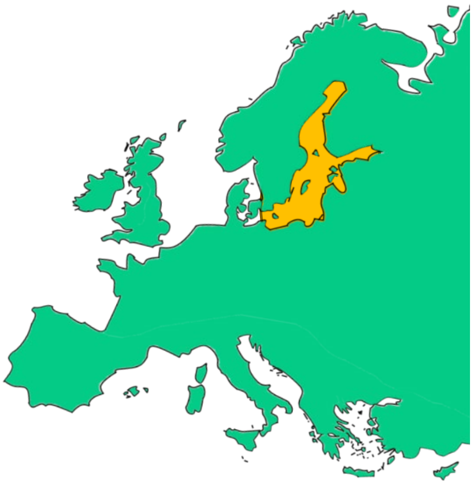
Case study



#15 Herring, sprat and cod in the Baltic Sea

#16 Herring in the North Sea

#17 Gadoids in the North Sea

Species background and economics

Cod (*Gadus morhua*), herring (*Clupea harengus*) and sprat (*Sprattus sprattus*) are the three main target species of the Baltic Sea commercial fishery.

Stocks of all three of these species are subject to extensive international demersal and pelagic mixed and target fisheries conducted with mainly trawls and gillnets. In 2014, the value of fisheries landings in the eastern and western Baltic fisheries was ~220 Mio € and > 75% was from these three species (45 Mio Euro for cod, 72 Mio Euro for herring, and 52 Mio Euro for sprat) highlighting their importance for the economic revenue in this region.

Expected projections under climate change

For the Baltic Sea, climate-driven changes in water temperature, salinity, and oxygen concentration are expected, which means that the sea will become warmer and fresher.

Eutrophication is an important issue in the Baltic Sea and both changes in climate and nutrient loads (e.g. nitrate and phosphate) will affect the spatial and temporal dynamics of hypoxia (low dissolved oxygen).

The physical and biogeochemical changes associated with future climate projections and nutrient scenarios for the Baltic Sea will result in changes in the productivity of stocks of cod, sprat and herring and concomitant changes in fishery resource availability and broader ecosystem health.

For example, the tendency towards reduced salinity in the climate projections and expansion of hypoxic waters at mid-depths in Baltic Sea Basins may decrease the survival of Baltic cod eggs and larvae. Warming of surface waters may increase the survival of sprat eggs and larvae yielding stronger recruitment.

In shallow water, coastal area, changes in water currents (e.g. increased currents from more frequent and longer storms) may decrease the survival of herring eggs attached to aquatic plants, thereby decreasing Baltic herring recruitment.

An ensemble of future climate projections based on dynamical and regional downscaling from general circulation models forced with two different climate scenarios, the representative pathways RCP4.5 and RCP8.5 were used to run the Rossby Center Ocean model-Swedish Coastal and Ocean Biogeochemical model (RCO-SCOBI) in the Baltic Sea.

The results from the ensemble average show a future increase in the volume averaged temperature and a tendency for reduction in the volume averaged salinity (Fig. 1).

In addition, three different nutrient load scenarios were applied; the reduction scenario BSAP (Baltic Sea Action Plan) where the nutrient loads were set to a maximum value, the reference scenario with a nutrient load similar to today and a worst case scenario in which the nutrient loads continue to increase with time (Fig. 2).

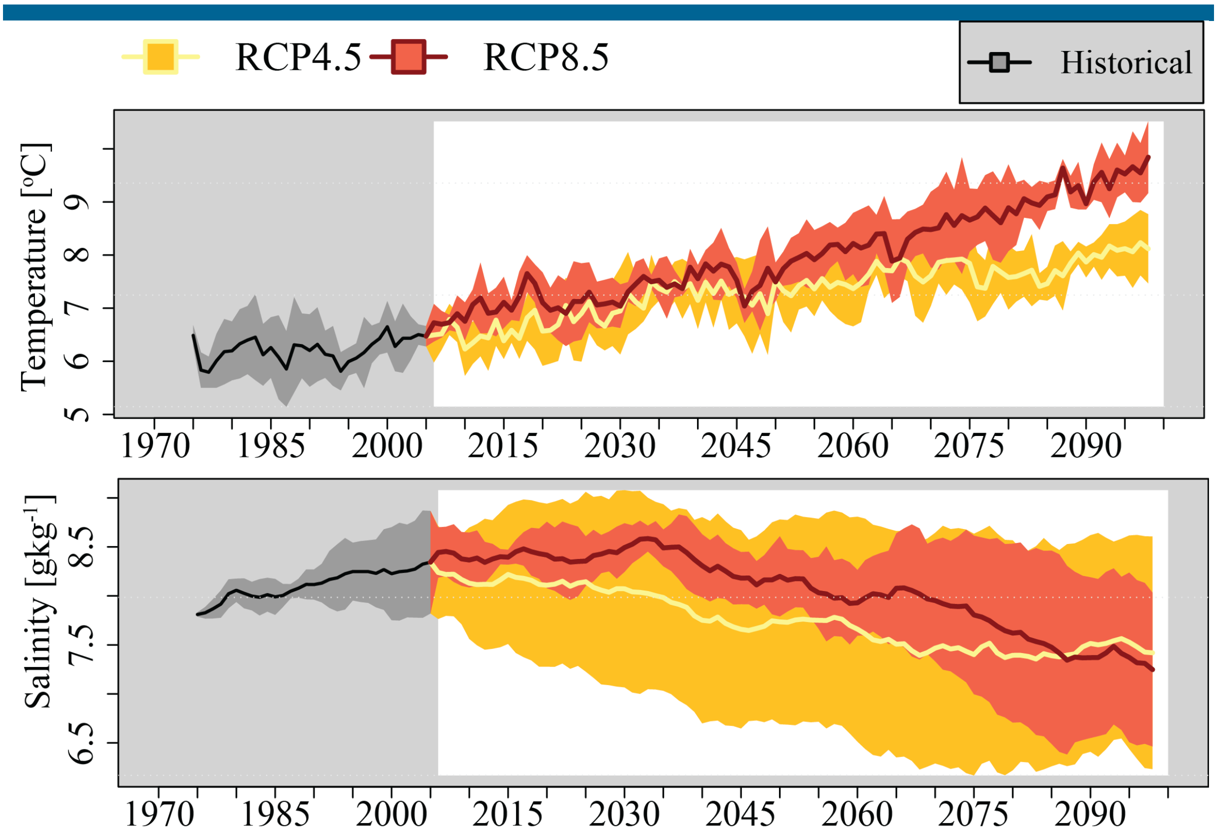


Fig. 1 Projected volume averaged modelled ensemble average (coloured lines) and ensemble standard deviation (coloured shaded area) of temperature (°C) and salinity (g kg^{-1}) for two climate scenarios of greenhouse gas concentrations RCP4.5 (yellow) and RCP8.5 (red). *Figure from Saraiva et al. 2019.*

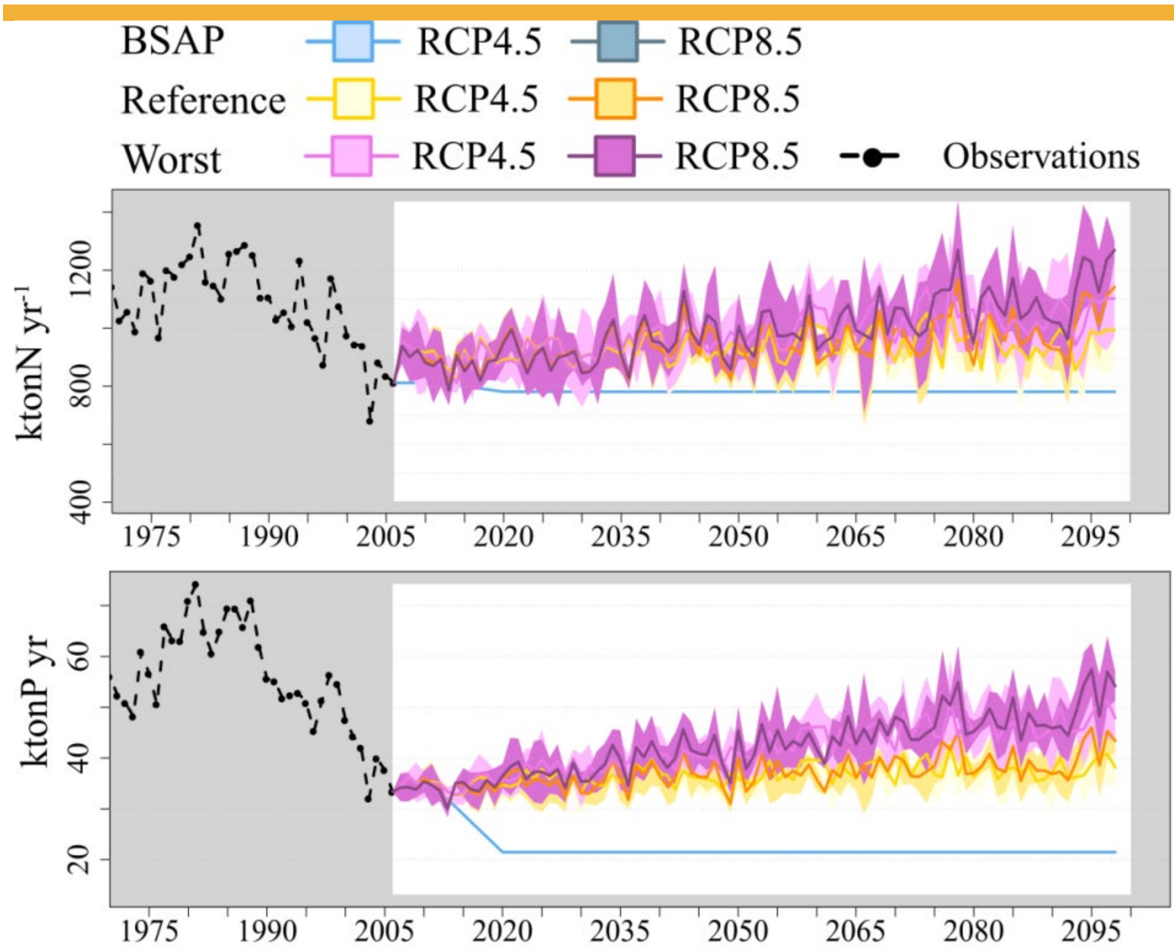


Fig. 2 Ensemble average (coloured lines) of the total river load (kton yr^{-1}) to the Baltic sea of bioavailable nitrogen (upper panel) and phosphorus (lower panel) for the two climate scenarios of greenhouse gas concentrations RCP4.5 (brighter colours) and RCP8.5 (darker colours) and the three nutrient load scenarios BSAP (blue), Reference (yellow) and Worst case (pink). The ensemble spreads calculated as one standard deviation are denoted by the coloured shaded areas. Black dashed line are observations. *Figure from Saraiva et al., 2019.*

These direct effects will combined with indirect effects of climate affect fisheries resources.

For example, climate-driven changes in the abundance and composition of prey for larvae and young juveniles in the water column (e.g. zooplankton) for all three species or the availability of benthic prey (invertebrates) for larger juvenile and adult cod are expected to impact fisheries yields.

Changed abundances of different life stages of cod, sprat and herring due to climate change directly impacts their biological interactions with changed predation and cannibalism patterns affecting the stock production and biomass. Depending on the magnitude of future eutrophication and climate change, these direct and indirect food-web mediated impacts on fisheries resources may be particularly important in the Baltic Sea including piscivorous predators such as seals in the Baltic proper.

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

Four CERES scenarios were developed for fisheries based on scenarios currently used by the IPCC (SSPs and RCPs). World Markets (WM) is a profit driven society with the highest population growth and fossil fuel use (SSP5, RCP8.5).

National Enterprise (NE) also has intensive fossil fuel use but also increased national isolation and lower economic growth (SSP3, RCP8.5).

Global Sustainability (GS) has the lowest fossil fuel use, highest use of renewable energy and lowest population growth rate (SSP1, RCP4.5). Local Stewardship (LS) focuses on local resources and strategies with intermediate levels of renewable energy and fossil fuel use (SSP2, RCP6.0).

The scenarios included different, future changes in economic, technological and management variables important to fishing including fish price, fuel efficiency, gear selectivity/discards, catch efficiency, exploitation rate, quota trading, etc.

Fuel and fish prices will be influenced by the global market. For this reason, CERES decided to use the trends of fish and fuel prices from the MAGNET model which is a global general equilibrium model. The model was used to run the SSP scenarios used as base for the CERES scenarios, and future trends in fish and fuel prices have been extracted for the period 2010-2050 (See CERES Report for Deliverable 4.1).

The prices were provided in real terms and were corrected for inflation using GDP deflator projection for Europe given that all models use nominal prices. The difference between scenarios is limited.

Annual change in rates ranged between +1.3 and +1.7% per year for fish and +2.6 and 2.9% per year for fuel prices. Unfortunately, in that model, fish species are taken as one commodity and aquaculture and fisheries are pooled.

Key research needs

Given the strong food-web coupling in the Baltic Sea, particularly among key fisheries resources, it is no longer sufficient to project the impacts of climate change on only specific species.

Holistic, ecosystem modelling is needed to evaluate integrated effects of the complex processes and interactions in the Baltic Sea ecosystem to future scenarios of climate change and eutrophication.

Furthermore, ecological changes in the availability of cod, sprat and herring as fisheries resources need to be evaluated with respect to broader, social and economic developments such as future fishing costs, fish prices and fisheries management targets.

CERES research

During the CERES project, the following activities occurred:

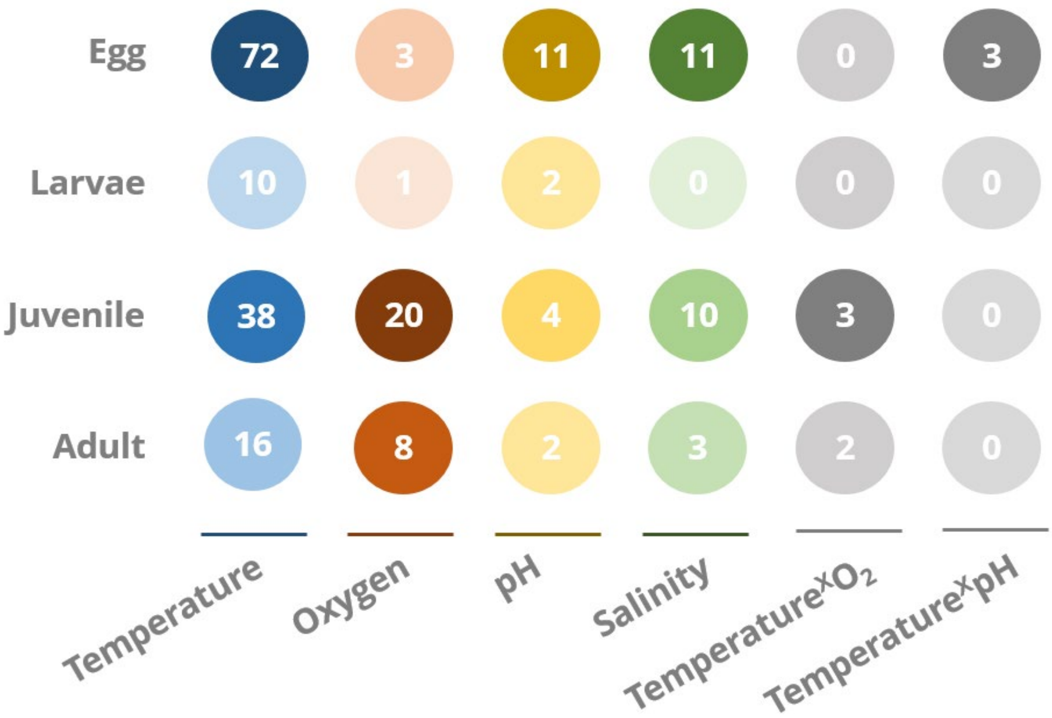
- Collated outputs from downscaled physical and biogeochemical projections using the RCO-SCOBI model based on scenarios of climate change (RCP4.5, 8.5) and three nutrient load scenarios.
- Conducted a systematic literature review, a GAP analysis and a Meta-analysis to examine direct effects of climate change (warming, acidification, deoxygenation, decreased salinity) on survival and growth physiology of cod, herring and sprat in the Baltic Sea.
- Parameterized the Atlantis end-to-end model for the Baltic Sea and performed extensive corroboration using historical time series.
- Projected the effects of different scenarios of climate change and eutrophication (2005 to 2097) on cod, herring and sprat and other ecosystem components and processes in the Baltic Sea including trophic cascades and changes in spatial dynamics.
- Projected the bio-economic consequences of different CERES scenarios including changes in fish prices, fuel price, and fuel efficiency to 2040.
- Engaged stakeholders to discuss CERES scenarios and Atlantis outputs including the Baltic Sea Advisory Council (BSAC) Executive Committee and key representatives of many

different important stakeholder organizations in the Baltic Sea and ecosystem modelers at the ICES Working Group of Physical-biological and Ecosystem Modelling.

- Developed a Bow-Tie diagram mapping the drivers and mitigation measures associated with key risks of climate change.

Ranked Baltic Sea countries and fishing fleets in a Europe-wide fisheries climate vulnerability assessment.

Results



- Herring ranked 1 out of 28 European fish and shellfish genera reviewed here (32 studies). Cod ranked 10 out of 28 (8 studies). Sprat ranked 12 out of 28 (7 studies).
- 14 out of 20 studies in the Baltic were performed in Germany.
- Most of the studies focused on embryos (15), no studies on adults were found.
- Growth was the most common response studied (12), followed by mortality (9).
- Temperature was the most common stressor studied (14), followed by salinity (5).

Biological

The review activities in Tasks 2.1 and 3.1 have included review and extraction of data from relevant databases and literature, compilation of the data, and preliminary analyses of the data from the RCO-SCOBI model and to parameterize and calibrate the Baltic Atlantis model to both the baseline scenarios and future climate and eutrophication scenarios as well as socio-economic scenarios.

This has been a very extensive work, and there have been focused upon obtaining as precise and robust parameters and model calibration as possible for the new calibrated Baltic ATLANTIS model with input from the RCO-SCOBI climate and eutrophication ensemble modelling.

Associated to Tasks 2.2 and 2.3 for the Baltic Sea case study, there have under the CERES project been used regionally downscaled output from Global Climate Models (GCM) as forcing to the RCO-SCOBI model. Three different GCMs (Model A = MPI-ESM-LR, Model B = EC-EARTH and Model D = HadGEM2-ES) were run with two different greenhouse gas scenarios (RCP4.5 and 8.5) to project effects of climate change.

The resulting output from the RCO-SCOBI model provides an ensemble mean and a range of changed hydrographical and hydrodynamic conditions in the Baltic Sea for each climate scenario.

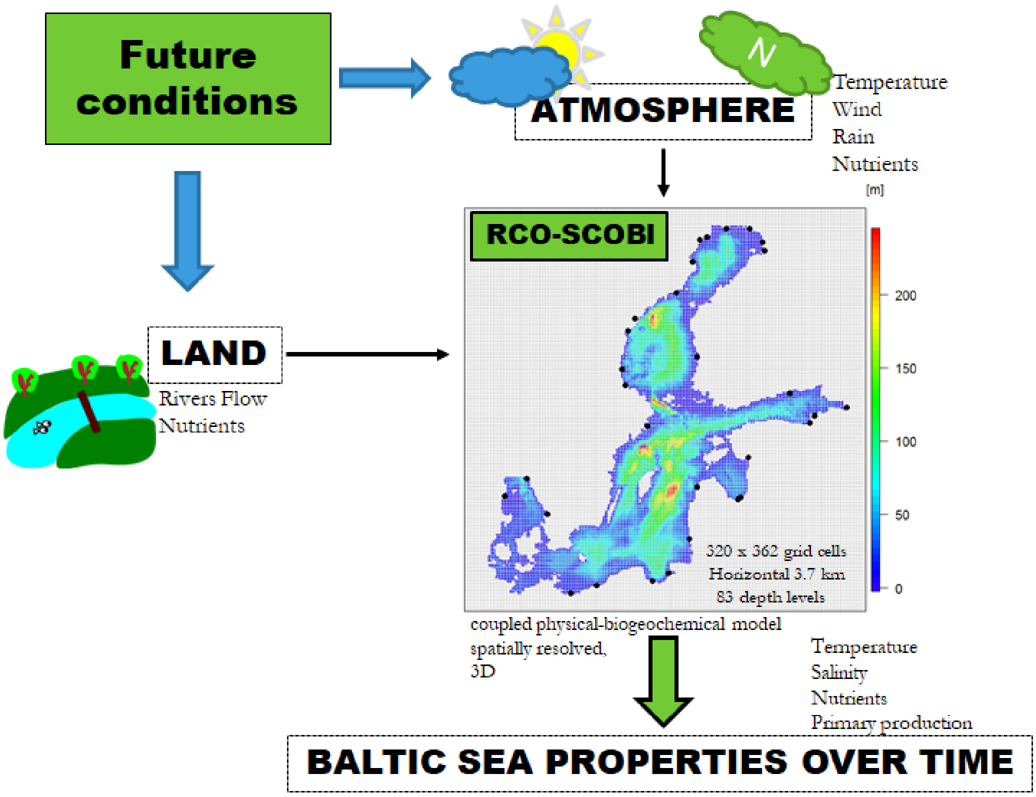
The means and ranges are accordingly estimated based on projections for each of the climate scenarios in relation to the forcing from these 3 different Global Climate Models), resulting in total 6 climate scenarios.

On top of each of those two climate scenarios there has been three nutrient load (eutrophication) scenarios for the Baltic Sea with the RCO-SCOBI model (respectively, SSP1 = Baltic Sea Action Plan (BSAP), SSP2 = Reference, SSP5 = Worst Case. As the reference and worst case in many respects are quite similar only the reference and BSAP have been used in current context. For each scenario the means and ranges of changed hydrographical conditions over a projection period up to year 2100 are provided given the climate change input from the 3 forcing Global Climate Models.

See also details on methodology and output in the CERES Report for Deliverable 4.1.

The extracted output used in Atlantis from the RCO-SCOBI modelling (currents, temperature, salinity, sea surface elevation, turbulent kinetic energy, oxygen, ammonium, nitrate, phosphate, N detritus, P detritus, phytoplankton 1, phytoplankton 2, phytoplankton 3, zooplankton) cover data from two 5 year periods, i.e. historical data (2000-2005) and projection data (future 2093-2097) for the different scenarios ((RCP4.5, RCP8.5)*(Reference, BSAP)*(2000-2005, 2093-2097).

Modelling approach



Climate and Eutrophication Scenarios & Ensemble Modeling Output (T2.1-2.3):

Forcing with climate models embedded in RCO-SCOBI

ModelA MPI-ESM-LR	Historical (1975-2005)	RCP 4.5 (2006-2100)	RCP 8.5 (2006-2100)
SSP1 - BSAP		Run A002	Run A005
SSP2 - ReferenceHype	Run A001	Run A003	Run A006
SSP5 - Worst		Run A004	Run A007

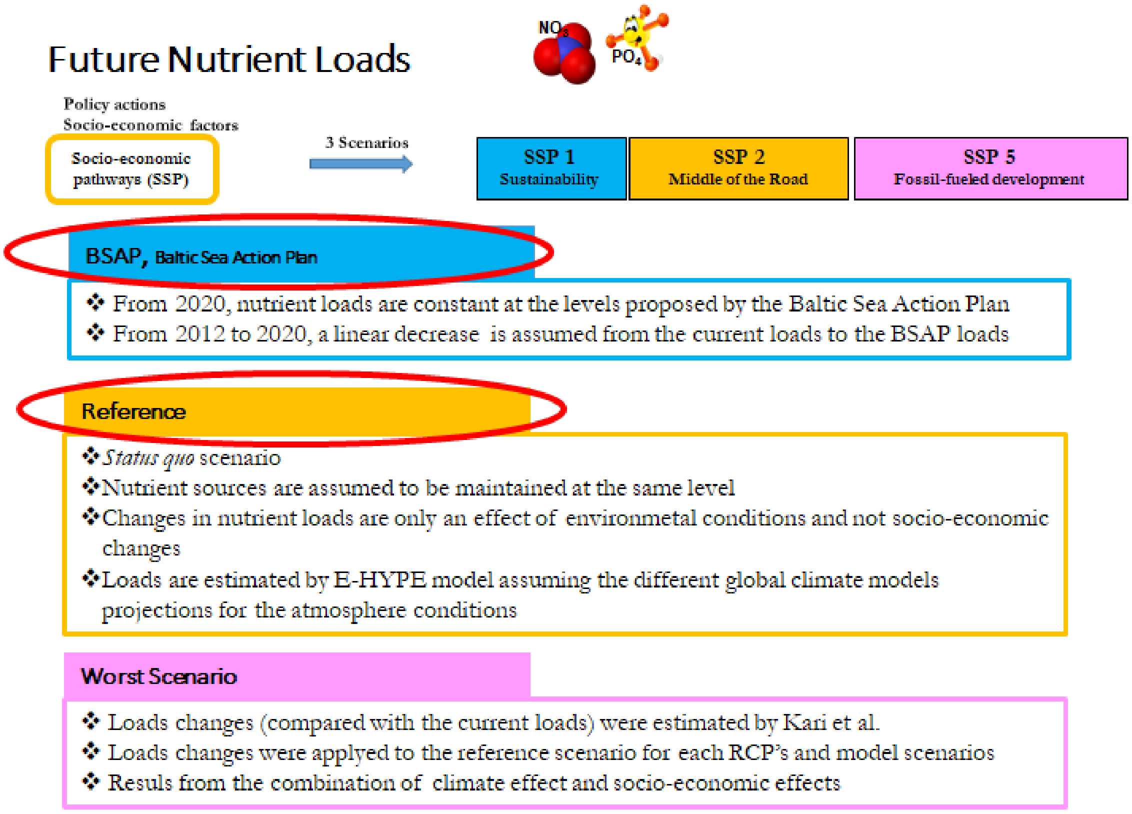
ModelC IPSL-CM5A-MR	Historical (1975-2005)	RCP 4.5 (2006-2100)
SSP1 - BSAP		Run C002
SSP2 - ReferenceHype	Run C001	Run C003
SSP5 - Worst		Run C004

ModelB EC-EARTH	Historical (1975-2005)	RCP 4.5 (2006-2100)	RCP 8.5 (2006-2100)
SSP1 - BSAP		Run B002	Run B005
SSP2 - ReferenceHype	Run B001	Run B003	Run B006
SSP5 - Worst		Run B004	Run B007

ModelD HadGEM2-ES	Historical (1975-2005)	RCP 4.5 (2006-2100)	RCP 8.5 (2006-2100)
SSP1 - BSAP		Run D002	Run D005
SSP2 - ReferenceHype	Run D001	Run D003	Run D006
SSP5 - Worst		Run D004	Run D007

- Historical period 1975-2005
- Projection period 2006-2100

- 4 Global Climate Model for atmosphere conditions
- 2 RCP's
- 3 Nutrient Scenarios



Figures 5-7 Overview of RCO-SCOBI climate and eutrophication modelling approach and ensemble modelling scenarios.

In CERES, the previous physical forcing from the HBM-ERGOM bio-geo-chemical model has been replaced by forcing with the RCO-SCOBI model with projections up to 2097.

Evaluations and projections with the new implementation of the Baltic Atlantis model have been made for the Baseline and the RCP4.5 and RCP8.5 climate scenarios using this RCO-SCOBI physical and bio-geo-chemical model with hydrodynamic forcing.

The outcomes of the RCO-SCOBI modelling associated to task 2.3 with respect to future climate and eutrophication ensemble model output is shown in the two figures presented above under section a.ii with respect to projected temperature, salinity, nitrogen and phosphorus load, as well as in the below figure 8 with respect to projections of primary production, N-fixation and hypoxic areas.

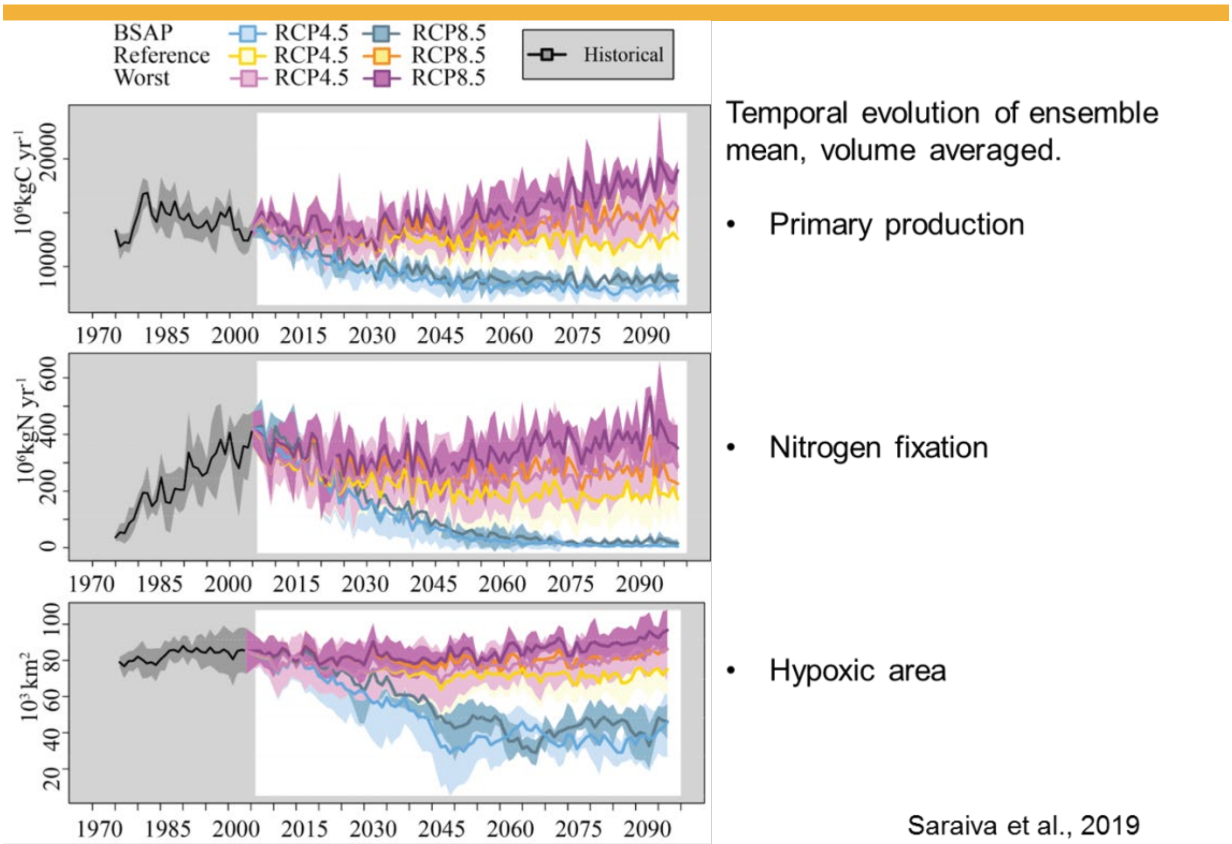


Figure 8 RCO-SCOBI model projections.

The following general results and trends appear from the RCO-SCOBI projections:

- High variability but similar patterns between models;
- Differences between the RCPs are significant;
- Clear differences in temperature and salinity between the different climate scenarios with increasing temperatures and decreasing salinities in the climate scenarios compared to the baseline with strongest effect of the RCP 8.5 scenario;
- Difference between nutrient scenarios is significant, for most properties more than between climate scenarios, i.e. there is a clear difference between nutrient scenarios;
- BSAP clearly leads to lower primary production and lower N fixation;
- BSAP leads to less hypoxic areas;
- 2100 projections considering BSAP are lower than hindcasts and historical simulated values;
- Reference and Worst scenarios overlap.

The projections are used in the Baltic Atlantis model to derive broader ecosystem responses on the changed climate and eutrophication parameters, and impacts have been evaluated including changed biomass and production levels for important fish stocks such as cod, herring and sprat, as well as recruitment, growth, consumption, spatial distribution and biological interactions.

In the current implementation, model data from regionally downscaled global climate model A has been used in relation to the analyses and for the results shown here, i.e.

RCO-SCOBI SSP2 Reference RunA001 (historical 2005), RunA003 (RCP4.5, 2006-2097) and Run A006 (RCP8.5, 2006-2097). Because of the spin-off period which the Baltic Atlantis needs in order to reach equilibrium, the first 35 years cannot be used.

The results from the new implementation of the Baltic Atlantis with projections for the Baseline and the RCP4.5 and RCP8.5 climate scenarios using the RCO-SCOBI physical and bio-geo-chemical model with hydrodynamic forcing show trends for cod, sprat and herring in the Baltic as well as for the other biological functional groups evaluated. The figure 9 below summarises relative changes in biomass for the biological functional groups between scenarios of RCP4.5 and RCP8.5 compared to the Baseline. Here the output from the Baltic Atlantis projection is shown as an average for the period 2040-2060 forced by the RCO-SCOBI Model.

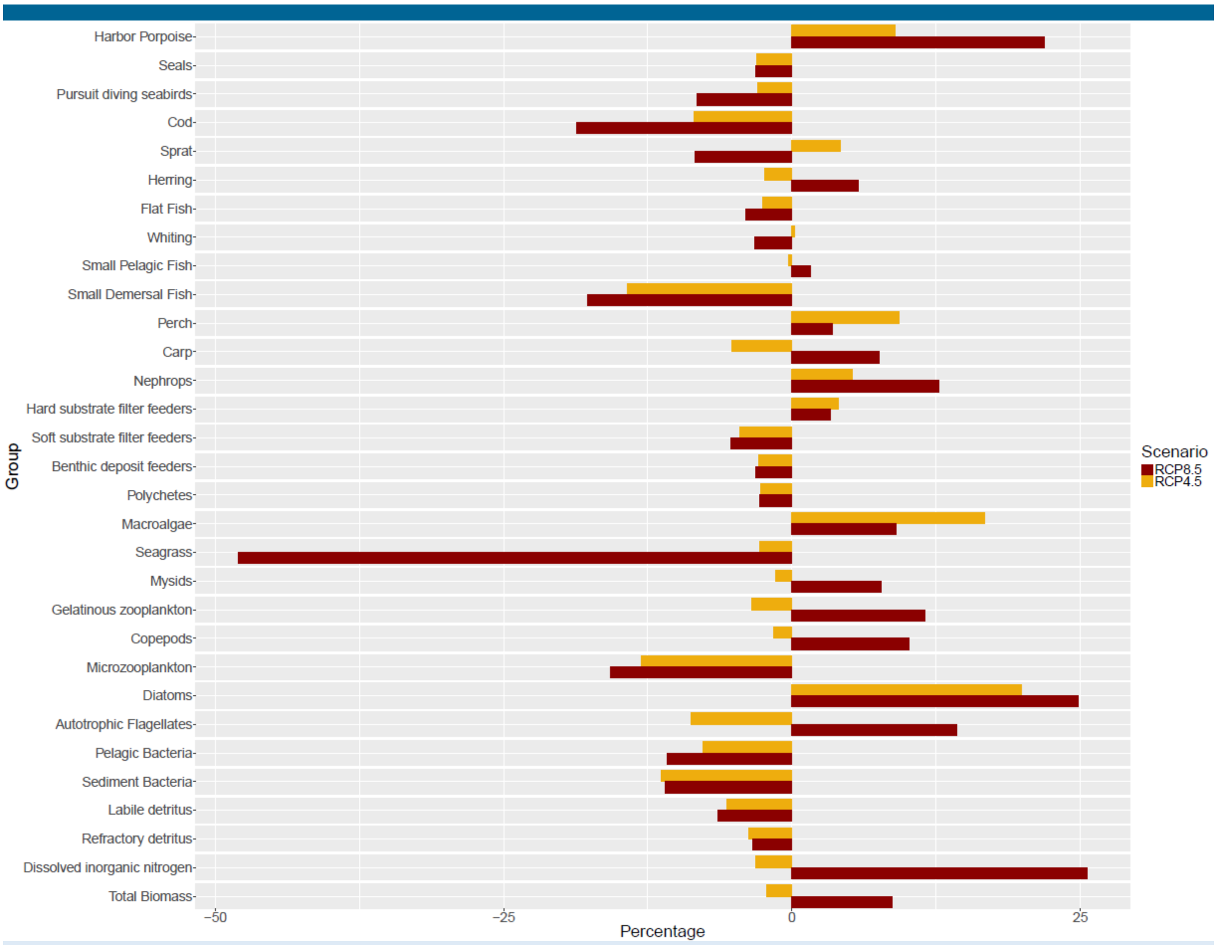


Figure 9 Relative changes in biomass for the biological functional groups between scenarios of RCP4.5 (yellow) and RCP8.5 (red) compared to the Baseline.

Figure 10 below gives examples of differences in geographical distribution of the three most important commercial exploited fish resources (cod, herring and sprat) as a comparison between change in absolute biomass between scenarios of RCP4.5 and RCP8.5 compared to the Baseline (average for the period 2040-2060 forced by the RCO-SCOBI Model.

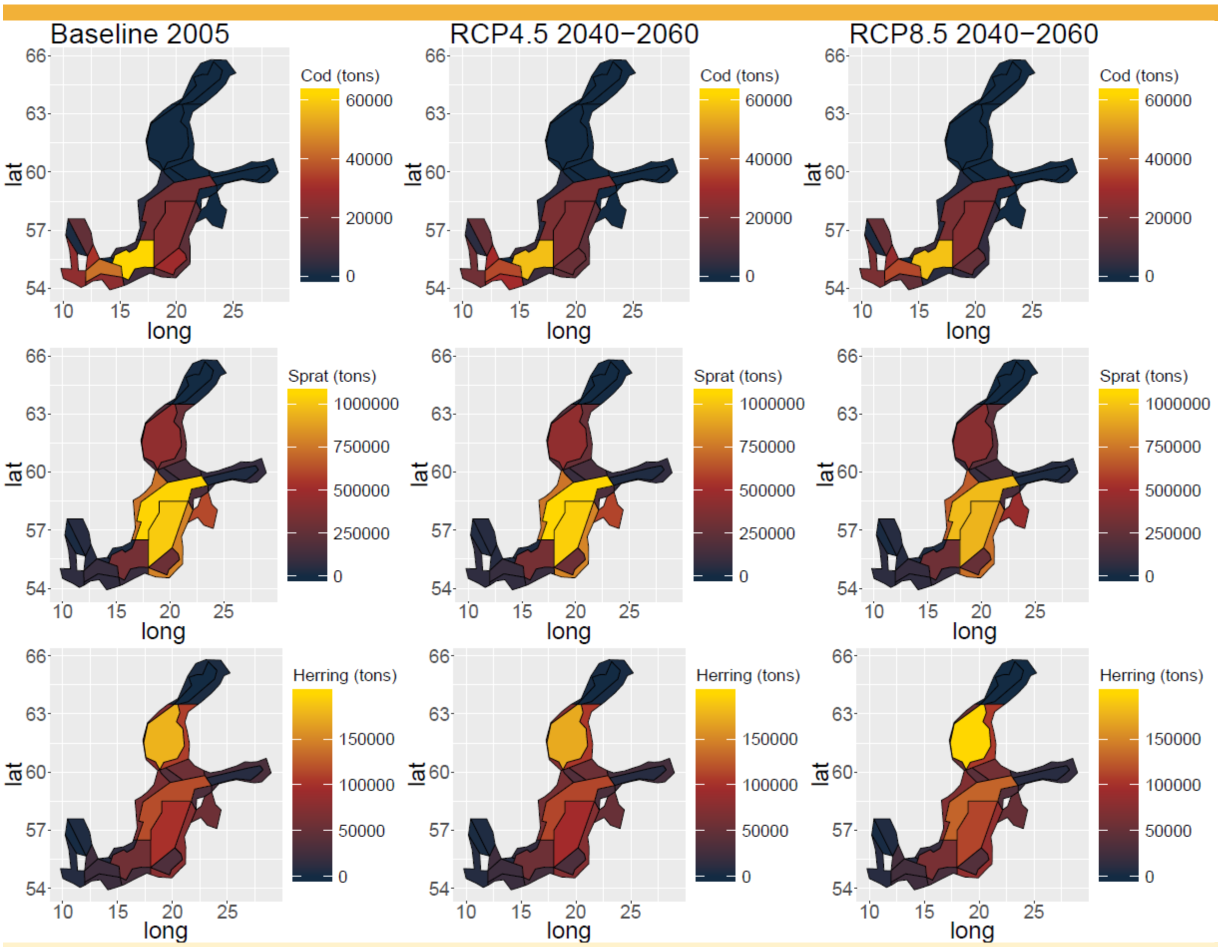
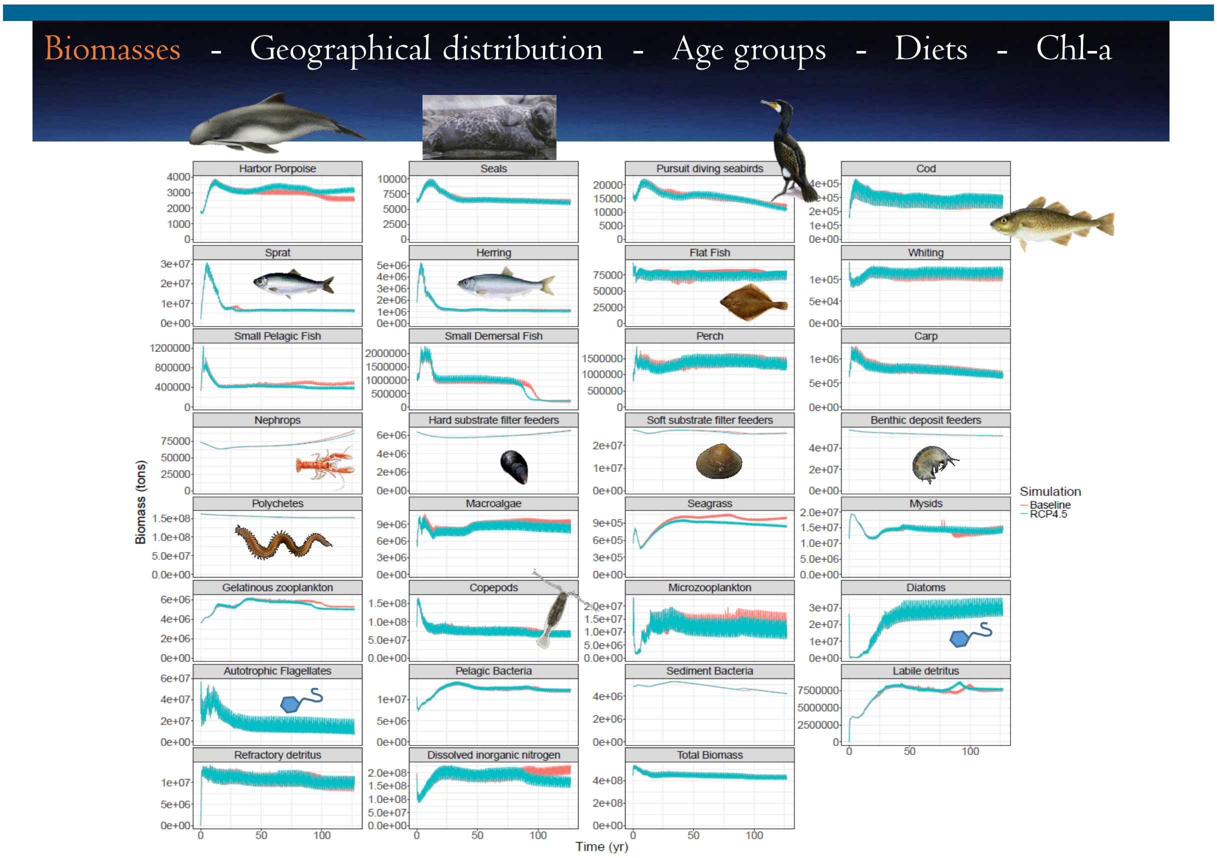
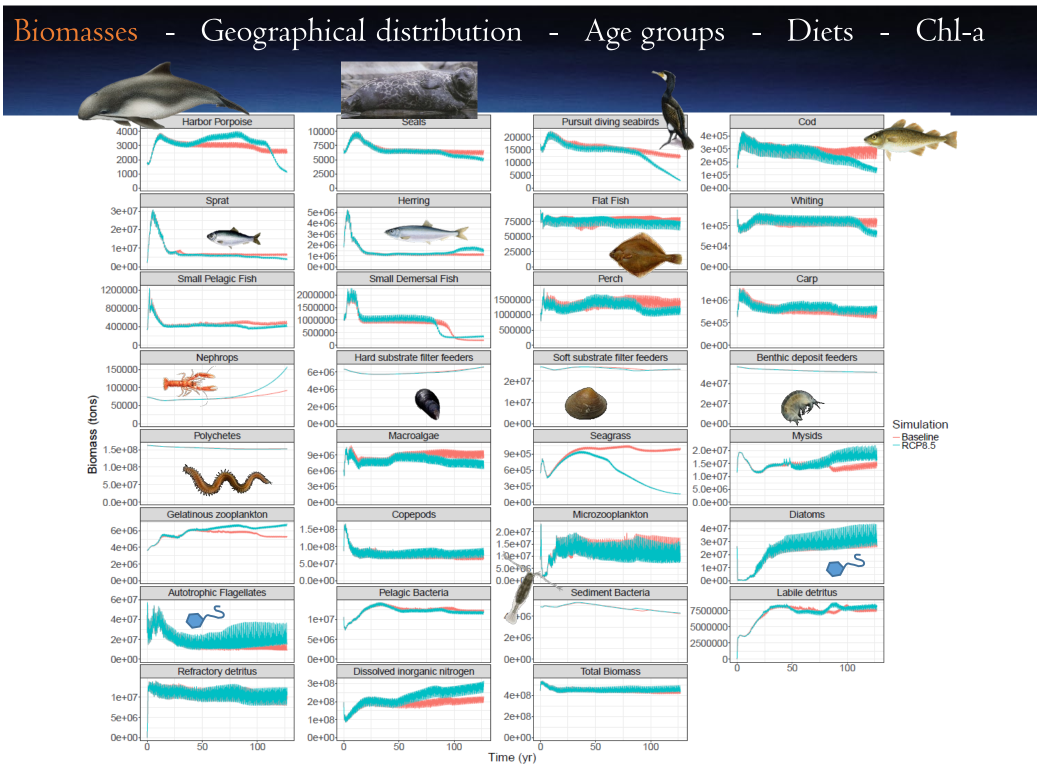


Figure 10 Differences in geographical distribution between species as a comparison between change in absolute biomass between scenarios of RCP4.5 (yellow) and RCP8.5 (red).





Figures 11-12 Trends in changes and equilibrium over time for respectively RCP 4.5 and RCP 8.5 (red) for the biological functional groups evaluated by Baltic Atlantis within the period 2005 – 2097.

The Figures 11-12 above show overview of resulting trends in changes and equilibrium over time for respectively RCP 4.5 and RCP 8.5 (red) for all biological functional groups evaluated by Baltic Atlantis within the period 2005 – 2097 (with a model spin-off period of 35 years before) compared to the baseline year 2005 (green) (time axis = days).

Overall, the biological responses of the Baltic ecosystem to the RCP 4.5 and RCP8.5 scenarios compared to the baseline (present time) show that highest effects on biomasses, both in terms of relative changes in biomass size (for all biological functional groups) and biomass distribution (for the 3 most important fish species cod, sprat and herring), are observed in the long term, i.e. with highest effects for the 2080-2097 period.

However, the effects occur gradually over time and relative effects in the medium term (2040-2060) are in the same direction as the long-term changes.

Accordingly, the relative changes in the medium term are distinct, but not as strong as on the longer term. Compared to the baseline the strongest effects on relative changes in biomass size and relative distribution are observed for the RCP8.5 climate scenarios compared to the RCP 4.5 scenarios.

Most important the model outputs indicate, that the RCP8.5 and RCP4.5 scenarios will result in a relative decrease of cod biomass (approximately 30% and 12%, respectively) compared to the baseline, while sprat will decrease around 12 % under RCP8.5 and increase around 8% under RCP4.5 in the medium term from 2040-2060.

In the same period, the results indicate that herring will increase around 8% and 1-2% under RCP8.5 and RCP4.5, respectively.

However, the model is missing the link between herring and seagrass, which they use to lay their eggs on and the results show a decrease in seagrass indicating a possible decrease in herring as well.

Flatfish and nephrops will also increase modestly, while whiting will decrease modestly. The climate scenarios will finally result in perch biomass increases in the interval 20-30%.

Economic consequences

Economic consequences are evaluated according to changed catches because of the changed abundances, as well as in relation to changes in fish prices and fishing costs, such as fuel costs and fuel efficiency. This has been done for the baseline and for the different climate RCP scenarios, as well as for the SSP scenarios (SSP5, SSP3, and SSP2) where the latter cover different levels of changed fish prices, changed fuel prices, and changed fuel consumption (given RCP climate conditions).

These changes naturally impact fishing conditions and viability of commercial fishery, including technological development which will impact fuel consumption efficiency and changed world market fish prices determined by fish demands for consumption, etc. Instead of using constant fishing mortality by species in the model, the management module of the Atlantis model has been calibrated with fleet- and fisheries-specific information.

The following results come from the best available calibration and parameterisation of the model. The current challenge is to have a model conditioned with the most realistic parameters, and especially to obtain realistic economic parameters.

In this analysis and simulation, the effort has been kept constant in the projection period, and there has also been assumed constant regulation and MSY reference points for the exploited stocks.

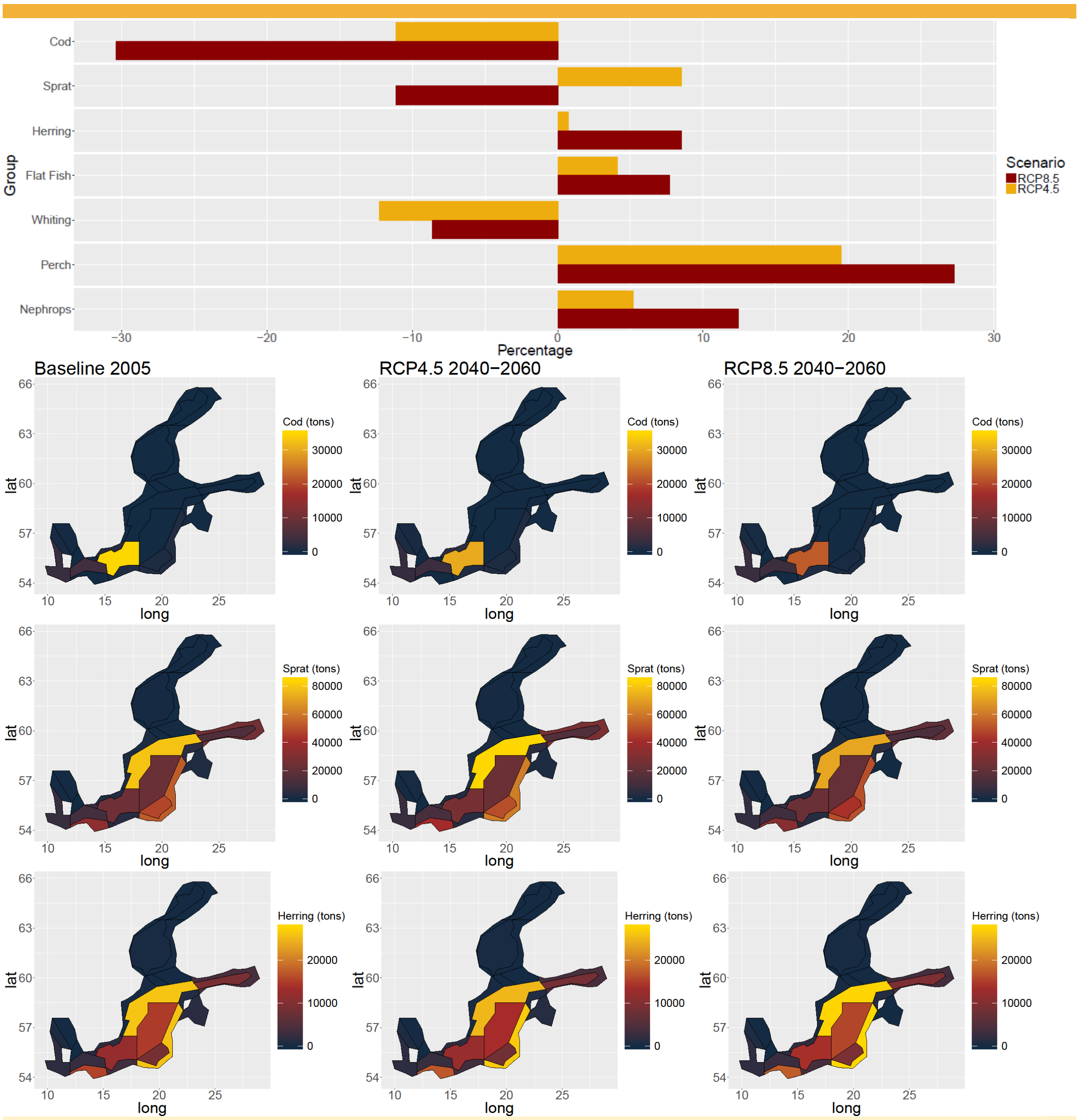
The resulting economic consequences on the fishing fleets with respect to fish landings, costs (fixed and variable costs), and revenues (and profit) in relative terms are given in detail in the CERES D4.1 Report for the different time periods covering the baseline/current), the medium term (2040-2060), and the long term (2080-2097) for the different combinations of climate scenarios and economic scenarios.

The model output indicates that on the medium term (2040-2060) the effects of the different scenarios for all the different fleets is a reduction in costs to 70-81% in SSP5 and SSP1, and to 86% and 91 % in SSP2 and SSP3 in the different climate scenarios.

The changes in revenue for the different fleets are to levels between 85% and 101 % for SSP5 and SSP3 and to levels between 90% and 103% for SSP1 and SSP2.

In general, the highest economic effects observed are due to the reduction in fuel consumption by the fishery because of the significant energy efficiency increases, while the general modest changes in fish prices and fuel prices have less relative effect.

The below figures summarizes respectively the relative change in landings for the most important commercial exploited fish resources (biological functional groups) and the change in distribution of landings (in weight) for the three most important commercial exploited fish resources (cod, sprat and herring biological functional groups) between scenarios of RCP4.5 and RCP8.5 compared to the Baseline for all fleets. The results are output from the Baltic Atlantis projections as averages for the period 2040-2060 forced by the RCO-SCOBI Model.



Figures 13-14 Relative change in landings (upper figure) for the most important commercial exploited fish resources and the change in distribution of landings (in weight) for cod, sprat and herring between scenarios of RCP4.5 (yellow) and RCP8.5 (red) compared to the Baseline for all fleets.

Climate-ready solutions

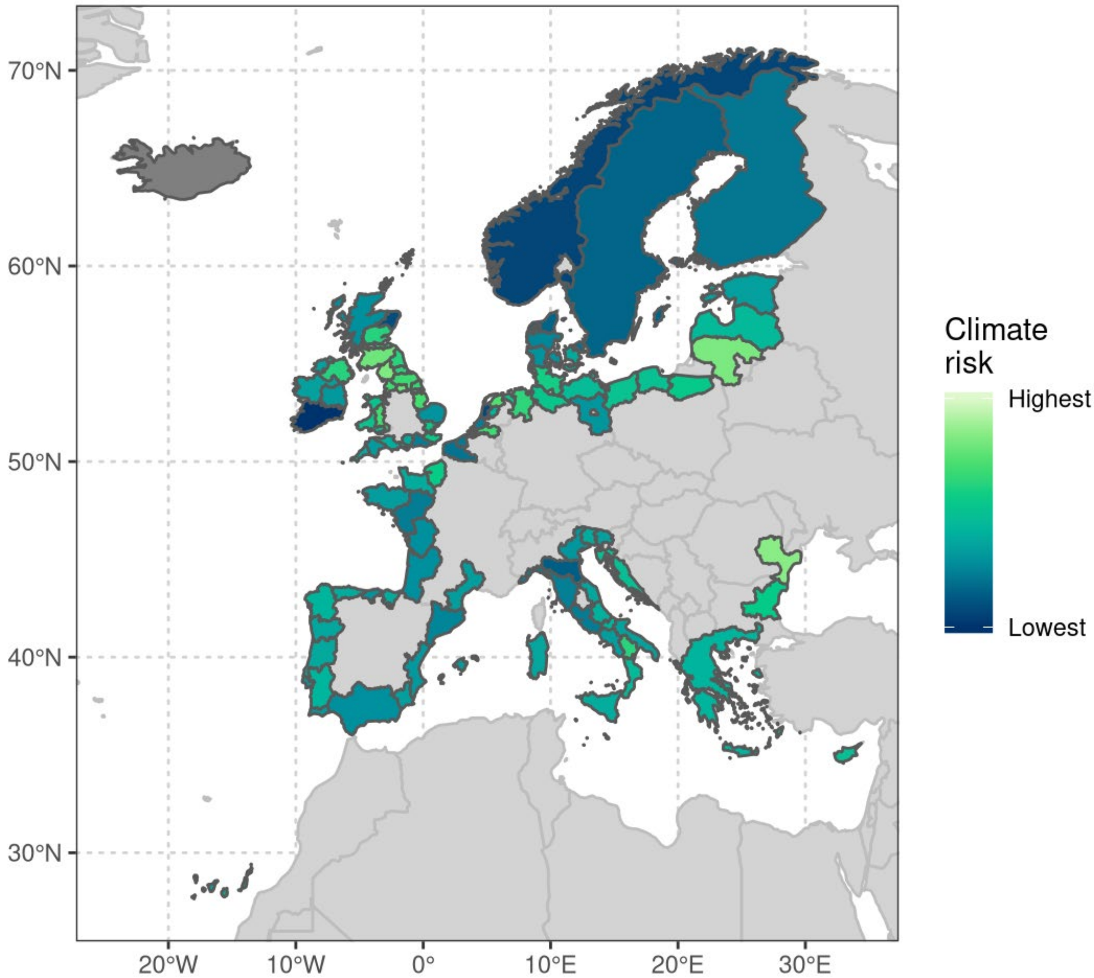


Figure 15 Map of the regional climate risk. Colour scale is linear in the value of the corresponding score, but is presented without values, as they have little direct meaning. National-level borders are shown for reference. *Credit : Mark Payne*

A climate vulnerability assessment for the European fisheries sector was conducted using the IPCC climate-risk assessment framework, including aspects of climate hazard, exposure and vulnerability.

The risk of European fishing fleets (421) and regions (102) to climate-driven changes in fish stocks was assessed based on the ecological characteristics of species landed (157 species in EU STECF) and the economic characteristics of these analysis units.

Considerable variation exists in climate risk, even within a single country (e.g. the UK), due to regional differences in the traits of species landed and economic indicators such as the dependence on fishing and the GDP / capita of fleets (e.g. GDP / capita). Risks are relatively low for Scandinavian countries due their relative wealth

Bowtie diagram

Fleets in this storyline have a moderate climate risk. In spite of the low hazard of these stocks, moderate-high specialisation (moderate-high exposure) and poor profitability (high vulnerability) generate a moderate climate-risk.

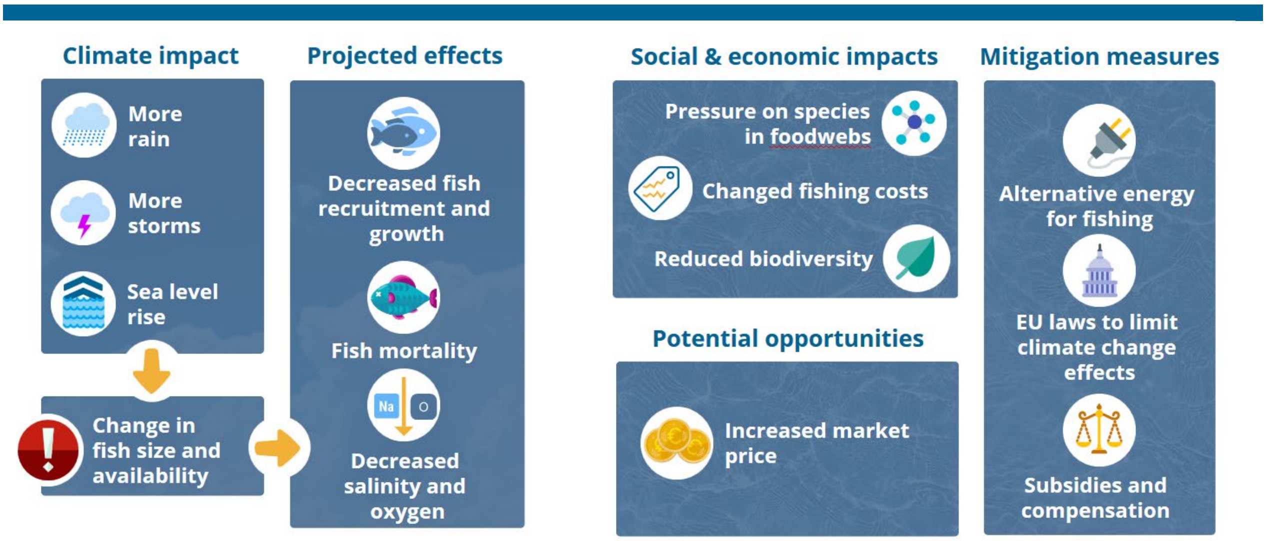


Figure 16 BowTie analysis based on stakeholder feedback. All full BowTies available http://bit.ly/CERESbowties2020 *Image: Katy Smyth*

Policy recommendations

Furthermore, when CERES have evaluated the changed stock abundances and biomasses of key Baltic fisheries resources and the changed fishing conditions for those given the climate, eutrophication and socio-economic scenarios and projections it will in a second step in future fisheries management advice be necessary to evaluate whether the fish stock carrying capacities and stock equilibria will change so much that it will be necessary to define new stock Maximum Sustainable Yield (MSY) reference levels compared to the current ones used in management advice for the major fishery resources.

Further reading

CERES publications

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Bossier, S, Nielsen, J.R. and Neuenfeldt, S. (Submitted). Trophic cascades state and control exemplified in its multitude of effects for the Baltic Sea ecosystem. (Submitted Ecological Modeling).

Saraiva, S., Meier, H. E. M., Andersson, H., Höglund, A., Dieterich, C., Gröger, M., Hordoir, R., Eilola, K., 2019. Uncertainties in Projections of the Baltic Sea Ecosystem Driven by an Ensemble of Global Climate Models. Frontiers in Earth Science. 6. Doi: 10.3389/feart.2018.00244.

Other publications:

References in Bossier et al. 2018.

Scientific, Technical and Economic Committee for Fisheries (STECF) - The 2017 Annual Economic report on the EU Fishing Fleet (STECF 17-12); Publications Office of the European Union, Luxembourg.

Baltic Atlantis movie published on www.youtube.com.