A scenario method to explore the future of marine social-ecological systems.

Authors

Benjamin Planque, Christian Mullon, Per Arneberg, Arne Eide, Jean-Marc Fromentin, Johanna Jacomina Heymans, Alf Håkon Hoel, Susa Niiranen, Geir Ottersen, Anne Britt Sandø, Martin Sommerkorn, Olivier Thébaud, Thorbjørn Thorvik

Supplementary material

The Barents Sea: state, trends and single perspectives scenarios

The development of the scenario method and its application to the Barents Sea MSES were conducted during a workshop held in Sommarøy, Troms, Norway in June 2016. The participants of this workshop were diverse: representatives of fishermen, fisheries policy, NGOs and researchers from several disciplines. The following description of the state and trends in the Barents in recent decades and the explorative narratives about contrasted futures in different perspectives have been written by the participants to the workshop.

1 Current states and recent trends

1.1 States and trends in Fisheries management

The Barents Sea is exploited by fisheries for a total annual catch of about 1.4 million tonnes. The main exploited species include cod (*Gadus morhua*, Gadidae), capelin (*Mallotus villosus*, Osmeridae), saithe (*Pollachius virens*, Gadidae), haddock (*Melanogrammus aeglefinus*, Gadidae), redfish (*Sebastes* spp., Sebastidae), Greenland halibut (*Reinhardtius hippoglossoides*, Pleuronectidae), shrimps, red king (*Paralithodes camtschaticus*, Lithodidae) and snow (*Chionoecetes opilio*, Oregoniidae) crabs. These are captured by coastal and long-distance fleets which operate a variety of fishing gears (nets, lines, traps and trawls). The cooperation between Norway and Russia has been central to the development of modern fisheries management in the Barents Sea region over the last fifty years (Eide *et al.* 2013). Bilateral cooperation between Norway and the Soviet Union started in 1975 with the establishment of the Joint Fisheries

Commission. Exclusive Economic Zones (EEZ) were established in 1977 (Norway) and 1978 (the Soviet Union). The Joint Norway - Russia Fisheries Commission for the shared fish stocks in the Barents Sea (JNRFC) has developed a robust scientific knowledge base, comprehensive and precautionary regulations of the fisheries and the coastal states provide for a strict enforcement regime (Hoel and Olsen 2012). The cooperation evolved through the setting of TACs for three shared stocks (cod, haddock, capelin). Illegal Unreported and Unregulated (IUU) fishing, disagreement on enforcement and different approaches to technical regulations have been among the challenges faced by the commission. In 2002, the JNRFC agreed on a new Harvest Control Rule (HCR) regime for cod and has later adopted HRCs for other shared stocks. As of 2017, Greenland halibut and redfish are also considered as shared stocks.

The scientific foundation of the Norwegian-Russian management cooperation is the cooperation between research institutes (IMR in Norway and PINRO in Russia) which is embedded in the International Council for the Exploration of the Sea (ICES). This ensures international quality control of the results of the research cooperation between the two countries, as well as a robust mechanism for the provision of scientific advice. A critical measure towards successful regulations has been the long-term management plans with harvest control rules that translate the precautionary principle into practical management measures (Hoel and Olsen 2012). Since the early 2000s, Norway has embraced the ecosystem approach to ocean management and adopted integrated management plans for the Barents, Norwegian and North Seas (Olsen *et al.* 2007; Ottersen *et al.* 2011). Although these plans have no regulatory function or other direct influence on fisheries, they may, in the long run, contribute towards a more ecosystem based approach to management of the fisheries.

While fisheries management traditionally focused on commercial exploitation of marine resources, the new Norwegian Marine Resources Act which entered into force in 2009 integrates conservation and sustainable use as basic principles, constituting a paradigm shift in the management of Norwegian fisheries (Gullestad *et al.* 2017). The current Norwegian fisheries management objectives are to ensure sustainable and economically profitable exploitation of wild living marine resources and genetic material and to ensure employment and settlement in coastal communities. These objectives include goals that have to be reconciled (employment, economic performance, stock conservation, settlement pattern along the coast, etc.). Recent adjustments to the management scheme in Norway has developed specific tools to address the challenges posed by the new act, in particular to get an overview of important challenges, to prioritize use of scarce scientific and management resources and to manage data-poor stocks (Gullestad *et al.* 2017). Present fisheries management in the Barents Sea is usually considered to be successful (Eide *et al.* 2013).

1.2 States and trends in the Ecosystem

The mean annual net primary production in the Barents Sea is estimated at about 59 million tonnes of carbon (Dalpadado *et al.* 2012). The dynamics of primary production are strongly seasonal and varies with ice conditions. Primary production in ice-free areas is dominated by phytoplankton while in ice-covered regions ice algae may be favoured (Reigstad *et al.* 2011) . Influx of nutrient rich Atlantic waters from the Norwegian Sea plays a significant role in controlling primary production in the Barents Sea. Secondary production by meso-zooplankton is characterized by large year-to-year fluctuations. Populations of pelagic invertebrates (e.g. krill, amphipods), pelagic fishes (e.g. capelin, polar cod, *Boreogadus saida*, Gadidae), demersal fishes (e.g. cod, haddock, saithe), benthic invertebrates (e.g. bivalves, echinoderms, crabs), mammals (e.g. whales and seals) and birds (e.g. puffins, fulmars and kittiwakes) interact and display strong seasonal, geographic and interannual variations. Some recent biogeographic changes have been attributed to ocean warming (Fossheim *et al.* 2015) .

In recent decades, the increase in sea temperature in the Barents Sea has been paralleled with biogeographical changes, many boreal species expanding their distribution towards the north and east while Arctic species have come under stress and declined in abundance or retracted in the same direction (Dalpadado *et al.* 2012; Fossheim *et al.* 2015; Eriksen *et al.* 2017). This overall pattern of change is described as the 'borealisation' of the Barents Sea. There have been large interannual fluctuations in total net annual primary production possibly accompanied by an upward long-term trend in productivity (Dalpadado et al., 2014). The stocks of the major demersal fish species have reached record high levels in recent years with an estimated current combined biomass of cod, saithe and haddock in excess of 5 million tonnes. The main boreal pelagic species, capelin and herring, have displayed large fluctuations in biomass over decadal time scales, while the sea ice dependent polar cod has generally declined (Johannesen *et al.* 2012; ICES 2016) . The biomass of gelatinous plankton has increased and populations of snow and king crabs have established and significantly expanded their geographical distribution over the last three decades. Some breeding populations of seabirds have increased over the last 25 years, while several others have declined considerably during the last decades (Arneberg and Jelmert 2017). This is particularly true for colonies in the south of the area.

1.3 States and trends in Ocean climate

The Barents Sea is a transition zone between the warm and saline water flowing from the Atlantic via the Norwegian Sea into the central Arctic Ocean, and the cold and less saline water flowing from the Arctic to the Atlantic. There are no major rivers flowing into the Barents Sea. Parts of the Barents Sea are seasonally ice-covered, and several feedback processes influence climate variability in the air-ice-ocean system (Smedsrud *et al.* 2013). The region is characterized by extreme environmental conditions with strong geographical gradients between Atlantic waters in the southwest and Arctic waters in the northeast, large seasonal changes in ocean climate and light regime and important inter-annual variations in the strength of Atlantic water inflow and exchange of cold Arctic water. These features result in large year-to-year variability in the Barents Sea climate, which can lead to alternatively mild or severely cold winters. At the scale of the entire Barents Sea, warming induced by increasing greenhouse gas concentrations generates a small, but sustained positive trend on top of these natural variations.

The most prominent trends in the ocean climate of the Barents Sea over the last decades are increasing sea temperatures and decreasing ice coverage in the previously ice-covered northern areas (Lind et al., 2018). Since remotely sensed earth observations started in 1979, a general decrease in ice coverage has been observed. Sea temperature at all the measuring points in the Barents Sea has increased significantly since the mid 1980’s. From the beginning of 1999, there has been a rapid temperature increase, with a small decrease since 2012, but during 2013-2015 temperatures still remained above average. There has been an increasing trend in the Barents Sea ocean temperature over the last 40 years, however with pronounced variability. Measurements in the Fugløya-Bear Island and Vardø-North sections, which run from Northern Norway into the Barents Sea, are representative of the dynamics in the Atlantic water masses that flow into the Barents Sea from southwest. The temperatures measured here in early 2016 were around 1°C above the 1977-2006 long-term average. Most years the maximum areal extent of ice cover in the Barents Sea is in April and minimum in September. Since satellite earth observations started in 1979 the decrease in Barents Sea ice coverage has been 9,7 % in April and 14,7 % in September (Arneberg and Jelmert 2017). The present Barents Sea ocean climate has never been observed before and it is uncertain whether these trends will continue at their current pace, accelerate, slow down or even reverse.

1.4 States and trends in Global context and governance

The market for Norwegian fish is mainly international. Most of the production is exported and Norway is the world's second largest fish exporter, with the EU being the most important market, followed by the USA and Asian countries. Globally, fish consumption has increased to about 20 kg per capita over the last 50 years (FAO, 2016). With global capture fisheries operating at their limit, further growth in consumption will be based on aquaculture. The market price of fish has not increased as much as the average income in Norway but profitability has increased as a result of a more efficient utilization of technologies and structural changes (i.e. a substantial reduction in the number of vessels and fishermen). As for most fisheries in developed countries, labour is being substituted by capital, with decreasing number of fishermen and development of more efficient capture techniques.

As for all MSESs, the global institutional context of the Barents Sea is defined by UNCLOS, the 1995 UN Fish Stocks Agreement and agreements and guidelines developed by the Food and Agriculture Organization over the last decades (Garcia and Cochrane 2005). Only a small part of the Barents Sea is outside EEZs (the Barents Sea loophole). There are agreements for fisheries access to this area, of which the bilateral agreement between Russia and Norway for the management of shared stocks is central. Third party countries are granted access and quotas in the Barents Sea through a comprehensive system of fisheries agreements with Norway and Russia respectively. Changes in global context and governance have occurred on the multi decadal time scale of multilateral negotiations. Significant changes in the world's fisheries after the introduction of EEZs can be characterized as Southern growth and Northern stagnation, with the largest fraction of world fish catches taken from least-developed and developing countries (FAO, 2016), many of which have poorly regulated or open access fisheries. Global trends of relevance for the Barents Sea are related to: (a) increasing ecosystems considerations in fisheries management implementation, (b) growing concerns for global food security and biodiversity, (c) consideration of mining, oil extraction and shipping, (d) raising public awareness on Arctic issues and concerns about possible threats, and (e) geopolitical developments in the high North. Recent growing interest in the Arctic gives polar treaties and the Arctic Council more political significance, although usually not in the fisheries sector where management regimes already exist for Arctic countries. In 2017, and agreement was reached to prevent unregulated fishing in the high seas area in the central Arctic Ocean.

2 Single perspective scenarios

Twelve single perspective scenarios, i.e. three for each perspective, are briefly described below. These contrasted narratives, written in the present tense, represent explorative-external scenarios (sensu Börjeson et al., 2006) for the future of the Barents Sea by 2050.

2.1 Fisheries management scenarios

Baseline: things are still going well. Fisheries management in the Barents Sea operates similarly to the 2010's. The economic situation of the fisheries and their regulation remain largely unchanged. The market value of commercial species is sustained. Fishing capacity and wealth concentration continue to increase although at a slower pace than in the 2010's. Norwegian fisheries management goals are maintained within a framework of cooperation between countries engaged in fisheries in the Barents Sea. Northeast Arctic cod being one of the most profitable stocks in the Barents Sea, the current strategy to prioritize high catch of cod and to take the catch of other fish as a 'residual' after cod consumption is pursued. The current HCR-based management plans for the main commercial species (cod, haddock, saithe, and herring), is further developed. The stocks remain harvested close to or below MSY. The capelin stock remains low, and managed by a target escapement strategy. Concerns remain about the size of the cod stock being too large, in relation to its pressure on capelin and polar cod, and to the risks associated with limited food availability/carrying capacity (ICES 2016). These concerns are addressed through a multi-species perspective on HCRs. There is no active price support policy, nor decline in market price. Prices are primarily determined on international markets for fish products and observed price trends for the main commercial species caught in the Barents Sea are assumed to continue: the industry is a 'price taker', i.e. there is no company big enough, or in position to affect the level of prices. Current stock productivity remain similar, in relative terms, to those of the 2010's.

Degraded: poor management practices and short-sighted views. Despite a growing understanding of the interactions between ecosystem components and species, fisheries management focus on selected single species approaches. TACs are often set above recommended safe levels. The market price of commercial species, due to race-to-fish conditions, leading to poor fishing practices and a concentration of landings over short periods of time, declines except when it is artificially maintained through active public price policies, despite the well-known fact that such policies elaborated to support small scale fisheries contribute to reinforce overall capacity. Technological advances significantly affect fishing practices and performances but are not considered in the design of fisheries regulations. Trust between scientists, managers, fishermen and civil society is eroded. Compliance with regulations declines. There is a gradual decline in the stability and development of international agreements for fisheries management.

Improved: participatory and ecologically responsible management. Objectives for the management of the fisheries are defined at the ecosystem level. Current regulations on individual species are supplemented with ecosystem-level regulations (e.g. multi-species TACs). There is an increased participation of actors with interest other than fisheries, such as conservation groups, other industries, communes or unions, into the management process. Technological advances are fully incorporated in the design of regulations, with an emphasis on conservation and improved fishing efficiency (e.g. less by-catch). Price trends for seafood are increasing relative to the general level of income and costs, due to improved quality of fish landed and efforts to meet the demand for high quality products.. Trust between scientists, managers, fishermen and the civil society is high and so is compliance with regulations.

2.2 Ecosystem scenarios

Baseline: increase then stabilization of biological production. There is a continuous increase then stabilization in the biological production of the Barents Sea. This leads to a similar pattern in the production of commercial demersal fish species as in the 2010's. Pelagic species fluctuate between high and low abundance levels on decadal time scales. This is accompanied by a geographical expansion of Atlantic/boreal species towards the northeast of the Barents Sea. The occurrence of species invasions has ecosystem impacts and creates opportunities for new fisheries. Although the ecosystem state varies on intra-annual and inter-annual time scales, the overall ecosystem 'health' is at a similar level as in the 2010's.

Pessimistic: collapse of fish stocks, degradation of ecosystem health. Most stocks of demersal fish species (cod in particular) fall below safe levels. Pelagic stocks fluctuate at faster rates than before. Invertebrate species pullulate (e.g. gelatinous macroplankton) and species invasions increase. Populations of top predators steadily decline. The general ecological situation in the Barents Sea is qualified as degraded or unhealthy. A combination of factors, including climate, fishing, pollution (noise, persistent organic pollutants, heavy metals, plastics, oil) and invasive species lead to severe modifications in the productivity and functioning of the Barents Sea ecosystem.

Optimistic: increase of biological production, ecosystem health and harvesting potential. There is a continuous increase in the biological production of the Barents Sea, paralleled by an increase in production of demersal and pelagic fish species and in their geographical expansion. Species that have recently been discovered to have a high commercial potential are also highly abundant and productive. Top predator populations are healthy and abundant. The general ecological situation in the Barents Sea is qualified as healthy with a high biological production channelled through to commercial species. A combination of factors, including climate change, fishing, petroleum activities and invasive species has led to modifications in the productivity and functioning of the Barents Sea ecosystem that have benefitted the harvesting potential of the system without reducing its health.

2.3 Ocean Climate scenarios

Baseline: Continued warming. Ocean warming continues, accompanied by a reduction in the geographical extent and thickness of sea ice and by ocean acidification. Natural climate oscillations (e.g. AMO) still modulate this climate trend. The polar front is pushed further northeast and the biological production season starts earlier and becomes longer. This can be associated with the RCP2.6 and RCP4.5 scenarios. The global atmospheric warming in those scenarios ranges from 0.3 to 2.6°C, where Arctic amplification would lead to a doubling of this in the Arctic regions. The annual mean ocean temperature increases by 0.3 to 1.0°C in the upper hundreds of meters. This leads to ice free conditions in September in the central Arctic Ocean and a reduction of ice extent by around 4 million km^2 in March. In the Barents Sea, this is manifested by a continuous retreat of the ice towards the northeast. In this scenario, the Atlantic Meridional Overturning Circulation (AMOC) is weakened due to increase in high latitude temperature and precipitation which make high latitude surface water lighter. The stability of these waters therefore increases, which in turn decrease the strength of the AMOC. The weakening is projected to start around 2050 before which, natural variability is expected to drive most variations in the AMOC.

Hot future: faster warming and ice melting. The rate of warming, ice melt and acidification exceed those observed in the 2010's. The new regimes of temperature, salinity, stratification and pH are outside the range of situations observed in the past with significant consequences on the biological system (e.g. production, species composition, biogeography). Extreme weather events become more frequent (with potential effects on biology and fishing activities). The global temperature increase is in the range 1.4-4.8°C. The change in the annual mean ocean temperature in the upper hundred meters north of 60°N is between 0.5°C and 3°C, and the Arctic becomes seasonally ice free (in September) by the middle of this century. The climate trend is so strong that the effects of natural climate oscillation become weak in comparison, while extreme weather events become more frequent. On this timescale, sea ice extent is neither expected to increase considerably nor return to the present state. Due to polar amplification, the temperature gradient between lower and higher latitudes weakens near the surface. At higher levels in the atmosphere, the temperature gradient increases due to increased temperature at equator and lower temperature at the poles.

Cold future: import of fresh water and shutdown of the AMOC. Surface melt draining into crevasses and hydro fracturing in the ice sheet lead to accelerated melting and dramatic increase in sea level from 2 to 17m. The increase in freshwater produces an amplifying feedback that further accelerates ice melt at depth by placing a lid of fresh and cold water on the polar ocean. This limits heat loss to the atmosphere and space, and thereby warms the ocean at the depth of ice shelves (Hansen et al. 2016). The increased stratification results in a shutdown of the AMOC, and thereby reduced poleward heat transport. In turn, the reduction in the AMOC leads to lower surface atmospheric temperature in the Arctic in some areas. This results in a colder and icier Barents Sea where the extent of winter ice expands back towards the southwest Barents Sea.

2.4 Scenarios of Global context and governance

Baseline: ongoing trends of multilateral governance and globalization continue. The role of UN organizations declines in some domains (UNESCO's crisis), but is re-affirmed in those related to the marine environment. The work to address the 2030 Sustainable Development Goals (SDGs) is on-going, but the targets of SDG-14 (Oceans) are met to different degrees and overfishing remains a problem globally. International conservation NGOs affirm themselves as important actors. The Law of the Sea Convention and the 1995 UN Fish Stocks Agreement are the building blocks for future development and are being actively implemented by a growing number of states. Free trade policies derived from the principles of the World Trade Organization (WTO) are prevalent in the international trade of seafood. The international Court of Justice and the International Tribunal for the Law of the Sea remains the main instruments for the resolution of disputes. The evolution of international offshore ocean governance and the progress towards a new institutional framework relevant to the conservation and management of biodiversity take place in this context of public concern for conservation, marginal changes in UNCLOS framework and judiciary as well as diplomatic resolution of disputes.

Pessimistic: decline of multilateral governance and raise of protectionism. Poverty alleviation and human development are not prioritized, nor are multilateral agreements. The development of the global framework based on UNCLOS is halted and protectionism takes precedence in trade relations. Bilateral treaties, based on political and economic considerations become the reference for all exchanges between countries (preferential trade agreements). There is a growing tendency for entities such as states, companies and fleets to operate individually in order to protect their own positions. Arbitration is generalized as a tool for solving international conflicts, even between states and private investors. This interferes, in environmental problem's solving. At a regional level, this leads to the degradation of the northeast Atlantic framework of fisheries agreements, including the Russian-Norwegian dialogue and agreements. Trust between actors declines, as well as compliance with regulations. Social equity and ecological health have low priority or are ignored. Consequences of technological advances are not appropriately considered in governance plans.

Optimistic: strengthening of multilateral governance. This scenario projects a return to the original principles of multilateralism which associates developed and developing countries, the strengthening of the UNCLOS-based legal framework and the implementation of the Sustainable

Development Goals. Global governance of marine resources and biodiversity is developed with explicit consideration of food security, ecosystem conservation, equity and economics through a new implementing agreement to UNCLOS. Regionally, this leads to an improved and expanded dialogue between Norway and Russia, a broadening of fisheries cooperation with regards to economic benefits, equity, ecological conservation and improved compliance with regulations. Consequences of technological advances are considered and incorporated into governance plans.

2.5 Summary of single-perspective scenarios

We have now constructed twelve narratives along four distinct single perspectives. It is possible to explore the uncertainties pertaining to each of these narratives and define their time horizon, key processes, time line and wild cards. For each scenario, it is also legitimized to ask how much the succession of events in this single perspective scenario depend on events that pertain to other perspectives. This will lead to the next and final step of the MSES scenario building process: multidisciplinary integration of scenarios across perspectives.

3 References

Arneberg, P., and Jelmert, A. (2017). Status for miljøet i Barentshavet og ytre påvirkning – rapport fra Overvåkingsgruppen (in Norwegian). http://www.imr.no/filarkiv/2017/06/1b-2017_ovg_statusrapport_barentshavet.pdf/nb-no

Börjeson, L., Höjer, M., Dreborg, K.-H., Ekvall, T., Finnveden, G. (2006) Scenario types and techniques: Towards a user’s guide. *Futures* **38,** 723-739. https://doi.org/10.1016/j.futures.2005.12.002

Dalpadado, P., Arrigo, K. R., Hjøllo, S. S., Rey, F., Ingvaldsen, R. B., Sperfeld, E., … Ottersen, G.(2014). Productivity in the Barents Sea - response to recent climate variability. PLoS ONE, 9: e95273. http://dx.doi.org/10.1371%2Fjournal.pone.0095273

Dalpadado, P., Ingvaldsen, R.B., Stige, L.C., Bogstad, B., Knutsen, T., Ottersen, G. and Ellertsen, B. (2012). Climate effects on Barents Sea ecosystem dynamics. *ICES Journal of Marine Science* **69**, 1303–1316. https://doi.org/10.1093/icesjms/fss063

Eide, A., Heen, K., Armstrong, C., Flaaten, O. and Vasiliev, A. (2013). Challenges and successes in the management of a shared fish stock–the case of the Russian–Norwegian

Barents Sea cod fishery. *Acta Borealia* **30**, 1–20. https://doi.org/10.1080/08003831.2012.678723

Eriksen, E., Skjoldal, H.R., Gjøsæter, H. and Primicerio, R. (2017). Spatial and temporal changes in the Barents Sea pelagic compartment during the recent warming. *Progress in Oceanography*. **151,** 206-226. https://doi.org/10.1016/j.pocean.2016.12.009

FAO (2016). The state of world fisheries and aquaculture 2015. *Food and agriculture organization of the United Nations, Rome*. http://www.fao.org/3/a-i5555e.pdf

Fossheim, M., Primicerio, R., Johannesen, E., Ingvaldsen, R.B., Aschan, M.M. and Dolgov, A.V. (2015). Recent warming leads to a rapid borealization of fish communities in the Arctic. *Nature Climate Change* **5**, 673–677. https://doi.org/10.1038/nclimate2647

Garcia, S.M. and Cochrane, K.L. (2005). Ecosystem approach to fisheries: a review of implementation guidelines. *ICES Journal of Marine Science* **62**, 311–318. https://doi.org/10.1016/j.icesjms.2004.12.003

Gullestad, P., Abotnes, A.M., Bakke, G., Skern-Mauritzen, M., Nedreaas, K. and Søvik, G. (2017). Towards ecosystem-based fisheries management in Norway–Practical tools for keeping track of relevant issues and prioritising management efforts. *Marine Policy* **77**, 104–110. https://doi.org/10.1016/j.marpol.2016.11.032

Hansen, J., Sato, M., Hearty, P., *Ruedy, R., Kelley, M., Masson-Delmotte, V., … Lo, K.W.* (2016) Ice melt, sea level rise and superstorms: evidence from paleoclimate data, climate modeling, and modern observations that 2°C global warming could be dangerous. *Atmos. Chem. Phys.* **16,** 3761-3812. https://doi.org/10.5194/acp-16-3761-2016

Hoel, A.H. and Olsen, E. (2012). Integrated ocean management as a strategy to meet rapid climate change: The Norwegian case. *Ambio* **41**, 85–95. https://doi.org/10.1007/s13280-011-0229-2

ICES (2016). Report of the Arctic fisheries working group (AFWG). http://www.ices.dk/sites/pub/Publication%20Reports/Expert%20Group%20Report/acom/2016/AFWG/01%20AFWG%20Report%202016.pdf

Johannesen, E., Ingvaldsen, R.B., Bogstad, B., Dalpadado, P., Eriksen, E., Gjøsæter, H., … Stiansen, J. E. (2012). Changes in arents Sea ecosystem state, 1970–2009: climate fluctuations, human impact, and trophic interactions. *ICES Journal of Marine Science* **69**, 880–889. https://doi.org/10.1093/icesjms/fss046

Lind, S., Ingvaldsen, R.B., Furevik, T. (2018) Arctic warming hotspot in the northern Barents Sea linked to declining sea-ice import. *Nature Climate Change* **8,** 634-639. https://doi.org/10.1038/s41558-018-0205-y

Olsen, E., Gjøsæter, H., Røttingen, I., Dommasnes, A., Fossum, P. and Sandberg, P. (2007). The Norwegian ecosystem-based management plan for the Barents Sea. *ICES Journal of Marine Science* **64**, 599–602. https://doi.org/10.1093/icesjms/fsm005

Ottersen, G., Olsen, E., van der Meeren, G.I., Dommasnes, A. and Loeng, H. (2011). The Norwegian plan for integrated ecosystem-based management of the marine environment in the Norwegian Sea. *Marine Policy* **35**, 389–398. https://doi.org/10.1016/j.marpol.2010.10.017https://doi.org/10.1016/j.marpol.2010.10.017

Reigstad, M., Carroll, J., Slagstad, D., Ellingsen, I. and Wassmann, P. (2011). Intra-regional comparison of productivity, carbon flux and ecosystem composition within the northern Barents Sea. *Progress in Oceanography* **90**, 33–46. https://doi.org/10.1016/j.pocean.2011.02.005

Smedsrud, L. H., Esau, I., Ingvaldsen, R. B., Eldevik, T., Haugan, P. M., Li, C., ... Risebrobakken, B. (2013). The role of the Barents Sea in the Arctic climate system. *Reviews of Geophysics* **51**, 415–449. https://doi.org/10.1002/rog.20017