calculation of mixing proportions of the basic waters: Atlantic, rivers, and melted waters as well as the relative content of ice-forming waters. Using these values in a system with the nutrient concentrations in the cores of these waters, a "conservative" concentration of these nutrients can be calculated, which is determined only by water mixing.

These concentrations are reference points for water nutrients reserve changes at the expense of the «non-conservative» factors (photosynthesize and geochemical sedimentation). Using this approach in the calculation of primary production allows moving from the constant stoichiometric ratios to the floating ratios observed in the actual ecosystem.

Based on the proposed method, the nutrient consumption features and primary production changes in the Barents Sea were studied. According to the maximum value of primary production in the summer or early-autumn, the following areas were identified: an area with the maximum values of gross primary production (GPP > 150 g C m^2), three regions with increased values (GPP > 100 g C m^2), and two regions with relatively low values (GPP < 100 g C m^2). A shift in the silicon (Si) values away from the Redfield-Richards ratio and toward dinoflagellates has been observed. Using this methodology with the available long-term salinity and nutrient data will allow future studies of the climatic variability of these parameters, from variability in nutrient uptake to variability in productivity of the study area.

The contents of the report are set out in the following article:

https://www.mdpi.com/2073-4441/15/2/328

Please refer to table 1, where $N\text{-}NO_4$, is $N - NO_3$

4.3 - Estimation of ecosystem effects on cohort growth of Northeast Arctic haddock

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Short communication

Abstract

Understanding, modelling and predicting growth variation and size at age in a stock is important for stock assessment and quota advice. Here we fitted cohort dependent Von Bertalanffy growth models to yearly length data of Northeast Arctic haddock (*Melanogrammus aeglefinus*) from three surveys: the Joint Norwegian Russian ecosystem survey (August-October), the Russian winter survey (October-December), and the Joint Norwegian Russian winter survey (February-March). We then did a simple analysis to test for temperature and density effects on cohort dependent growth variation. We found that cohort dependent growth estimated independently to each survey was strongly correlated, indicating consistent growth trajectories for the different cohorts across surveys. As expected, the effect of density on cohort growth was negative, indicating intra-cohort competition. The effect of temperature in the year of birth was negative; likely an indirect effect arising from positive effect of temperature on recruitment. Individual length within each age group varied considerably, parts of this variation was due to a geographical pattern in the size at age, with smaller haddock in the eastern Barents Sea. We suggest further studies focusing on local effects of temperature, food and density on haddock growth. We also suggest more in-depth studies to understand at what life stage the cohort effect on growth is the strongest and what are the limiting factors of individual growth of NEA haddock.

Introduction

Understanding, modelling and predicting growth and size at age is important for stock assessment and quota advice. In statistical catch at age models, weight at age estimates are needed to calculate stock biomasses, and for quota advice, future weight at age in the stock and in the catch must be predicted. Furthermore, for the evaluation of Harvest Control Rules and Management Strategies, models of stock dynamics are used, including size at age, often modelled as a function of stock biomass, for instance for North East Arctic (NEA) haddock (*Melanogrammus aeglefinus*) (ICES 2006). Growth and size at age and other demographic parameters can also be indicators of the “health” or state of a stock. In standard stock assessment, the state of the stock is assessed in relation to SSB levels (B_{lim} , B_{pa}), but there are many examples of this being a too simplistic measure of stock resilience to fishing or other external disturbances (Mangel and Levin 2005).

Drivers of growth variation in fish includes factors such as temperature and food. Often density is used as a proxy for food, based on the assumption that stock density varies much more than food abundance. In some species and stocks, with a broad diet and large variation in density, such as NEA haddock, this might be a reasonable assumption.

There are not many published studies on growth variation in NEA haddock, but Korsbrekke (1999) found that length at age varied between cohorts and that growth tended to be slower for strong cohorts. Also, cohorts following strong cohorts tend to have slower growth (Russkikh and Dingsør 2011). Therefore, in 2006 it was decided to use von Bertalanffy (VB) length growth models with cohort dependent K parameter and constant weight and length relationship to provide weight at age inputs for assessment and forecasts of NEA haddock

(ICES 2006).

Here we fitted VB length models with cohort dependent K-parameters to yearly length at age data from three surveys: the Joint Norwegian Russian ecosystem survey (BESS, August-October), the Russian winter survey (November-December), and the Joint Norwegian Russian winter survey (January-March), to examine if the surveys showed similar trends in haddock growth. We then did a simple analysis to test for temperature and density effects on cohort dependent growth.

Currently, the winter survey data is the only data set used for weight at age and maturity at age calculations for NEA haddock stock assessments. We fitted a simple gam model to individual length at age data from the winter survey to assess the variation in size at age for different age groups and how size at age varies geographically.

Material and Methods

NEA haddock is the second most important commercial stock in the Barents Sea, after cod (*Gadus morhua*). The stock is harvested primarily by Norway and Russia. Haddock spawns mainly along the shelf break between the Barents Sea and the Norwegian sea (Figure 1, Johannesen et al 2024), and the main feeding and nursery grounds are in the Barents Sea (Figure 1, Russkikh and Dingsør 2011, Russkikh and Filin 2019). Haddock feeds on a wide variety of prey (Dolgov et al this issue). Recruitment is highly variable, and tend to be positively correlated with high temperatures, but cod predation is also a driver of recruitment variabilities in some years (Russkikh and Filin 2019). Three surveys have been used in assessment (Figure 1), but one of the surveys (the Russian winter survey) was discontinued in 2019.

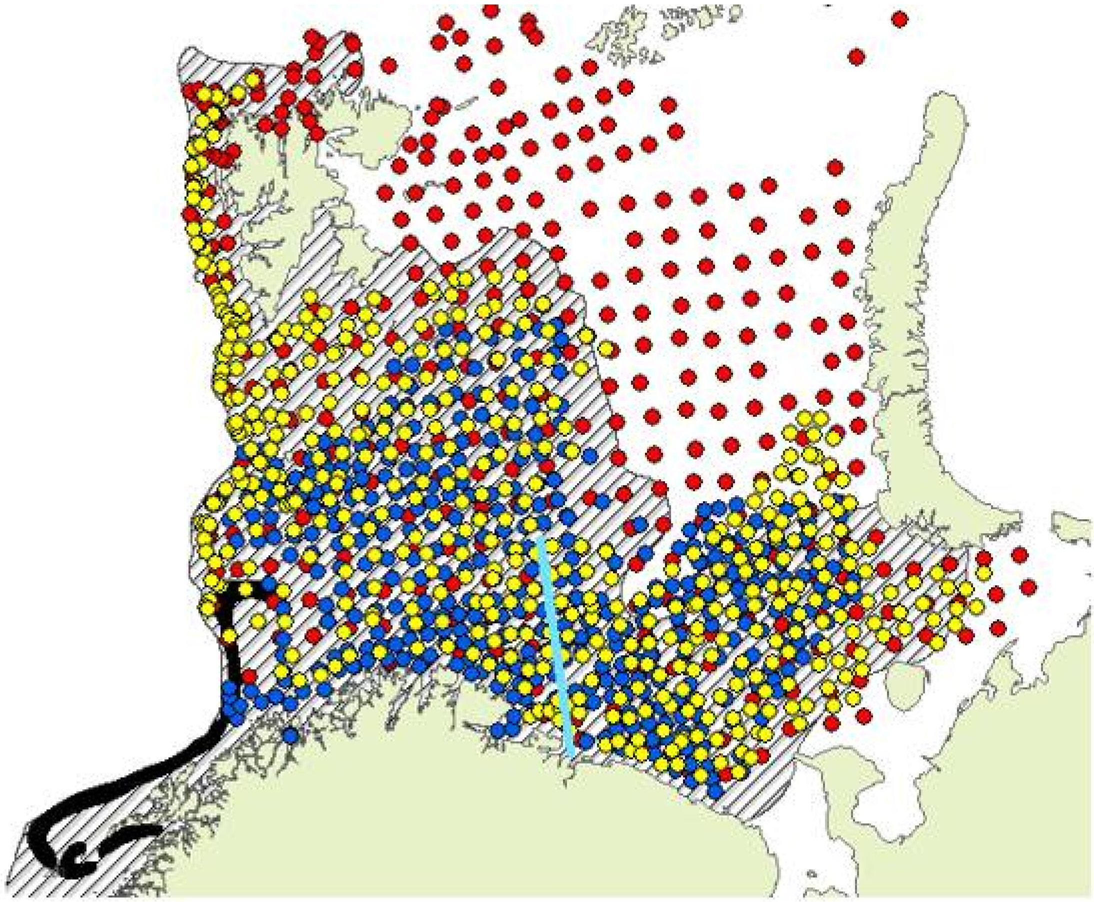

Figure 1. Map over the Barents Sea with the Kola oceanographic section (turquoise) and the distribution area (hatched) and main spawning ground (black) from the most recent official map from IMR. Circles: bottom trawl stations taken in 2011 by IMR and PINRO. Blue: Joint Norwegian Russian winter survey, note that the survey area was expanded in 2014. Red: ecosystem survey. Yellow: Russian winter survey, discontinued in 2019.

VB growth modelling

Yearly estimates of length at age data from the Joint Russian Norwegian winter survey (1982-2020), the Russian winter survey (1983-2015, 2017) and the Joint Russian Norwegian ecosystem survey (2004-2017, 2019) was taken from survey and assessment reports (Figure 1).

A specialised von Bertalanffy length growth model with cohort dependent K parameters was fitted to each of the three length-at-age survey series:

Eq. 1 $L_{A,y} = L_{\infty} - L_{\infty} e^{\text{¿¿}}$

where L_{∞} and A $_0$ parameters are fitted as a single parameter across all cohorts, whereas the K parameter is fitted separately for each cohort (y). A is age. The model was fitted to yearly average length at age (ages 1 and older) data with the TMB package in R.

The resulting K parameters for each cohort were correlated (Pearson correlation coefficient, r) across survey. A simple linear regression with annual Kola section temperature in the year of birth and log of the abundance of the cohort at age 3, the age of recruitment into the fishery, (R# ICES 2021) as predictor and survey specific K estimate, were then performed.

Individual length at age from the winter survey

We fitted a gam model to the individual length at age data from winter survey (1994-2020), with length as a function of smoothed age. We then plotted the residuals on a map to visualize spatial variation in size at age.

Eq. 2 gam_had<-gam(LengthCentimeter ~ s(age))

Results

Fitting growth models by survey

The temporal variation in K was similar for all three surveys (Figure 2). The positive correlation was strongest for the winter and ecosystem surveys (r=0.97, p<0.0001), compared to the winter survey and the Russian survey (r=0.74, p<0.0001) and the Russian survey and the ecosystem survey (r=0.72, p=0.01).

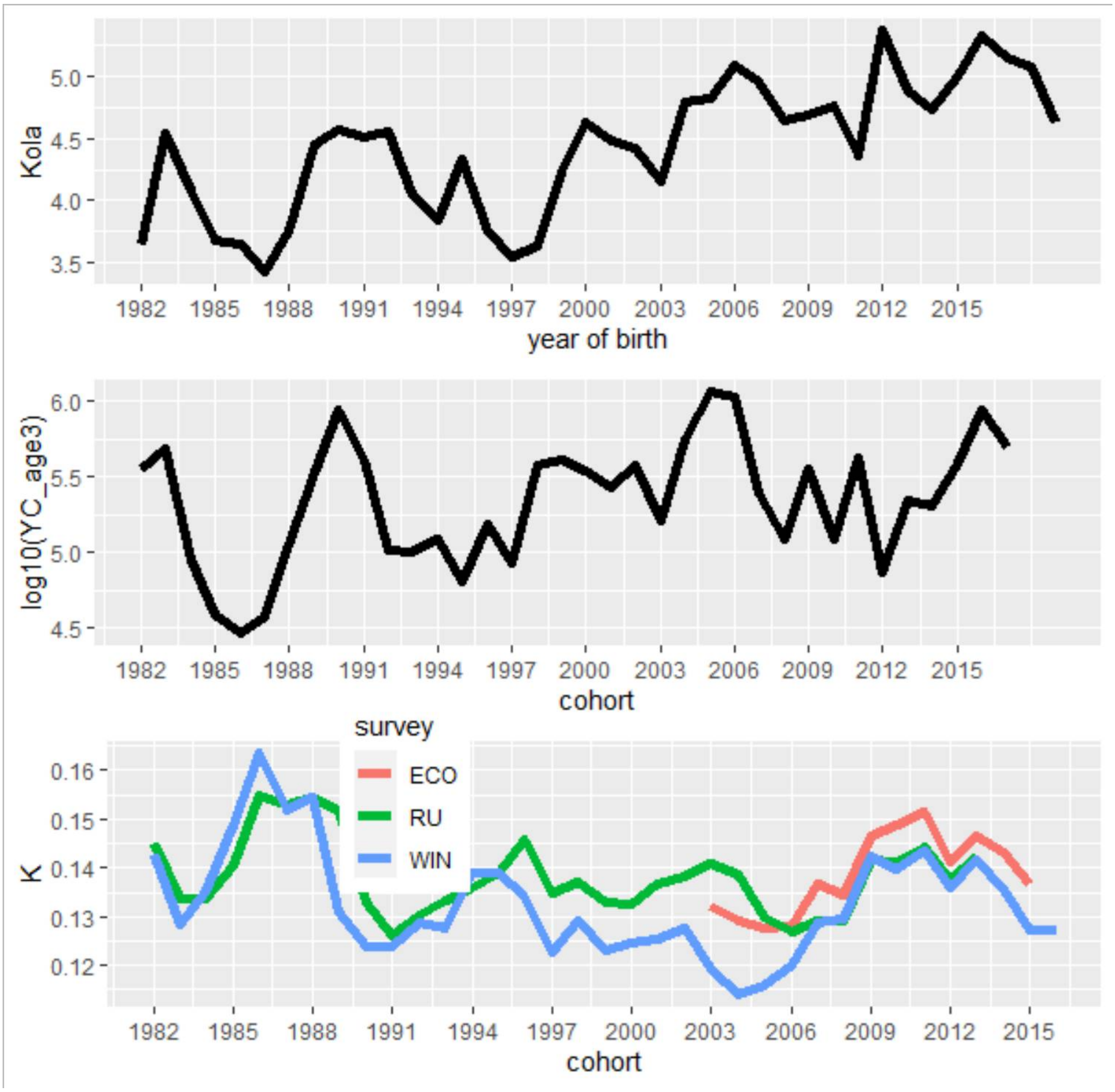

Figure 2. Upper: Annual temperatures from the Kola section. Middle: log10 of R3 from latest assessment, cohort dependent K from Eq 1 fitted to ecosystem survey (ECO, red), winter survey (WIN, blue) and Russian survey (RU green).

Kola temperature in the year of birth and cohort abundance at age 3 (Log10 transformed R3) was positively correlated (n=36, Pearson correlation r=0.6, p<0.001). The relationships between the Kola temperature and K estimated for all surveys were negative, significantly so for the Russian survey (Table 2). The effects of cohort abundance (log10 transformed R3) on K for all surveys, were negative significantly so for the winter survey only (Table 1).

Table 2. Slope estimates with standard errors and p-values for the linear regression of the effect of Kola temperature in the year of birth and abundance at age 3 (R3) (predictors) on cohort varying K parameters (response).

	Winter survey	**Russian survey**	**Ecosystem survey**
Kola temperature	-0.01 se 0.02 p=0.4	-0.3 se=0.01 p=0.04	-0.02 se: 0.03, p=0.7

R3 (log10)	-0.02 se=0.004 p<0.001	-0.005 Se 0.003 p=0.18	-0.01 se: 0.01, p=0.13
Adj. R^2	0.40	0.25	0.07

There was considerable variation in length within each age group (Figure 3).

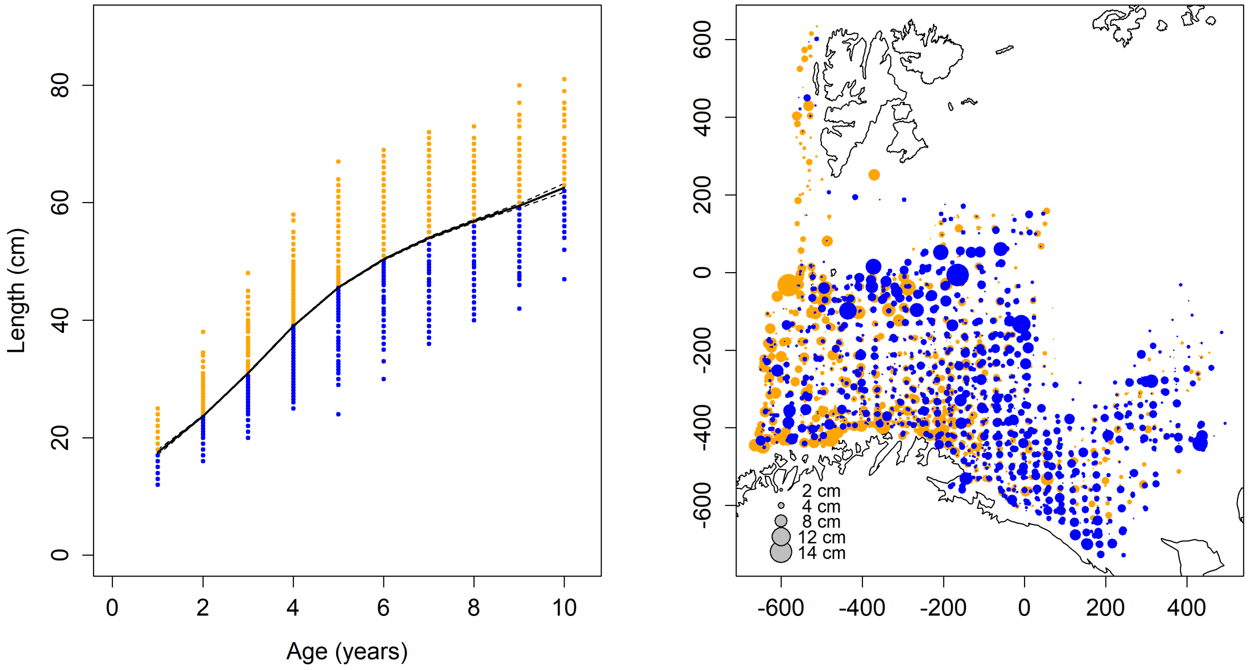

Figure 3. Left: Gam model (Eq. 2) fitted to individual length at age data (dots) from the winter survey, individuals smaller than predicted from the growth curve is shown in blue, and larger individuals are shown in orange. Right: map of residuals of all ages from eq.2, negative residuals shown in blue, positive residuals shown in orange.

Plotting the residuals from the simple growth curve model (Eq. 2) on a map, revealed a geographical pattern, with more negative residuals in the eastern Barents Sea compared to the western Barents Sea and along the coast of Northern Norway (Figure3).

Discussion

Haddock has highly variable recruitment, and NEA haddock has one of the most variable recruitments of all haddock stocks globally (Johannesen et al 2022). The strong cohort variation drive variation in growth and maturation (Korsbrekke 1999). Therefore, cohort dependent growth models have been used when estimating weight and maturity at age inputs to NEA haddock stock assessments since 2006 (ICES 2006).

The cohort K parameters fitted to each survey was strongly correlated indicating a consistency in growth trajectories for the different cohorts. The K parameters varied most in the 1980' until the early 1990's. After 2000, the cohorts 2004-2006 had small K parameters, the growth increased thereafter, but has declined since 2013.

We found negative effects of both temperature in the year of birth and R3 on cohort specific K's. The negative effect of temperature was unexpected given that NEA haddock is the northernmost haddock stock in the world, inhabiting temperatures below those that are optimal for growth. Landa et al (2014) found that at high densities, haddock expanded into colder parts of the Barents Sea, so that in warm years, the ambient temperatures experienced by haddock was actually lower compared to in cold years. Recruitment and temperature are positively correlated in NEA haddock (e.g. Filin and Russkikh 2019). The negative temperature effect is therefore likely to be caused by the positive effect of temperature on recruitment, leading to higher densities, stronger competition, range expansion and slower growth in cohorts born in warm years.

Consistently, and consistent with intra-cohort competition and density dependent growth, a negative relationship between R3 and K was found for all surveys, although only significantly so for the winter survey.

There was large variation in size within age groups; some of this variation was spatial, as individuals of the same age tended to be smaller in the east compared to along the coast of Northern Norway and along the shelf break north to Svalbard/Spitsbergen. This pattern is consistent with results from Korsbrekke (1999) and a recent paper by Breivik et al (2024).

Further work on the cohort effects and what is causing them would be valuable. Are differences in size at age among cohorts determined early in life and then the slow growing cohorts are not able to compensate later in life? What are the factors limiting their growth early in life? Alternatively, are the limiting factors (high densities, low temperatures, low food availability) experienced by the cohorts throughout longer periods of their life?

The cohort dependent variation in size at age could be investigated by analysing spatial variation, focusing on the effect of local densities and temperatures on size of different age groups and cohorts. By looking at densities and temperatures experienced by the cohorts in space and time, we can examine if slow early growth can be compensated for with good growth conditions later in life. An evaluation of the spatial variation in food quantity and quality would also be of interest, but the data for a thorough analysis might be too limited.

Finally, the recent benchmark of NEA haddock (ICES 2020) revealed challenges in estimating weight at age. For example, the discontinuation of one survey had to be accounted for by ad hoc methods (ICES 2020). Problems to forecast growth and selectivity of an incoming strong year class has potentially led to a too optimistic quota advice (ICES 2021). Hence, more research on mechanisms affecting growth from the current period is needed to improve assessments, forecasts and improve models used in management strategy evaluations for NEA haddock.

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4.4 - How revision of fish diets of the Barents Sea Ecopath model influence prediction of the current ecosystem status

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Abstract

Evaluation of ecosystem predictions may be a test of the level of understanding and scientific knowledge. We test if a highly resolved dynamic ecosystem model (Ecosim) for the Barents Sea ecosystem can predict fish diets and ecosystem state for the period 2013-2020. The dynamic Ecosim model comprise 108 functional groups and was based on an Ecopath model for year 2000. Biomass, production/biomass and consumption/biomass ratios and diet composition were important input values for functional groups in this model. The original model input diet composition matrix is mostly based on studies from the period 1970 - 2000, and it is uncertain how well it represent the state of the ecosystem during the period 2013-2020. The Ecosim model has been calibrated for the period 1950-1997 using time-series of observed biomasses and fishery catches. We test if the model can predict fish diet for year 2015 when a large fish stomach sampling program by IMR and PINRO took place in the Barents Sea. Diet composition was available for a total of 70 species (including two genera) and was based on more than 27 thousand stomachs with high spatial and temporal resolution.

Model predicted fish diet compositions were compared to fish stomach content data sampled from the field surveys in 2015 and the accuracy and precision of the predictions are evaluated. The modelled and observed number of feeding links were compared. It was attempted to update and revise the diet composition in the model and it was tested if this revision had any effects on the prediction of functional groups biomasses and other ecosystem characteristics for the period 2013-2020.

4.5 - Inference for causal relationships among balaenopterids and their prey using categorical data analyses

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Abstract

Although many countries have formally committed to Ecosystem-Based Fisheries Management (EBFM), actual progress toward these goals has been slow. This paper presents two independent case studies that have combined strategic advice from ecosystem modelling with the tactical advice of single-species assessment models to provide practical ecosystem-based management advice. With this approach, stock status, reference points, and initial target F are computed from a single-species model, then an ecosystem model rescales the target F according to ecosystem indicators without crossing pre-calculated single-species precautionary limits. Finally, the single-species model computes the quota advice from the rescaled target F, termed here Feco. Such a methodology incorporates both the detailed population reconstructions of the single-species model and the broader ecosystem perspective from ecosystem-based modelling, and fits into existing management schemes. The advocated method has arisen from independent work on EBFM in two international fisheries management systems: (1) Atlantic menhaden in the United States and (2) the multi species fisheries of the Irish Sea, in the Celtic Seas ecoregion. In the Atlantic menhaden example, the objective was to develop ecological reference points (ERPs) that account for the effect of menhaden harvest on predator populations and the tradeoffs associated with forage fish management. In the Irish Sea, the objective was to account for ecosystem variability when setting quotas for the individual target species. These two exercises were aimed at different management needs, but both arrived at a process of adjusting the target F used within the current single-species management. Although the approach has limitations, it represents a practical step toward EBFM, which can be adapted to a range of ecosystem objectives and applied within current management systems.

Link to the electronic version of the published article:

Howell, D., Schueller, A.M., Bentley, J.W., Buchheister, A., Chagaris, D., Cieri, M., Drew, K., Lundy, M.G., Pedreschi, D., Reid, D.G., and Townsend, H. 2021 Combining Ecosystem and Single-Species Modeling to Provide Ecosystem-Based Fisheries Management Advice Within Current Management Systems. Front. Mar. Sci. 7:607831. https://doi.org/10.3389/fmars.2020.607831

Appendix 1

Earlier Norwegian - Russian Symposia

1. Reproduction and Recruitment of Arctic Cod

Leningrad, 26–30 September 1983 Proceedings edited by O.R. Godø and S. Tilseth (1984)

2. The Barents Sea Capelin

Bergen, 14–17 August 1984 Proceedings edited by H. Gjøsæter (1985)

3. The Effect of Oceanographic Conditions on Distribution and Population Dynamics of Commercial Fish Stocks in the Barents Sea

Murmansk, 26–28 May 1986 Proceedings edited by H. Loeng (1987)

4. Biology and Fisheries of the Norwegian Spring Spawning Herring and Blue Whiting in the Northeast Atlantic

Bergen, 12–16 June 1989 Proceedings edited by T. Monstad (1990)

5. Interrelations between Fish Populations in the Barents Sea

Murmansk, 12–16 August 1991 Proceedings edited by B. Bogstad and S. Tjelmeland (1992)

6. Precision and Relevance of Pre-Recruit Studies for Fishery Management Related to Fish Stocks in the Barents Sea and Adjacent Waters

Bergen, 14–17 June 1994 Proceedings edited by A. Hylen (1995)

7. Gear Selection and Sampling Gears

Murmansk, 23–24 June 1997 Proceedings edited by V. Shleinik and M. Zaferman (1997)

8. Management Strategies for the Fish Stocks in the Barents Sea

Bergen, 14–16 June 1999 Proceedings edited by T. Jakobsen (2000)

9. Technical Regulations and By-catch Criteria in the Barents Sea Fisheries

Murmansk, 14–15 August 2001 Proceedings edited by M. Shlevelev and S. Lisovsky (2001)

10. Management Strategies for Commercial Marine Species in Northern Ecosystems

Bergen, 14–15 August 2003 Proceedings edited by Å. Bjordal, H. Gjøsæter and S. Mehl (2004)

11. Ecosystem Dynamics and Optimal Long-Term Harvest in the Barents Sea Fisheries

Murmansk, 15–17 August 2005 Proceedings edited by Vladimir Shibanov (2005)

12. Long-Term Bilateral Russia-Norwegian Scientific Co-operation as a Basis for Sustainable Management of Living Marine Resources in the Barents Sea

Tromsø, 21–22 August 2007 Proceedings edited by Tore Haug, Ole Arve Misund, Harald Gjøsæter and Ingolf Røttingen (2007)

13. Prospects for Future Sealing in the North Atlantic

Tromsø 25–26 August 2008 Proceedings edited by Daniel Pike, Tom Hansen and Tore Haug (2008)

14. The Kamchatka (Red King) Crab in the Barents Sea and Its Effects on the Barents Sea Ecosystem

Moscow, 11–13 August 2009 Abstract volume compiled by VNIRO, Moscow (2009)

15. Climate Change and Effects on the Barents Sea Marine Living Resources

Longyearbyen, 7–8 September 2011 Proceedings edited by Tore Haug, Andrey Dolgov, Konstantin Drevetnyak, Ingolf Røttingen, Knut Sunnanå and Oleg Titov (2011)

16. Assessment for Management of Living Marine Resources in the Barents Sea and Adjacent Waters – a Focus on Methodology

Sochi, Russia, 10–12 September 2013 Proceedings edited by Knut Sunnanå, Yury Kovalev, Harald Gjøsæter, Espen Johnsen and Evgeny Shamray (2014)

17. Long-Term Sustainable Management of Living Marine Resources in the Northern Seas

Bergen, 16–17 March 2016 Proceedings edited by Harald Gjøsæter, Bjarte Bogstad, Katja Enberg, Yury Kovalev and Evgeny Shamray (2016)

18. Influence of Ecosystem Changes on Harvestable Resources at High Latitudes

Murmansk, 5–7 June 2018 Proceedings e dited by Evgeny Shamray, Geir Huse, Alexander Trofimov, Svein Sundby, Andrey Dolgov, Hein Rune Skjoldal, Konstantin Sokolov, Lis Lindal Jørgensen, Anatoly Filin, Tore Haug and Vladimir Zabavnikov (2019)

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