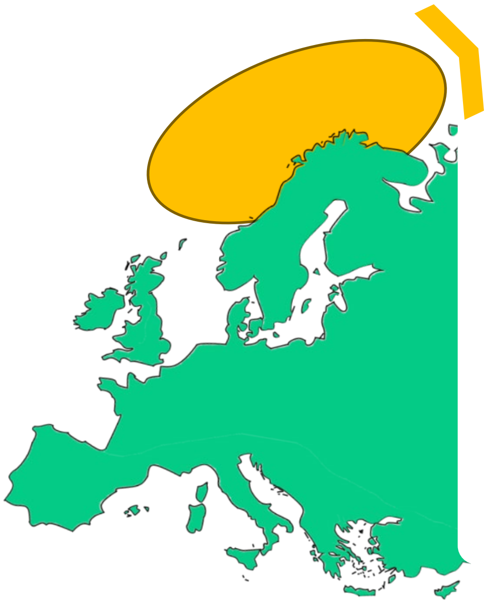
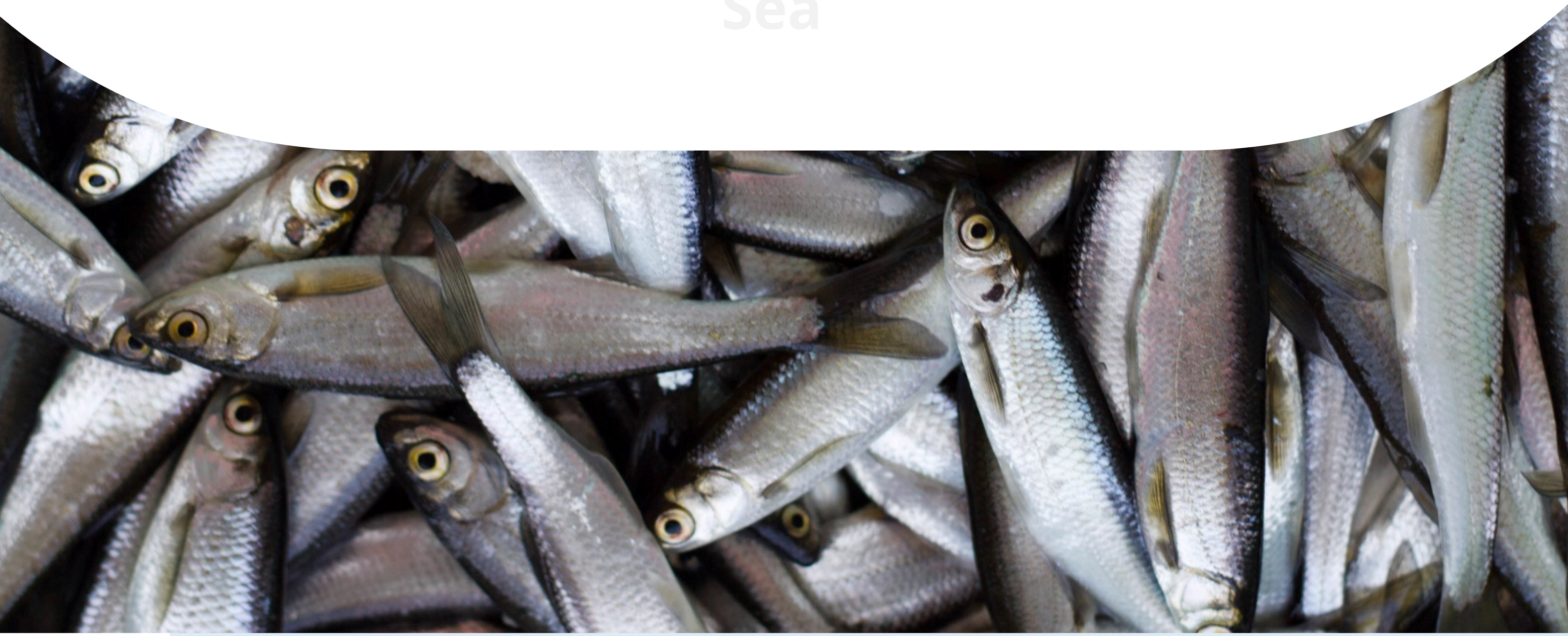
Case study



#14 Herring, capelin, and cod in the Barents and north-west sea

#15 Herring, sprat and cod in the Baltic Sea

#16 Herring in the North Sea



Species background and economics

Areas at high latitudes are expected to face rapid climate change, which potentially can alter the structure and function of their ecosystems. Such changes are already being observed in the Norwegian and Barents Seas.

Recently, large shifts in the distribution of fisheries targets in the Barents Sea have occurred due to increasing inflow of Atlantic Water (termed Atlantification) resulting in an unprecedented overlap between boreal and arctic species.

Among the primary fisheries targets in the Norwegian and Barents Seas are herring (*Clupea harengus*), cod (*Gadus morhua*) and capelin (*Mallotus villosus*), which have complex predator-prey interactions. The distribution of cod in the Barents Sea now fully overlaps with capelin. For herring, only juveniles overlap with cod and capelin since adult herring migrate into the Norwegian Sea.

The catches of cod are largest and most valuable of the three species. Recently, cod catches have been between 0.7 and 1 million tons per year, with a value of up to 7 billion NOK (754 million €).

In comparison, the value of herring and capelin catches was 2.4 billion NOK (258 million €) and 239 million NOK (25.7 million €) in 2016, respectively. Catches and the value of those catches of capelin, however, are highly variable.

In the future, the production of phytoplankton and zooplankton will depend on the physical oceanographic characteristics of the region. Some model projections suggest increases in zooplankton production while others suggest decreases.

Since energy flow in the Barents Sea food web is largely channelled through multiple fish species feeding on zooplankton, large changes at lower trophic levels are likely to introduce changes at mid- and higher trophic levels, impacting not only the structure and function of the ecosystem, but also the economy of the area.

Expected projections under climate change

Projections from NORESM (Norwegian Earth System Model) suggest that sea surface temperatures will rise by 0.5°C in the Norwegian Sea and 2.5°C in the Barents Sea by 2060 relative to present conditions under a moderate climate scenario RCP4.5 (Skogen et al., 2014).

Simulations beyond 2060 or based on RCP8.5 have not yet been made using a high-resolution ESM in the Barents and Norwegian Seas.

The percent increase in temperature in the RCP4.5 projected by Global Climate Models between 2060 and 2100 suggests that sea surface temperatures in 2100 would increase an extra 0.1°C to 0.6°C in the Norwegian Sea and warming of just under 3°C in the Barents Sea compared to present day.

Using the same method for RCP8.5 translate to increases of 1°C in the Norwegian Sea and 5.3°C in the Barents Sea above present day.

These are rather imprecise projections but they agree well with CMIP5 projections that suggest a 3°C increase in the Norwegian Sea and 4 to 5°C increase in the Barents Sea (Alexander et al., 2018).

Increased precipitation and melting sea ice will freshen the water but increased Atlantic Water inflow will tend to increase the salinity.

Some climate models suggest a decrease in near surface salinity and, in combination with increasing temperatures, an increase in vertical density stratification.

With the high heat content in the Barents Sea, sea ice will decrease and disappear altogether in the Barents Sea during summer under RCP8.5.

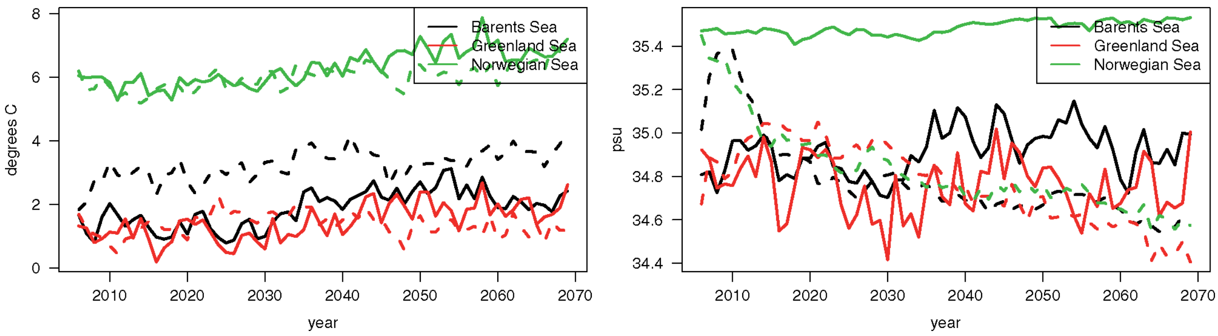


Figure 1 (Skogen et al., 2018, Figure 3). Annual mean sea surface temperature (SST, left) and salinity (SSS, right) for Barents Sea (black), Greenland Sea (red) and Norwegian Sea (green) for Norwecom.e2e (dashed line). Solid lines are from NorESM1-ME (global model).

Scenarios describing future society and economy

CERES uses models to estimate economic developments in Europe's fishery and aquaculture based on select, pre-defined physical and socio-economical future scenarios.

These future scenarios were specified by industry partners and stakeholders in the first year of CERES (e.g. fish prices, fuel prices, technological advancements, regional policy issues, etc.).

'World Markets'	'National enterprise'
• Personal independence, high mobility and consumerism • Reduced taxes, stripped-away regulations • Privatised public services • High fossil fuel dependency • Highly engineered infrastructure and ecosystems	• National isolation and independence • Protection of national industry • High resource intensity and fossil fuel dependency • Low investment in technological development and education • Low priority for environmental protection
'Global sustainability'	**'Local stewardship'**
• High priority for welfare and environmental protection • Cooperative local society • Intense international cooperation • Increased income equality • Low resource intensity and fossil fuel dependency	• Promotion of small scale and regional economy • Less attention for global (environmental) problems • Moderate population growth • Income of industrialised and developing countries converge • No overarching strategy to manage ecosystems

Table 1 Outline of the four social-political scenarios developed by CERES partners and stakeholders

Socio-economic effects

Fisheries in the regions are well managed, applying different harvest control rules and decisions for each stock. Some of the stocks (e.g. herring, mackerel) shared with other nations have recently been overfished due to disagreements on shares.

CERES developed four future scenarios of social, economic and other changes that map onto scenarios of greenhouse gas emissions in the IPCC RCPs.

These future scenarios of fishing were applied within an end-to-end Atlantis model to project future changes in fisheries targets and the broader ecological impacts to the Norwegian and Barents Seas.

The **Global Sustainability scenario** with reduced fishing pressure (f=0.6Fmsy) is based upon higher awareness of climate change, a continual striving to develop lower impact gears and potential increases in marine protected areas

world market scenario represents fishing at maximum economic yield (0.8Fmsy) recognizing an ever increasing demand for cheaper fish but avoids stock depletions

the **local stewardship scenario** (Fmsy); and the **national enterprise** (1.1Fmsy) with reduced cooperation among partners, something that has already been the case in the Norwegian Sea.

Key research needs

Do changes in the oceanography in the Barents and Norwegian seas under climate change affect their ecosystem components, especially fish populations? If it does, then how? How does any combined changes in climate and fisheries impact the ecosystems in the Norwegian and Barents seas?

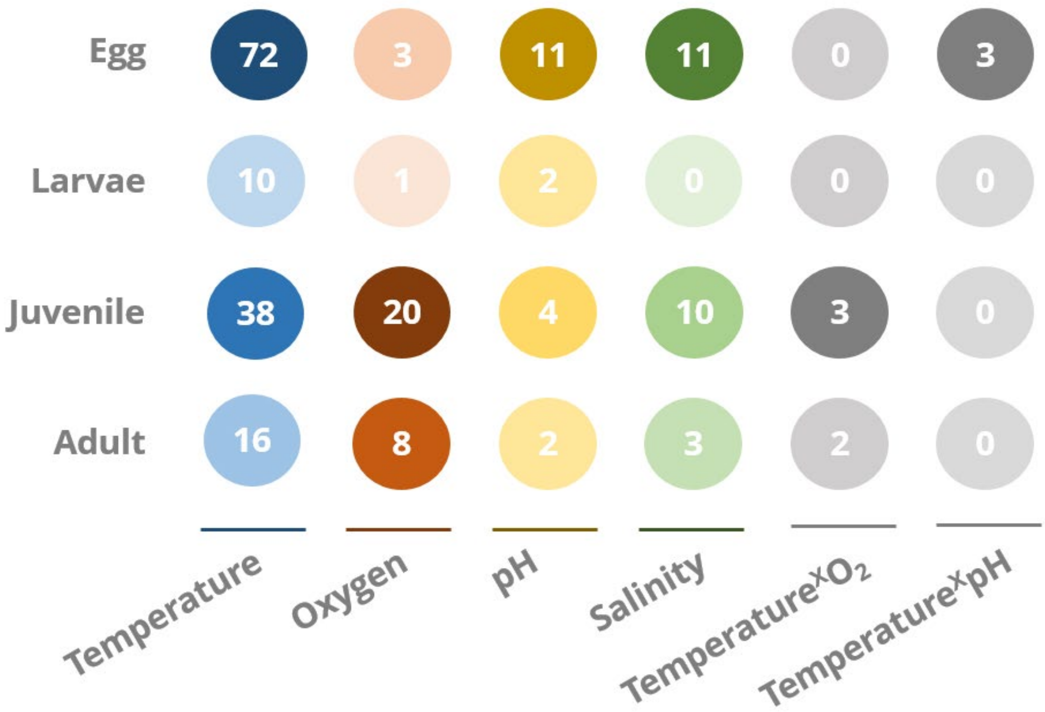
CERES research

CERES has:

- Conducted a systematic literature review, a GAP analysis and a meta-analysis to examine direct effects of climate change (warming, acidification, deoxygenation) on the survival and growth physiology of commercially important European fish and shellfish including cod, capelin and herring in the Norwegian and Barents Seas.
- Analysed long-term time series data (1902-2018) using multiple factor analysis to determine relationships between fish and abiotic indices, including long term, large-scale climate indices such as the NAO and the AMO.
- Projected the ecological consequences of climate change and different fishing regimes using the Atlantis end-to-end model for the Nordic and Barents Seas (NoBa)
- Explored the bioeconomic consequences for climate, fishing and socio-economic scenarios by projecting the revenue from 2040-2060 catches of harvested species in the Barents and Norwegian Seas.
- Engaged stakeholder to regionalise CERES scenarios and develop a conceptual map (BowTie) of the major risks and mitigation measure of climate change for fisheries in the Norwegian region.

Results

Biological



- Herring ranked 1 out of 28 European fish and shellfish genera reviewed here (32 studies). Cod ranked 10 out of 28 (8 studies). No studies were performed on capelin.
- 11 studies were performed in the Norwegian Sea and Barents sea, mainly in Norway (8).
- Embryos (5) and juveniles (4) were well studied, no studies on adults were found
- Growth was the most common response studied (8).
- Temperature was the most common stressor studied (8).

For the Barents and Norwegian seas, the majority of studies of climate effects on the ecosystem involve ocean temperatures, with fewer studies on the impact due to other single stressors or on cumulative impacts.

There are more studies on climate change impacts in these high latitude regions compared to most European seas, possibly due to the economic importance to Norway, Russia and other surrounding regions.

Atlantic cod is the most studied species in the Barents Sea. Herring and mackerel growth in the Norwegian and Barents seas were not found to be significantly different from most other European seas, however, the only significant difference in herring's length-mass relationship was between the Irish Sea and Scottish waters.

Changes in temperature have an impact on the summer distributions of cod, herring and capelin plus other commercial and non-commercial species.

Earlier time series studies of over 100 years of data showed that temperature affects NEA cod recruitment, growth and distribution with higher cod abundance during warm periods, although high temperatures are a necessary but not sufficient condition for high abundance. This includes long period variability of the cod and herring that appear linked to the Atlantic Multidecadal variability including growth, distribution, and spawning location.

Using Barents Sea data from 1980-2017, a multifactor/PCA revealed that polar cod and smaller-sized large zooplankton decreased, whereas mesozooplankton and Atlantic cod increased over the last decade.

The overall change in the Barents Sea has been from cold conditions, low demersal stocks levels and high fishing pressure in the 1980s to warm conditions, large demersal stocks and lower fishing pressure, in recent years.

Since the recent warming is occurring during a period of increasing age structure of cod due to moderate fishing pressure, it difficult is separate the effects of climate and relatively low fishing pressure.

Previous predictions of the future recruitment of Atlantic cod under climate change were tested using new data for 17 cod stocks in the North Atlantic. For the 17 stocks, only for 6 did the projected changes in recruitment match the observations. For the NE Arctic cod stock in the Barents Sea, the temperature-based predictions indicated an increase in recruitment but there was no significant trend observed, although the recruitment was relatively strong.

These results suggest that temperature alone cannot explain the recruitment trends during 2000-2016 and we expect that fishing is likely a second major factor in recruitment trends. Model projections under climate change suggest that primary production in the Barents Sea will initially increase by order 10% but that due to increasing stratification and hence possibly reduced nutrient input through less vertical mixing, that by the end of this century primary production will decrease such that it may be equal or less than present day production.

With projected higher influx of warmer Atlantic water, the average size of the zooplankton within the Barents Sea is projected to decrease. With projected losses of sea ice and warmer waters, the cod's feeding distribution in the Barents Sea is projected to expand even farther north and east as the cod follows the capelin, a result that has already been observed.

Cod is not projected to inhabit the Arctic basins year-round but rather could enter the Arctic basins to feed. Projected higher temperatures will promote individual cod growth and higher recruitment but not guarantee them. The response of the Atlantic cod, herring and capelin stocks will depend the changes to their food supply and their distributional overlap. The level of fishing effort will also influence the fish responses to climate change.

To study the importance of food-web effects from changes in climate and fisheries management, the Nordic and Barents Seas (NoBa) Atlantis model was run for a total of eight management scenarios, using the Fmsy multiplier defined in the four CERES scenarios: 0.6 (global sustainability, gs) , 0.8 (world market, wm), 1.0 (local stewardship, ls) and 1.1 (national enterprise, ne). NoBa was using forcing from a downscaled ROMS model representing the RCP4.5 scenario for the period 2006-2068.

As large, complex end-to-end ecosystem models such as Atlantis introduces a fair bit of uncertainty, we chose to run multiple replicates of each scenario, changing the mesozooplankton growth rate. NoBa was evaluated by comparing time series of demersal and pelagic guild with corresponding time series from assessments (ICES AFWG and ICES WGWIDE). These were found to be overlapping and for the demersal guild, in addition showing a strong correlation (r=0.97, p=0).

It has to be noted that the model was forced using historical fishing mortality, hence model and observations are not entirely independent. The model predicts a decline in the herring stock from 2018 and onwards. The model is not able to catch the strong year classes, but even within the reruns including these, the stock declined. The pelagic guild (including mackerel, capelin and blue whiting) experienced a decrease in the total biomass compared to historical biomasses.

The simulated capelin stock was highly variable, but NoBa did not replicate the collapses observed in the real system. The stock does not show any significant trends with the changes in the management systems, mainly due to the harvest regime applied for this stock. The level of cod relates strongly to the level of fishing pressure and to the number of components being harvested.

For the global sustainability scenario (F=0.6 x Fmsy), the cod stock biomass stabilizes at approximately todays levels. The stock experienced a decrease for the other management scenarios. The demersal guild (including additional demersal species) experiences an increasing negative trend when more ecosystem components are being harvested.

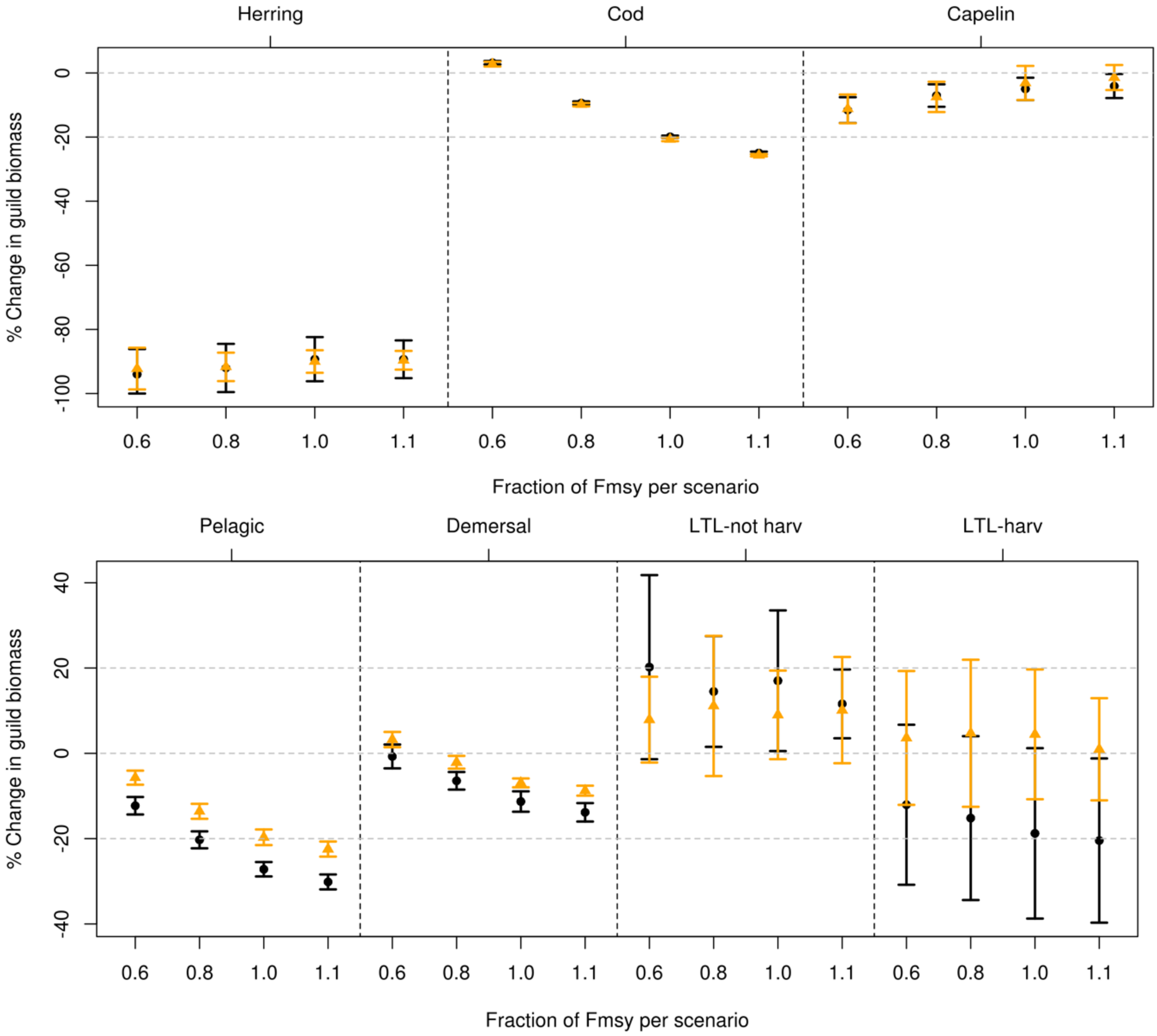


Figure 2 Upper panel shows the biomass changes in the three key species for each of the eight scenarios between the future time slot (2055-2065) and the historical time slot (2005-2020). The collapse in herring is evident for all scenarios, and the difference between the 'all in' scenarios (black) and 'commercial only' (orange) is low. In the lower panel (Hansen et al., 2019, figure 2), the components in the model are put together in guilds. For these, we notice an increasing negative response in the biomass to the increased fishing pressure between the 'all in' and 'commercial only'.

Economic consequences

The effect of the combined climate and management scenarios were to a large degree controlled by the changes in the harvesting strategies. Using simple ecological and economic indicators revealed that although adding more ecosystem components to the harvesting regime introduced a negative impact on the ecosystem, the added yield on the lower trophic level would by far make up for the losses in the pelagic and demersal sectors. It is noted though, that the negative response in the pelagic and demersal guilds increases with increasing fishing pressure, seemingly pushing the ecosystem into a more vulnerable state.

Currently, the sectors involved in pelagic and demersal harvests are not the same as those harvesting on lower trophic levels. The trade-offs between sectors and the ecosystem trade-offs need to be considered before initiating any large-scale fisheries on the lower trophic levels.

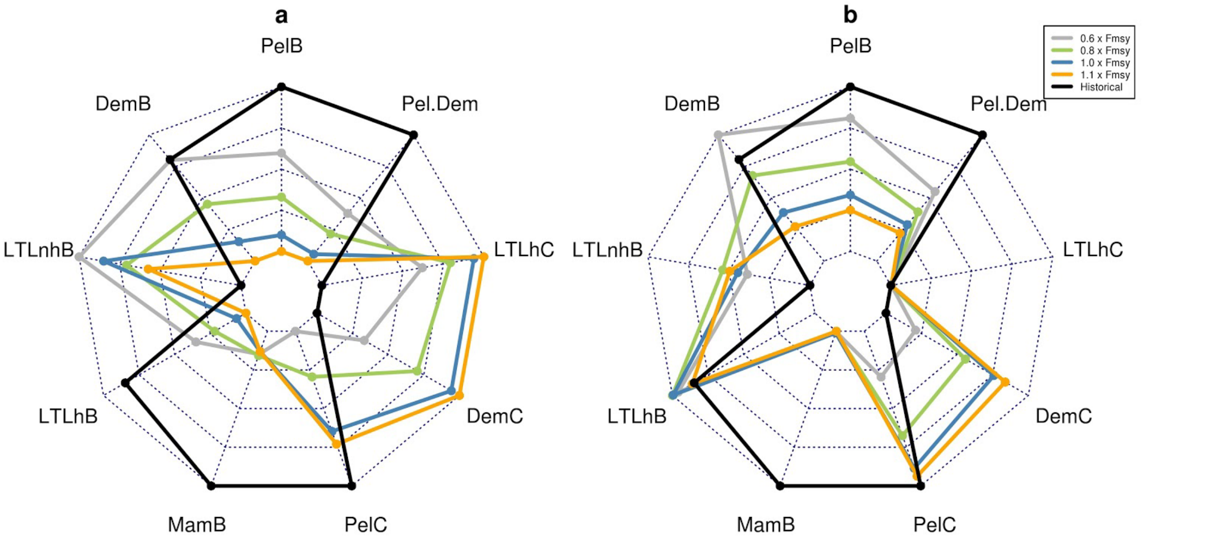


Figure 3 (Hansen et al., (2019)): Simple ecological indicators for the eight scenarios (Pel=pelagic, Dem=demersal, Mam=mammals, LTLh=harvested lower trophic levels, LTLnh=non-harvested lower trophic levels. B=biomass, C=catch. Pel.Dem is the relationship between total pelagic biomass and total demersal biomass). 0.6 x Fmsy corresponds to global sustainability (grey), 0.8 x Fmsy is world markets (green), 1.0 x Fmsy (blue) is the local stewardship and 1.1 x Fmsy (orange) is the national enterprise scenario. The black line are indicators representing the 2005-2015 period. a) represents the scenarios including harvest on the lower trophic levels, while b) represent the results from the scenarios only including harvest on the currently harvested ecosystem components. The results from the eight scenarios are averages over the period 2055-2065.

Climate-ready solutions

Fisheries climate vulnerability was assessed across European countries (via sensitivity of species landed) and all 421 fleets (Europe only, via economic factors and diversity of catch).

Norway has a relatively low vulnerability rank based on the catch composition.

Norway has highly industrialised fleets with more adaptive capacity than small, artisanal fleets that target only a few species

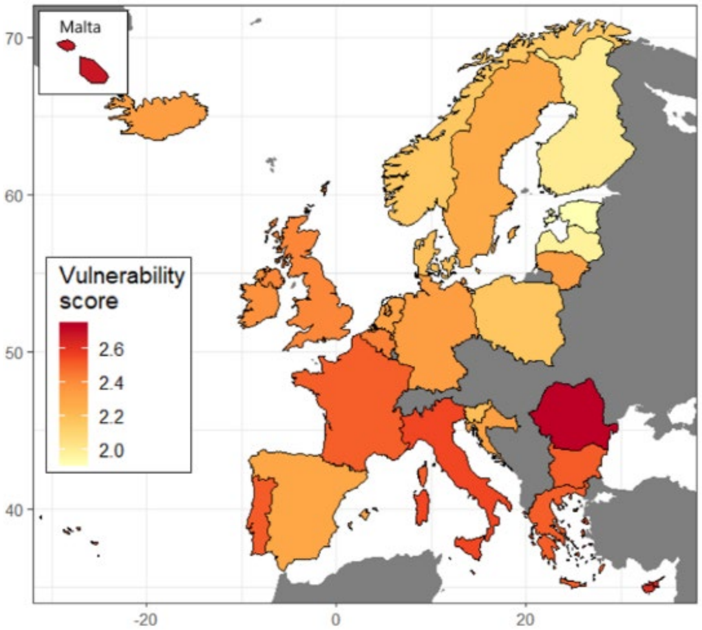


Figure 4 Map of the regional climate risk. National-level borders are shown for reference.

Fishers in the Norwegian and Barents Seas may benefit from climate change although future, ecosystem-level impacts of changes in species composition and productivity are challenging to predict.

Policy recommendations

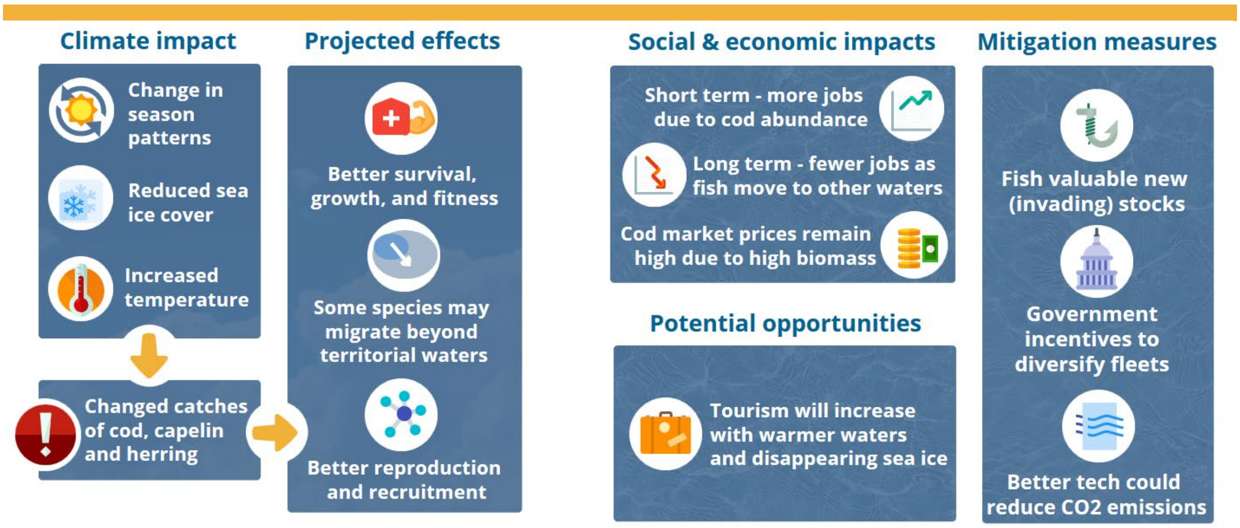


Figure 6 Bowtie for the Barents and Norwegian Seas. 1-alternative stocks available for fisheries, 2: Alternative stocks harvested to release pressure on cod/capelin/herring (C/C/H). 3: Government incentives – diversify fleets to switch to alternative species. 4: Technology: transfer between sectors and industry. 5: Improved technology reducing CO_2. 6: Fisheries management: greater reliability in stock management. 7: local legislation. 8: Government incentives. 9: habitat creation or offsetting (closed areas). 10: EU legislation. 11: EU legislation: adoption of new legislation. 12: trade: greater level of traceability and labelling. 13: catch and release (pelagic fisheries)

Main findings: 1-6 ranked high, 7-9 medium. Major challenges are potential changes in distributions that would have an impact on the travelling distance for the fisheries, leading to a possible decrease in employment. Shared stocks might change their migration and distribution, causing less quotas for Norway. Changes in foodweb from arctic to boreal (already happening).

Based on the model simulations performed, large-scale harvest on lower trophic levels should be carefully considered. The trade-offs between the currently important fisheries sectors (pelagic and demersal) and a potential new sector targeting the mesopelagic layer (including mesozooplankton), are numerous. Although the total yield would increase in such a scale that it would be very difficult to earn less on the marine fisheries in total, an increasing negative response in the fish components are evidence of an increasingly vulnerable ecosystem which potentially can increase the risk of negative responses to cumulative effects.

CERES publications:

Hansen, C., Nash, R., Drinkwater K.F., Hjøllo, S.S. (2019): Management scenarios under climate change – a study of the Nordic and Barents Seas. Front. Mar. Sci. | doi:10.3389/fmars.2019.00668

Other publications:

https://www.ssb.no/290270/fiskeri.fangstverdi-for-fiskeslag-og-hovudgruppe-av-fiskeslag.millionar-kroner

Alexander, M.A., Scott, J.D., Friedland, K.D., Mills, K.E., Nye, J.A., Pershing, A.J., Thomas, A.C. 2018. Projected sea surface temperatures over the 21st century: Changes in the mean, variability and extremes for large marine ecosystem regions of Northern Oceans. Elementa Science of the Anthropocene 6(1), p.9. doi: http://doi.org/10.1525/elementa.191.

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 (2017).

Skogen, M.D.,Olsen, A., Børsheim, K.Y., Sandø, A.B.,Skjelvan, I. 2014. Modelling ocean acidification in the Nordic and Barents Seas in present and future climate. Journal of Marine Systems 131, 10-20.

Skogen, M.D., Hjøllo, S.S., Sandø, A.B., Tjiputra, J. 2018. Future ecosystem changes in the Northeast Atlantic: a comparison between a global and a regional model system. ICES Journal of Marine Science 75 (7), 2355-2369

ICES (2018) Working Group for Integrated Ecosystem Assessment in the Barents Seas report

Drinkwater, K.F., Harada, N., Nishino, S., Cherici, M., Danielson, S.L., Ingvaldsen, R., Kristiansen, T., Hunt, G.L., Jr., Stiansen, J.E. (In prep.) Possible futures for Subarctic and Arctic marine systems: I. Climate and physical and chemical oceanographic changes.

Mueter, F., Planque, B., Hunt, G.L., Jr., Alabia, I., Hirawake, T., Eisner, L., Dalpadado, P., Drinkwater, K.F., Harada, N. (In prep.) Possible futures for Subarctic and Arctic marine systems: II. Prey resources, food webs, fish and fisheries