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Part 2a Multiple Driver Scenarios, NE Atlantic, North Sea, Baltic Sea and Biscay

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D4.3 Synthesis report on the comparison of WP3 and WP4 simulations:

Part 2a Multiple Driver Scenarios, NE Atlantic, North Sea, Baltic Sea and Biscay

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Introduction

Marine ecosystems are being affected by anthropogenic environmental change, for example through climate-induced changes in physical properties and ocean acidification along with direct anthropogenic pressures, such as pollution, eutrophication and fishing. If we are to maintain a safe environment in this century and beyond, it is essential that we improve our understanding of responses of marine ecosystem to external drivers so that we can better quantify and project its responses.

The sensitivity of a range of marine ecosystems to direct anthropogenic drivers has been addressed by means of coupled physical ecological numerical models at a regional scale. A wide range of regional seas have been considered ranging from enclosed (Baltic Sea, Black Sea Adriatic Sea) to shelf seas characterised by cross shelf oceanic exchange (Barents, N Sea, Biscay, N Aegean) and strong upwelling regions (Benguela). The focus has been on simulating the sensitivity the systems to a combination of multiple drivers both climate scales and direct anthropogenic drivers, such as the discharge of pollutants (from inorganic nutrients to organic pollutants and heavy metals), changes in coloured dissolved organic matter and the impact of fisheries.

All of these drivers may impact on the Good Environmental Status of marine ecosystems and therefore provide context for management decisions. Generally speaking the MEECE simulations allowed the determination of the sensitivity to combinations of drivers. Below we summarise the regional sensitivities individually.

The sensitivity of marine ecosystem to direct anthropogenic drivers (input of eutrophicating substances, fisheries, the anthropogenically mediated introduction of alien invasive species) synergistically acting, has been addressed by means of coupled physical ecological numerical models. The modelling effort considered several regions/basins of the European Seas.

The main focus has been on the simulation of the sensitivity of the marine systems to the so-called direct anthropogenic drivers, such as the discharge of pollutants (from inorganic nutrient to organic pollutants and heavy metals) and the impact of Fisheries.

The main findings concerning specific marine regions/basins are given in a specific policy relevant summary for each of the areas considered.

Generally speaking the modelling effort allowed for determining the sensitivity to specific drivers, in some case highlighting how the implementation of environmental policies allowed for a potential mitigation of the impact.

Multiple Driver Simulations by Region

The multiple driver scenarios combine both climate and anthropogenic drivers. To ensure policy relevance the climate scenario considers the BU (2030-2040) scenario, with additional anthropogenic drivers.

IPSL-CM4 A1B + SC1 world market (A1)

IPSL-CM4 A1B + SC2 global commons (B1)[1]

IPSL-CM4 A1B + SC3 Fortress nation (A2)

IPSL-CM4 A1B + SC4 local responsibility (B2)[2]

Compulsory scenarios in bold.

[1] *N Sea, NE Atlantic, Baltic, Biscay , Benguela, Barents*

[2] *Adriatic, N Aegean, Black Sea*

A summary of the scenarios region by region is given in table 1. The exact perturbation used for each driver is to be guided by the ELME interpretations of each driver under the above scenarios (http://www.elme-eu.org/ELME_Results.pdf). The sign of the perturbation should follow the trend of the relevant pressure/driver evidenced by the outcomes of ELME (the synoptic tables of the regional BBN models and/or the extended tables showing regional trends for the drivers in the different scenarios; see annex 1 of D1.5) while the magnitude of the perturbation could to be defined according to historical trends and/or natural variability.

Table 1: *Table of showing the scenarios combinations of drivers considered in D4.3 and the MEECE Atlas; A1B 2080-2100 time-slice, BU 2030-2040 time-slice; GC global commons, WM world Market, LR local responsibility, C= climate, E = eutrophication, F = fishing, DF = demersal fishing, NIS = Non Indigenous species*

Region	Model	A1B	BU	GC	WM	LR
NE Atlantic	POLCOMS -ERSEM	C	C	C +E + DF	C + E + DF	-
North Sea	ECOSMO	C	C	C + E	C + E	-
	++EwE	C	C	C +E + F	C +E + F	
	DARWIN*	C + NIS	C			
Baltic Sea	ECOSMO	C	C	C + E	C + E	-
	+ SMS	C + F		C + F	C + F	
	DARWIN*	C + NIS				

Biscay	ROMS NPZD OSMOSE	C C		C +F	C + F	-

*NIS modelling is reported in D4.3 part 3.

Regional Synthesis

1. Northeast Atlantic

1.1 Model description

The Atlantic Margin Model (AMM) is a coupled hydrodynamics-ecosystem model comprising the Proudman Oceanographic Laboratory Coastal Ocean Modelling System (POLCOMS) coupled to the European Regional Seas Ecosystem Model (ERSEM) developed at Plymouth Marine Laboratory. The model domain covers the northwest European shelf and adjacent areas of the North Atlantic (Figure 1), extending from 20°W to 13°E and 40°N to 65°N on a 1/9^{o} latitude by 1/6^{o} longitude grid (~12 km resolution) with 42 s-coordinate levels in the vertical.

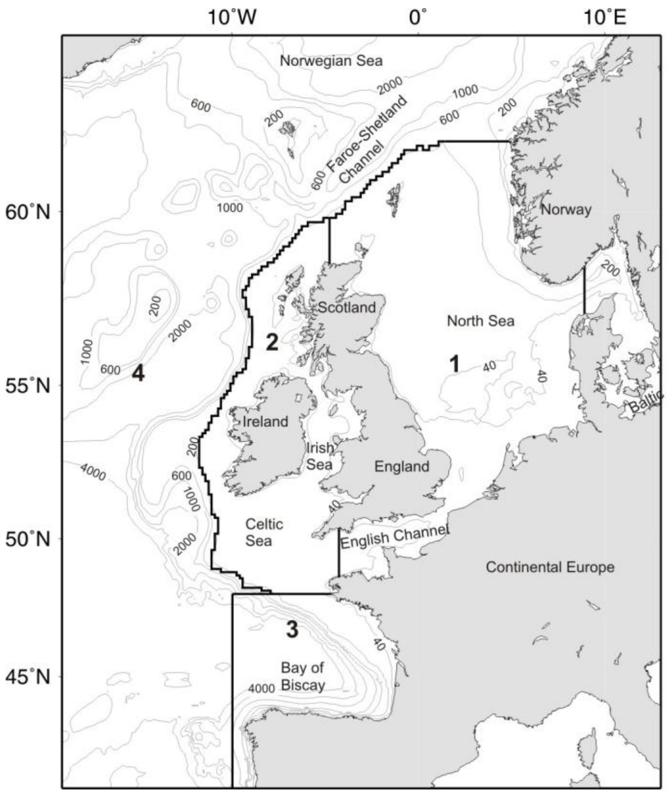


Figure 1: Location map and bathymetry of the Atlantic Margin Model (AMM). Also shown are regions used for area integrals: 1. Greater North Sea; 2. Celtic Seas; 3. Bay of Biscay and Iberian Shelf and 4. Wider Atlantic

We use a time-slice approach, which is commonly used in climate impact studies, whereby mean conditions in an experiment are compared with mean conditions in a reference to give a measure of the climatic/anthropogenic change, on the assumption that conditions in both time-slices are approximately stationary. We use the direct forcing downscaling approach described in D3.1, focusing on the A1B SRES scenario and consider five experiments: CNTRL, A1B, BASE, WM and GC, outlined below and summarized in Table 2**Error! Reference source not found.**. The CNTRL simulation is a present day simulation forced by the IPSL-CM4 20C model for the nominal present day period 1983-2000. A1B is a future climate scenario representative of possible conditions in 2082-2099 under a business as usual emissions scenario: SRES A1B. Full details of the POLCOMS-ERSEM setup and the forcing used for the CNTRL and A1B simulations are given in MEECE deliverable D3.4.

CNTRL and A1B are identical to the simulations described in D3.4 except that bottom trawling (described in D4.1) has been explicitly added to the ERSEM code. The impact of trawling on the biomass of deposit feeders, filter feeders, meiobenthos and aerobic bacteria is parameterized following D1.4. The method uses hours of fishing effort for Beam and Otter trawlers in the North Sea part of the model domain only. The effects of bottom trawling on other areas of the shelf are not considered here.

The baseline simulation for the near future, BASE, uses atmospheric forcing for the period 2030 to 2040 and has anthropogenic drivers held at present day values. As for the A1B simulation, atmospheric forcing from the IPSL-CM4 A1B2 model is used under a Business as Usual (BU) emissions scenario SRES A1B. River flows are perturbed by changes in regional rainfall. Open-boundary nutrient values (nitrate, silicate and phosphate) are perturbed by the fractional change in nutrients from the OA-GCM PISCES ecosystem model (Aumont et al., 2003) between this time-slice and CNTRL using the delta change approach described in D3.1.

The simulations CNTRL, A1B and BASE use atmospheric forcing, open boundary forcing and river flows (modified by changes in rainfall) derived from different time periods of the same OA-GCM. All three simulations use the same datasets for the anthropogenic drivers of river nutrient loads and trawling effort.

The final two simulations explore the impact of changes in anthropogenic drivers in addition to the climate change signal for the period 2030 to 2040. The simulations are the same as BASE but with changes in the river nutrient load and trawling drivers consistent with the World Market (WM) and Global Community (GC) scenarios of the European Lifestyles and Marine Ecosystems (ELME) project (http://www.elme-eu.org/ELME_Results.pdf). In the ELME project, socio-economic drivers for four future scenarios are used to define environmental pressures impacting on ecosystems. In the World Markets scenario there is rapid economic growth and limited environmental policies; an increase in the use of nitrogen fertiliser in agriculture combined with no changes in urban waste water treatment (UWWT) leads to an increase in river nitrogen loads whereas river phosphate levels remain unchanged. Trawling effort is also unchanged from present day levels. The other scenario considered, Global Community, has economic growth constrained by environmental objectives; reductions in the use of phosphate fertiliser together with increases in UWWT and a reduction in industrial discharge lead to a decrease in levels of both nitrogen and phosphate released to rivers. There is also a reduction in trawling effort.

In the World Market simulation, WM, river loads of total nitrogen (nitrate and ammonium) are increased by an arbitrary 50% compared to the present day values used in the CNTRL, A1B and BASE simulations. River phosphate levels and trawling effort are unchanged from the present day.

In the Global Community simulation, GC, river loads of total nitrogen and phosphate are reduced by 50% compared to the present day values. Relative change between the two trawling methods is estimated using observations from the years 1997-2004 (from D1.1), with the effort of Otter trawling reducing at about 1.5 times the rate for Beam trawling. For the GC simulation, trawling effort is reduced by 50% for Beam trawlers and 75% for Otter trawlers.

To allow the model to adjust to its lateral boundary and surface forcing conditions and changes in anthropogenic drivers, all simulations have a 5 year spin up period before calculating the average results presented here.

Table 2: Summary of experiments

Experiment	Description
CNTRL	1983-2000, control run
A1B	2082-2099, climate forcing; river nutrient loads and trawling effort as in CNTRL
BASE	2030-2040, climate forcing; river nutrient loads and trawling effort as in CNTRL
WM	2030-2040, climate forcing; river nitrogen increased, river phosphate and trawling effort unchanged
GC	2030-2040, climate forcing; river nitrogen and phosphate reduced, trawling effort reduced

Metrics considered (from D3.2)

- Surface temperature
- Surface salinity
- Surface nutrients
- Depth integrated phytoplankton biomass (small and large)
- Depth integrated zooplankton biomass (small and large)

- Benthic biomass
- Net primary production (net primary production)

Linkages with MEECE deliverables

Deliverable	Comments
D1.1	Data on trawling effort used for input to ERSEM
D1.4	Parameterisation for the effect of trawling on biomass
D1.5	Outline of driver response scenarios (ELME)
D2.2	Details of carbon sub-model
D3.1	Outline of model scenarios
D3.2	Description of metrics to consider
D3.4	Details of the POLCOMS-ERSEM implementation for the NE Atlantic
D3.5	Atlas of marine ecosystem climate response
D4.1	Description of single driver experiments
D4.4	Atlas of marine ecosystem climate response

1.2 Results

The impacts of the climate change and the anthropogenic scenario forcing are investigated by calculating the differences between mean conditions in pairs of the experiments (Table 3). The Kruskal-Wallis test is used to define where the difference between experiments is significant compared to the interannual variability of the two time series. We define differences with a Kruskal-Wallis p-value of less than 0.05 to be significant; regions where the p-value exceeds 0.05 are masked to grey in the figures.

The hydrodynamic climate change signal between 1983-2000 and 2082-2099, characterized by the differences between the CNTRL and A1B simulations, is described in detail in D3.4. For the near future baseline simulation (BASE) the pattern of change in sea surface temperature (Figure 2) is similar to the difference between CNTRL and A1B, with largest increases on the shelf and in the Norwegian Sea and smaller increases in the open ocean, especially in the Bay of Biscay. The mean temperature change increases from 1.5°C in the near future to 2.7°C by the end of the century. For the sea surface salinity (Figure 3), the initial freshening by 2030-2040 in the BASE simulation in the Bay of Biscay increases in magnitude and spreads north and east by 2082-2099 (A1B). Northern areas experience an increase in salinity, which increases in magnitude by the end of the century.

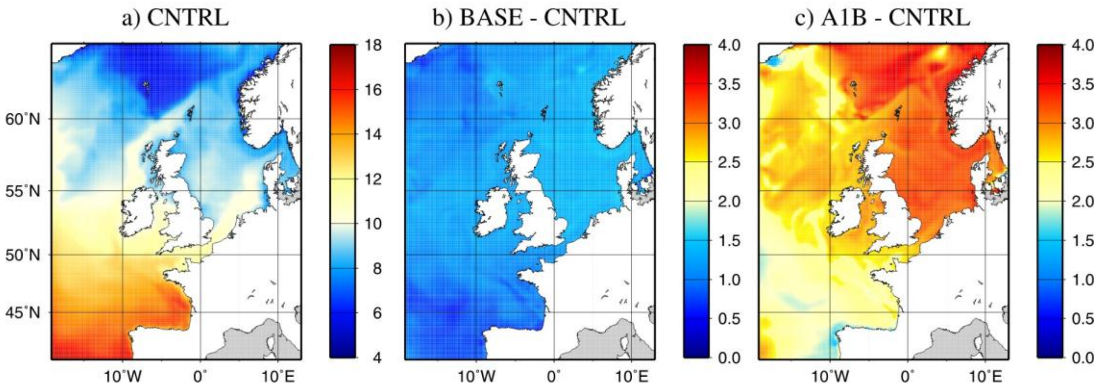


Figure 1: a) Mean sea surface temperature for the control simulation and the differences between b) the BASE and CNTRL simulations and c) the A1B and CNTRL simulations (°C)

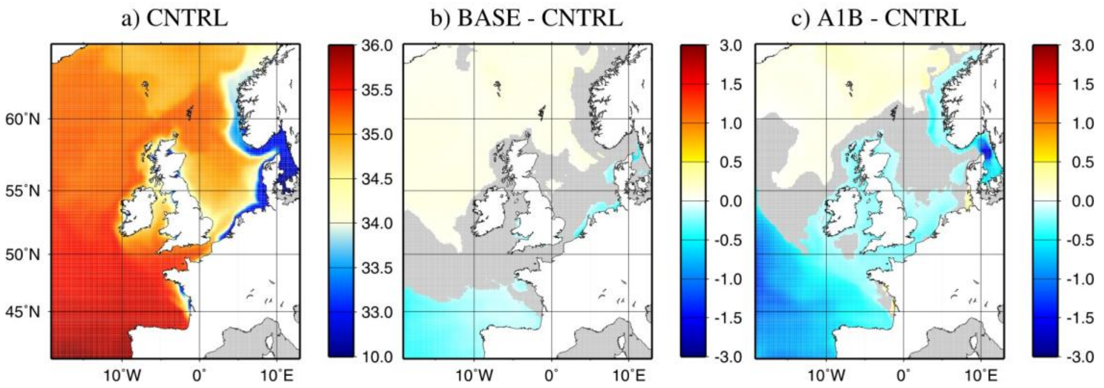


Figure 2: a) Mean sea surface salinity for the control simulation and the differences between b) the BASE and CNTRL simulations and c) the A1B and CNTRL simulations

Fractional changes for each experiment compared to the control run, CNTRL, and for the scenario simulations compared to the baseline simulation for 2030-2040, BASE, (Figure 4 to Figure 11) demonstrate changes due to climate change and anthropogenic policy scenarios separately and the impacts of the climate and policy drivers combined.

Climate change

In some metrics, there are consistent changes between the near future (2030-2040) and the far future (2082-2099) simulations with changes intensifying with time compared to the present day simulation, whilst other metrics show changes in the near future which reverse later in the century. In the Celtic and Irish Seas, the southern North Sea and a patch in the Bay of Biscay, the net primary production (Figure 4) increases in the near future (BASE) compared to the past (CNTRL). By the end of the century (A1B), much of the change in the Celtic Sea and southern North Sea is not significant compared to inter-annual variability, whilst net primary production decreases in the northern North Sea and in large areas off shelf. The biomass of small zooplankton (Figure 5) reduces in the near future, with the changes increasing in magnitude and spreading to other areas by the end of the century. A similar change occurs in the biomass of small phytoplankton (Figure 6) although, in the near future, values increase in patches in the Bay of Biscay and in some coastal regions, especially of the UK and Northern France, a pattern that persists but weakens in the far future. The main significant change in large zooplankton biomass (Figure 7) is an increase in the near future in the Celtic Sea and the Bay of Biscay; these signals weaken by the end of the century and there are large-scale decreases in biomass in other areas. There are initial increases in the biomass of large phytoplankton (Figure 8) over most of the shelf, the Bay of Biscay and the Norwegian Sea in the near future, which tends to continue to increase into the far future, except for in the North Sea, where large regions are found to be not significantly different from the CNTRL simulation by the end of the century; in the southwest of the domain, biomass decreases in the future simulations. The increase in large phytoplankton arises partly from an earlier spring bloom, which allows the diatoms to more efficiently utilize the winter store of silicate before stratification inhibits its vertical resupply (D3.4). The higher levels in the North Sea in the near future are also a consequence of changes in the supply of silicate from the south and southwestern boundaries of the model. Boundary values here are seen to increase in the near future. This leads to a peak in the level of silicate on the shelf in the near future, which reduces by the end of the century, fuelling stronger diatom growth in the near future simulation than in the recent past or the far future. Surface nitrate and phosphate (Figure 9, Figure 10) in the open ocean and northern North Sea decrease in the future, with the changes becoming significant over larger areas between the near future and the end of the century. Near future increases in the southern North Sea and the Irish Sea do not persist to the end of the century. Changes in the benthic biomass (Figure 11) in the near future are patchy, with the main significant changes being a strong increase south of Iceland and weaker increases in the North Sea; by the end of the century, the simulation shows a reduction in benthic biomass over most of the shelf. Note that, in the far future, large values (>10) of fractional change in the deep waters of the Norwegian Sea and the Faroe-Shetland Channel represent relatively small absolute increases (~5 mg C m^{-2}) from low values (~4×10^{-3} mg C m^{-2}) of benthic biomass in the CNTRL simulation.

Scenario changes

Comparing the two scenario experiments, WM and GC, with the near future baseline experiment (BASE) (Figure 4 to Figure 11, e and f) gives an estimate of the impact of changing multiple anthropogenic drivers in the absence of climate change. These results build on those reported in D4.1, which show the sensitivity of a hindcast simulation to single anthropogenic drivers.

The WM simulation differs from BASE only in the river nitrogen loads which are increased in WM. The surface nitrogen increases significantly in coastal areas of the

UK and continental Europe, especially in the southern North Sea. The other metrics are not significantly affected by the increase in river nitrogen loads.

The GC simulation differs from BASE by a reduction in river nitrogen and phosphate levels and a reduction in the trawling effort. The impacts of these changes are largest near the southern coasts of the North Sea, where net primary production, the biomass of small zooplankton, the biomass of small and large sizes of phytoplankton and surface nitrate and phosphate all reduce in value. The biomass of large zooplankton is not affected significantly. As a response to the reduction in trawling in the North Sea, the benthic biomass increases in this region; the patchy nature of the change is partially due to the coarse resolution of the data used to simulate trawling.

Scenario and climate changes

The combined effects of the multiple driver scenarios and the change in climate in the near future are analysed by comparing the scenario simulations WM and GC to the recent past simulation, CNTRL (Figure 4 to Figure 11, b and c). The open ocean changes are dominated by the climate change signal, with the scenario forcing impacting on (mainly) local regions on the shelf, primarily in the North Sea.

Of the metrics considered, the WM scenario primarily affects surface nitrate levels; the combined climate and scenario forcing extends the effect of increasing nitrogen into regions of the Irish Sea and central North Sea that were not significantly changed under the separate climate and scenario simulations.

For the impacts of the combined GC and climate change forcing, some of the changes are attenuating with regions of the North Sea that experienced significant changes under climate change having no significant changes in the combined experiment, for example, net primary production and phytoplankton biomass. However, the impact on small zooplankton is to amplify the two effects; regions that were not affected by climate change or the scenario forcing individually experience reduced levels of biomass under the combined forcing. Two regions that experience increases in surface phosphate under climate change, the southern North Sea and the Irish Sea, become regions of no significant change and phosphate reduction, respectively, under the combined climate change and scenario forcing. The effects of the combined forcing on the benthic biomass in the North Sea is slightly attenuating; elsewhere, since there is no trawling simulated outside the North Sea, the changes are dominated by the climate change signal with a small impact from changes in river forcing in near coastal regions.

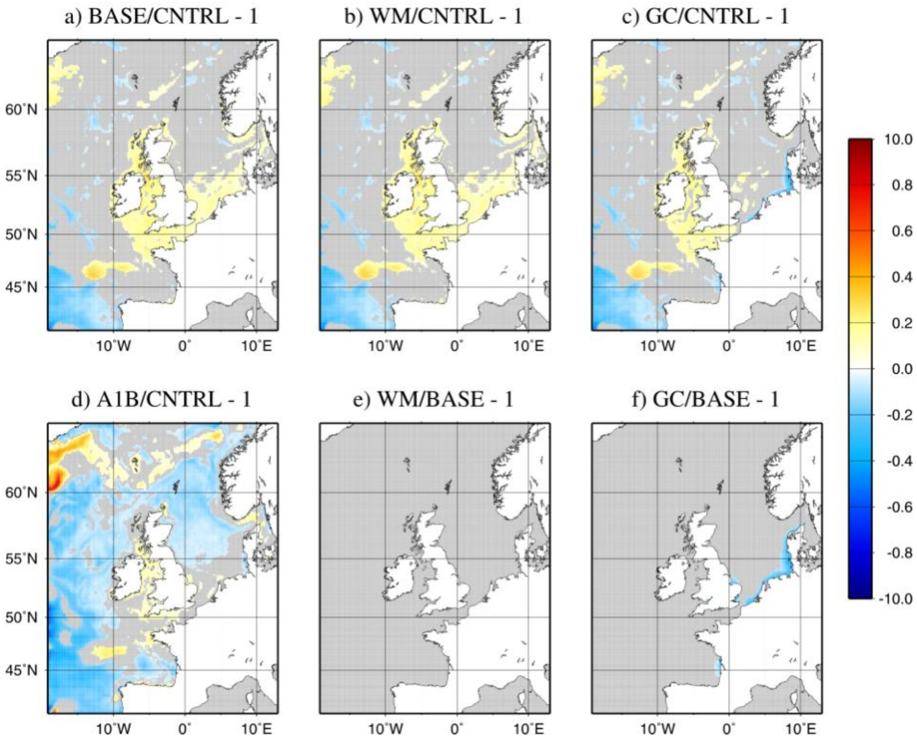


Figure 3: Fractional changes in depth integrated net primary production

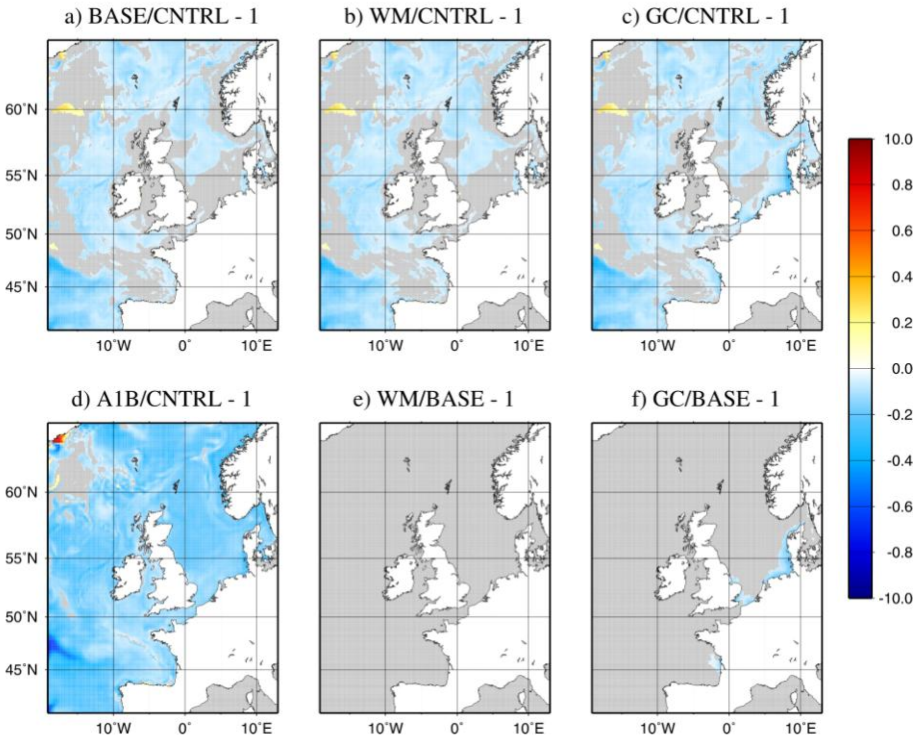


Figure 4: Fractional changes in the biomass of small zooplankton

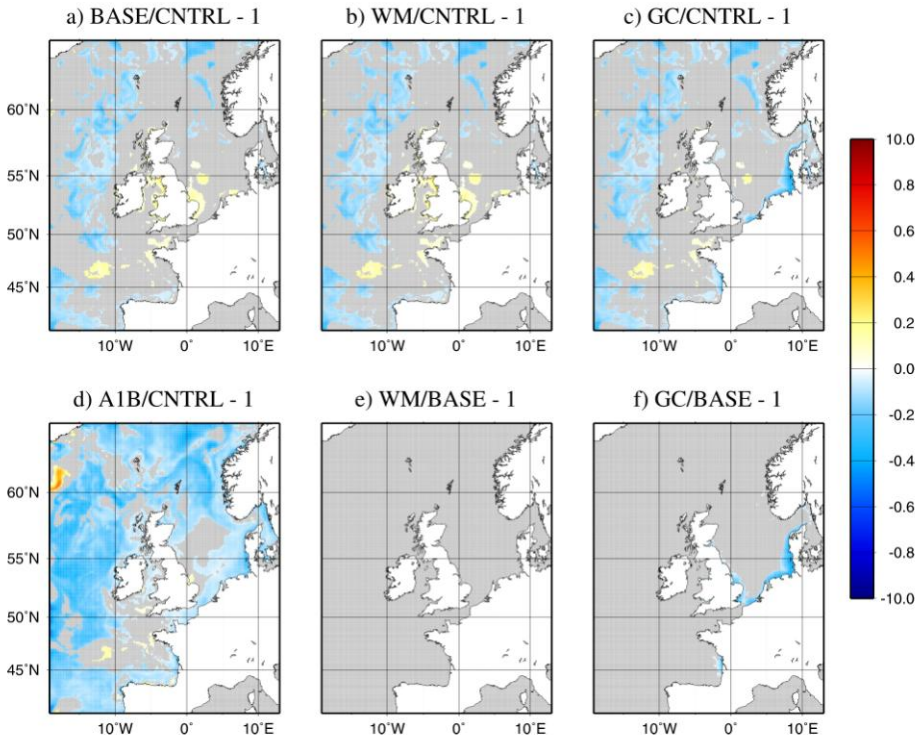


Figure 5: Fractional changes in the biomass of small phytoplankton

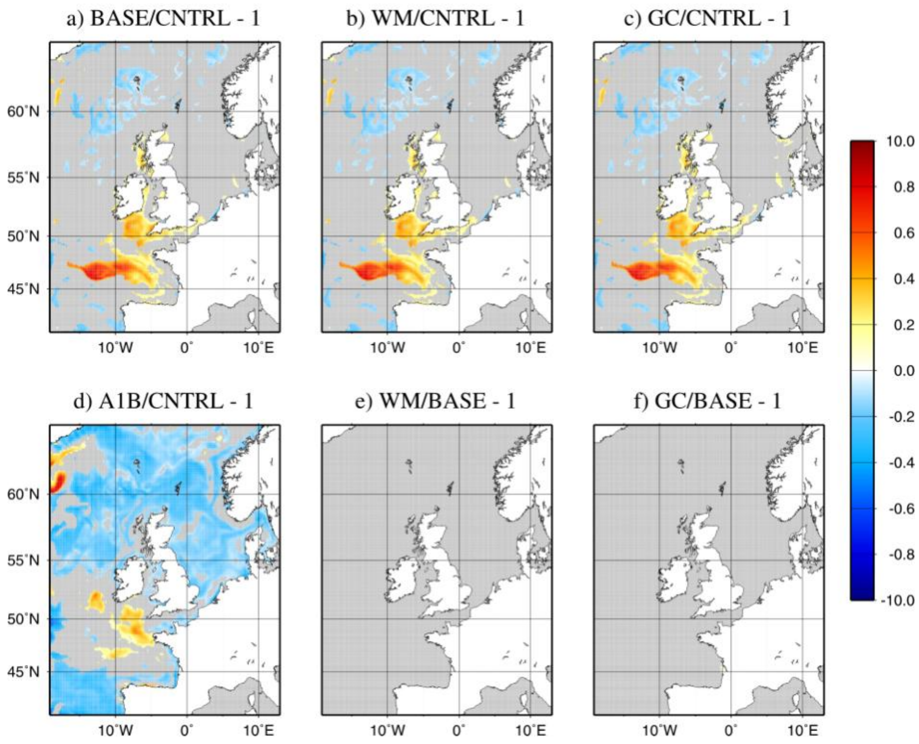


Figure 6: Fractional changes in the biomass of large zooplankton

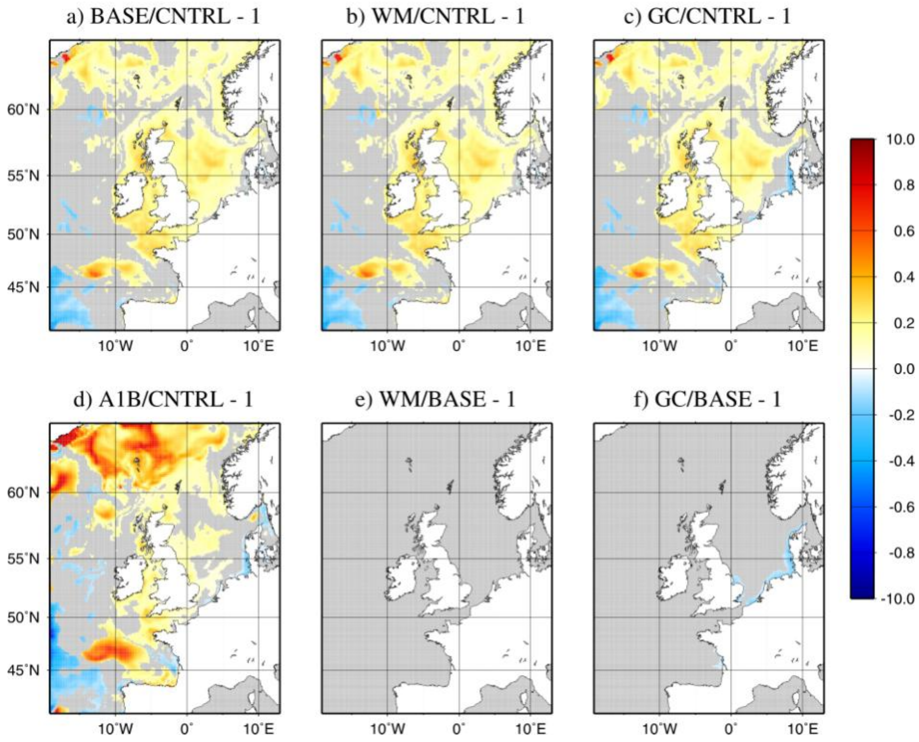


Figure 7: Fractional changes in the biomass of large phytoplankton

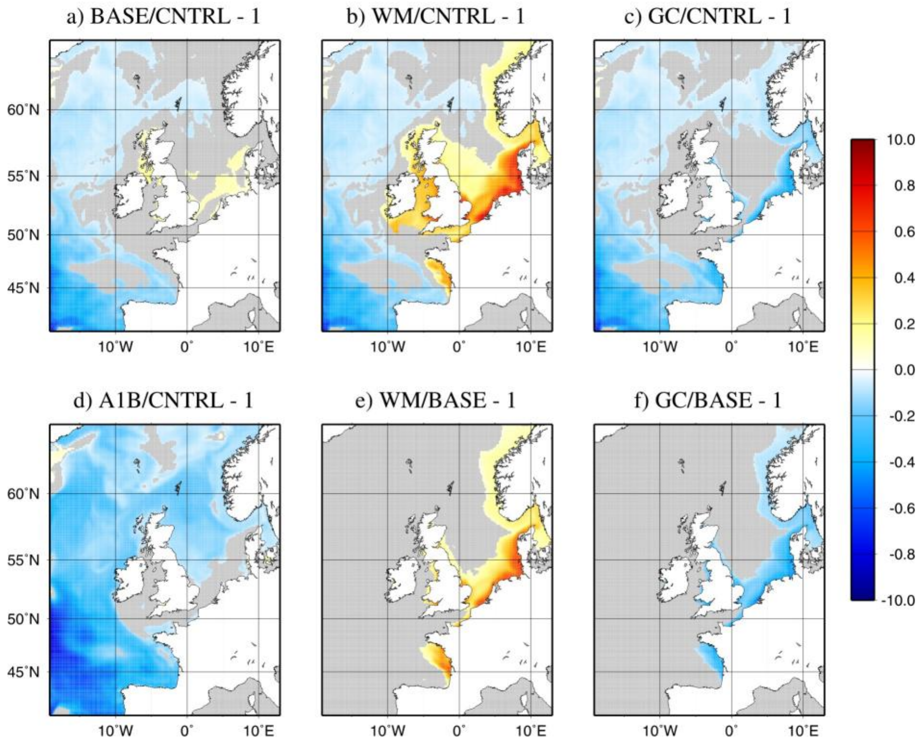


Figure 8: Fractional changes in the surface nitrate concentration

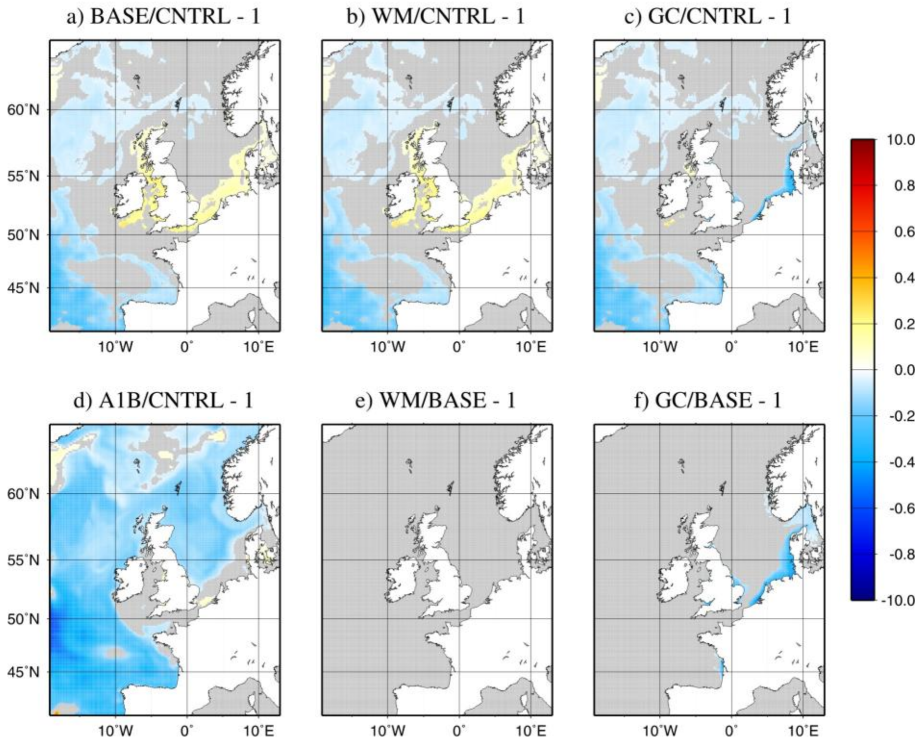


Figure 9: Fractional changes in the surface phosphate concentration

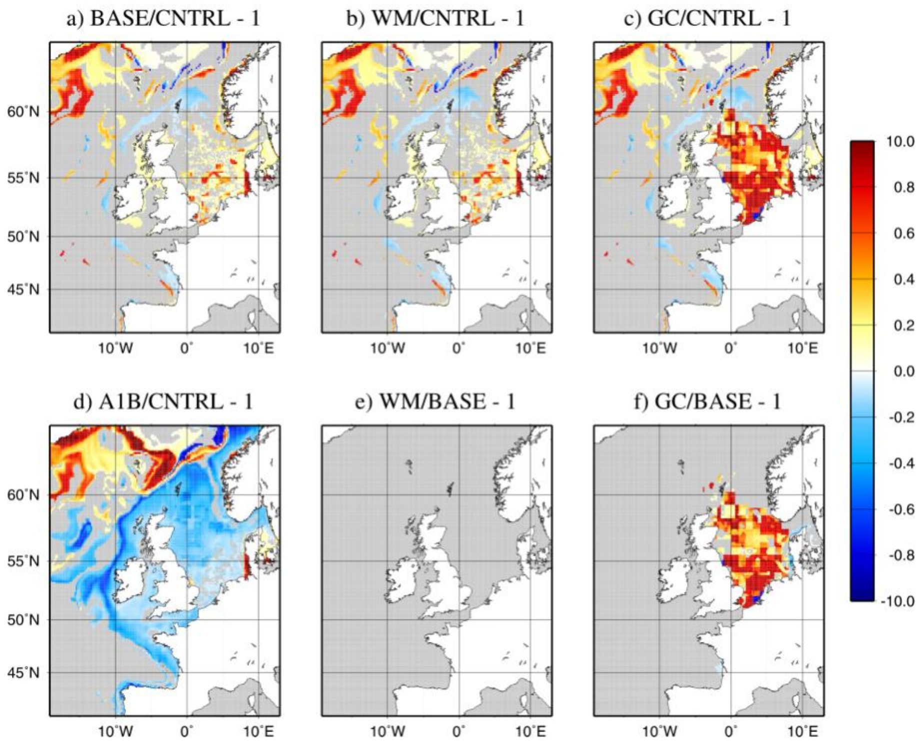


Figure 10: Fractional changes in the benthic biomass of filter feeders, deposit feeders and meiobenthos.

To study the impacts of changes in climatic and anthropogenic forcings on a regional scale, changes in net primary production are integrated over sub-regions (Figure 1) of the model domain. In the off-shelf wider Atlantic (Table 3), net primary production decreases progressively until the end of the 21st century. In the Bay of Biscay, reductions in net primary production are not significant until the end of the century. On the continental shelf, there is a significant increase in net primary production in the near future, which is attenuated by the Global Community scenario and slightly amplified by the World Market scenario. By the end of the century, net primary production reduces compared to the recent past in the Greater North Sea region.

Table 3: Mean percentage change in net primary production between future simulations and the recent past CNTRL run, integrated over sub-regions; errors are standard deviations of annual values. KW are Kruskal-Wallis p-values; values in bold indicate that the changes are significant ($p < 0.05$) compared to interannual variability.

region	Greater North Sea		Celtic Seas		Bay of Biscay		Wider Atlantic	
simulation	mean	KW	mean	KW	mean	KW	mean	KW
A1B	**-3.7 ± 5.9 %**	**0.03**	3.9 ± 9.0 %	0.39	**-2.9 ± 6.2 %**	**0.04**	**-9.5 ± 4.7 %**	**0.00**
BASE	**6.7 ± 7.7 %**	**0.02**	**12.9 ± 12.2 %**	**0.00**	1.6 ± 4.5 %	0.19	**-4.2 ± 2.2 %**	**0.00**
WM	**7.0 ± 7.7 %**	**0.02**	**13.1 ± 12.2 %**	**0.00**	1.7 ± 4.5 %	0.16	**-4.1 ± 2.2 %**	**0.00**
GC	1.1 ± 8.0 %	0.75	**10.6 ± 12.3 %**	**0.03**	0.1 ± 4.5 %	0.69	**-4.3 ± 2.2 %**	**0.00**

1.3 Discussion

The POLCOMS-ERSEM results for the northeast Atlantic are forced by a single, consistent ocean-atmosphere dataset representing possible future conditions under the SRES A1B emissions scenario. While the simulations are not predictions of the future they can be used to explore the ecosystem response to potential future climatic conditions and to the results of socio-economic policies that might be imposed.

In the absence of changes in anthropogenic forcing, many of the ecosystem changes detailed in D3.4 for the end of the 21st century exist in the near future simulations described here. There is a high degree of consistency in the changes in plankton biomass, with reductions in the biomass of small phytoplankton and two sizes of zooplankton in the near future becoming stronger and more widespread by the end of the century. Decreases in open ocean surface nitrate and phosphate also become more extensive during the century. Patterns of changes in net primary production are not so consistent with initial increases in net production in the Celtic Seas and southern North Sea in 2030-2040 decreasing, and in some regions becoming not significant compared to interannual variability by the end of the century. This is a consequence of the increase in silicate concentrations on the shelf in the near future, which then decline by the end of the century, fuelling stronger diatom production in the near future simulation than in the recent past or the far future. In the Open Ocean and northern North Sea the situation is clearer with the net primary production reducing throughout the century. There are small increases in the benthic biomass in the North Sea in the near future which changes to a shelf-wide decrease by the end of the century.

To examine the ecosystem response to changes in anthropogenic forcing governed by policy decisions, we varied two drivers that are impacted by policy: river nutrient loads and bottom trawling effort. Although the driver changes are relatively large (50% changes in river nutrient loads; 50% and 75% reductions in trawling effort), the impacts tend to be localized and climate-forced changes exceed those resulting from changes in anthropogenic drivers in the open ocean and for much of the continental shelf. Ecosystem sensitivity to changes in river nutrients tends to be restricted to near-coastal regions and is particularly strong in the southern North Sea. This may reflect how the optics in the model are prescribed. By forcing with a fixed annual cycle of abiotic attenuation we may be restricting the effects on the model by imposing excessive light limitation or lack of variability in this. Significant sensitivity to changes in trawling effort is restricted to the benthic biomass.

The ELME World Market scenario, characterized by rapid economic growth and the application of limited environmental policies, leads to an increase in nitrogen loads in rivers but no changes in river phosphate or trawling effort. The ecosystem shows little sensitivity to this anthropogenic change, with the only significant changes being in surface nitrate levels in coastal regions. In combination with climate change, surface nitrate levels are additionally raised over much of the North Sea, the Celtic and Irish Seas and the English Channel. However, the increased river nitrogen load has no discernible impact on the other metrics considered on a local scale. On a regional scale, the impact of the anthropogenic change in the near future slightly amplifies the effects of climate change on net primary production. The net primary production appears to be limited by the availability of light and phosphate so that increasing levels of nitrogen has little impact.

The ELME Global Community scenario, with economic growth constrained by environmental policies, has a larger impact on the ecosystem than the policies of the World Market scenario. River nutrient loads of nitrogen and phosphate are reduced from present day values and there is less trawling effort. With the exception of large zooplankton, which is not significantly affected by these changes, all the pelagic metrics considered show decreases in coastal regions, with the strongest signal being in the Southern Bight of the North Sea. Locally, these changes exceed those due to climate change alone by 2030-2040. In some cases, the changes due to climate change are mitigated by the scenario, for example, net primary production in the southern North Sea experiences increasing net primary production under climate change alone but, when combined with the scenario forcing, the changes are no longer significant according to the Kruskal-Wallis significance test. Phytoplankton biomass also exhibits this mitigation effect. The climate change and scenario affects amplify reductions in small zooplankton biomass, with regions that had no significant change under either climate change or the scenario forcing experiencing decreases under the combined impact. With the exception of the biomass of large phytoplankton, the pelagic metrics tend to show decreases in all variables by 2082-2099 compared to the present day, which would act to increase the amplifying effect of the anthropogenic scenario and climate change acting together. The change in the benthic biomass due to the scenario forcing is dominated by the impact of reducing bottom trawling effort in the North Sea.

One further driver of ecosystem change is the input of optically active colour dissolved organic matter (CDOM), which may have a substantial impact on the light climate in the water column and therefore on primary production. In POLCOMS-ERSEM, the total diffuse light attenuation comprises contributions from pure water, phytoplankton and abiotic (CDOM and sediment) sources, where the abiotic absorption is constrained to SeaWiFS observations. This method does not allow us to separate the riverine/anthropogenic signals from background values. Thus, although the model is sensitive to this driver (shown in D4.1), it is not possible to assess the impact of policy aimed at reducing the discharge of CDOM to the marine environment and we have not considered it here.

1.4 Conclusions

Here we consider possible future impacts of a single climate change scenario combined with two possible future policy scenarios relating to fishing and riverine nutrient input. While these give a plausible and self-consistent future, no estimate of the likelihood of this is possible. Nonetheless this work does inform on the possible combined future response of the system and direct how this might be explored further, for example with an ensemble approach.

Under climate change alone, net primary production is expected to increase in regions of the shelf in the near future especially in the Irish and Celtic Seas and the southern North Sea, as temperature effects dominate over oceanic effects. This has the potential to increase eutrophication. Using policies to reduce nutrient outflows from rivers mitigates this effect in the North Sea in the near future. By the end of the century net primary production is expected to reduce in the North Sea even under present day levels of river nutrient loads, and oceanic effects become more prominent.

On the continental shelf the biomass of phytoplankton increases in the near future, with large phytoplankton biomass increasing until the end of the century while small phytoplankton biomass declines, with a potential impact on the structure of food webs and on biodiversity. Policies to reduce river nutrient loads lead to decreases in both small and large phytoplankton biomass in near coastal regions.

On the shelf the biomass of small zooplankton decreases under climate change, an impact strengthened in coastal regions by policies reducing river nutrient loads. In the near future, local increases in the biomass of large zooplankton in the Bay of Biscay and the Celtic Sea have a potential impact on the structure of food webs and on biodiversity in these regions. Except for areas of the Bay of Biscay and the Celtic Sea, the large zooplankton biomass is found to widely decrease by the end of the century. The biomass of large zooplankton appears unaffected by river nutrient reduction policies.

Reducing the effort of trawling in the North Sea leads to an increase in benthic biomass. In the long term, climate change is expected to decrease the benthic biomass on the shelf.

2. North Sea

2.1 ECOMSO – combined climate change and land derived nutrient scenarios

2.1.1 Model Description

LTL Model: ECOSMO (ECOSystem Model, Schrum, Alekseeva, & St. John, 2006) provides spatial-temporal information about the ecosystem state in terms of physical properties (e.g. temperature, salinity, current field, turbulence, mixed layer depth) and lower trophic level ecosystem components (e.g. nutrient concentration, primary and secondary production, oxygen) to address fisheries impacts on the North Sea ecosystem. ECOSMO is a coupled physical-biogeochemical model, with the hydrodynamics based on the HAMSOM (HAMburg Shelf Ocean Model; Schrum & Backhaus, 1999) including a free-surface 3D baroclinic coupled sea-ice model (Figure 12). The bio-chemical sub-module (Figure 13) solves 12 state variables and resolves 3 nutrient cycles. Phytoplankton and zooplankton are each resolved with 2 functional groups, in addition the model uses 2 state variables for detritus and one for oxygen. The primary production in ECOSMO is limited by either the availability of the 3 macro nutrients (nitrogen, phosphorus and silicate) or light.

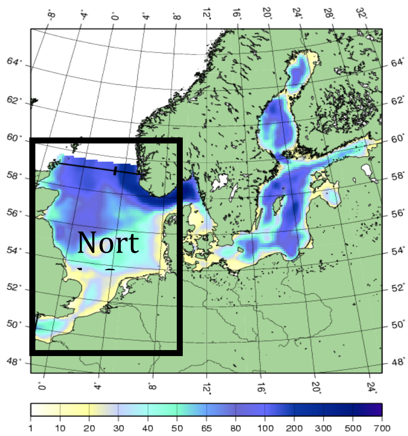
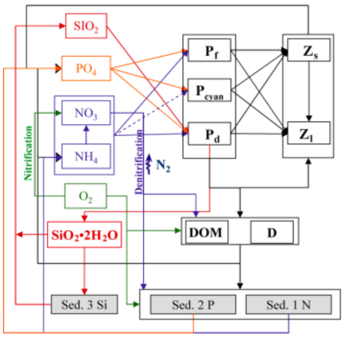


Figure 12. Model area and bathymetry [m].



P_f	Flagellates
P_{cyan}	Cyanobacteria
P_d	Diatoms
Z_l	large zooplankton
Z_s	small zooplankton
DOM	"dissolved organic matter"
D	detritus
Sed. 1	Silicate sediment pool
Sed. 2	Phosphate sediment pool
Sed. 3	Nitrate sediment pool

Figure 13. Schematic diagram of biological interactions in ECOSMO II.

<u>Scenarios: model setup and scenario definition</u>

Present Day (PD) reference for the time period 1980-1999 (outline of scenario, see D1.5)

A present day simulation (for outline of scenario see D1.5, additional and complementary information is provided in D3.4) was performed using atmospheric boundary conditions from the the IPSL-ESM A1B scenario.

Multi Driver scenarios

The multi driver scenarios emphasize the combined effect of climate change and anthropogenic drivers like eutrophication on the respective marine ecosystem. The scenarios were defined for the time period 2030-2040 (D1.5). The reference baseline is a “business as usual” (BU) scenario with river nutrient supply assumed to be equal to the present day conditions, while atmospheric forcing and boundary conditions where adapted from the IPSL-ESM (IPCC-A1B scenario) downscaled with a delta-change approach (see D3.4).

As agreed in D1.5, the choice for the anthropogenic driver scenarios based on the results from the EU FP6 project ELME (European Lifestyles & Marine Ecosystems). The chosen scenarios were “World Market” and “Global Community”. Our results from the anthropogenic driver sensitivity studies in D4.1 revealed that the parameterization in ECOSMO doesn’t allow for a quantitative assessment of fishery impacts on the ecosystem dynamics, we will therefore hereafter focus only on eutrophication impacts.

<u>Scenarios:</u>

World Market: Increase in Nitrate-loads forced by an increase in N fertiliser use, while Phosphate is kept constant. (N: +20%, P: --)

Global Community: Decrease in both Nitrate & Phosphate as consequence of a general decrease in Industrial discharges and P fertiliser use. (N&P: -20%)

Metrics considered (from D3.2)

- Surface temperature

- Surface salinity
- Surface nutrients
- Depth integrated phytoplankton biomass (small and large)
- Depth integrated zooplankton biomass (small and large)
- Benthic biomass
- Net primary production (net primary production)

Linkages with MEECE deliverables

Deliverable	Comments
D1.5	Outline of driver response scenarios (ELME)
D2.2	Details of carbon sub-model
D3.1	Outline of model scenarios
D3.2	Description of metrics to consider
D3.4	Details of the ECOSMO implementation for the North Sea
D3.5	Atlas of marine ecosystem climate response
D4.1	Description of single driver experiments
D4.4	Atlas of marine ecosystem climate response

2.1.2 Results

Climate impacts → present day vs. baseline

Our projection for the time period 2030-2040 using the IPSL-ESM A1B scenario to the force ECOSMO shows that the SST in the North Sea is increases substantially by around 1.3 °C in the next 20 to 30 years compared to the reference period 1980-1999 (Fig. 14). The temperature increase is a robust signal with only small spatial variations. The projection suggests only small changes in sea surface salinity with slight increases in the western and southern North Sea and more pronounced decrease in the east at the entrance to the Baltic Sea.

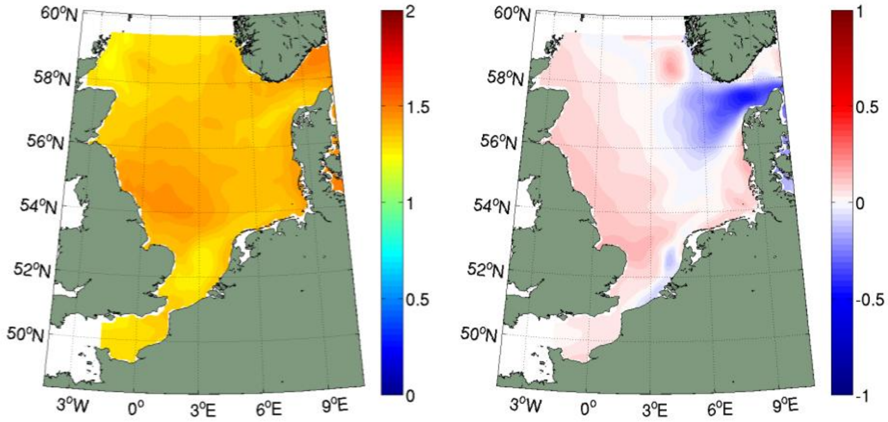


Figure 14. Physical parameters total change in average annual SST (left) and SSS (right) between future projection (2020-2049: IPSL-ESM) and present day reference (1980-1999).

For primary production (Fig. 15) the model projects a general decrease in the range of -0.05 (fractional change). Locally, the changes could be of larger amplitude. Specifically in northern and central NS and at Dogger Bank production can decrease with a fractional change of up to 0.2.

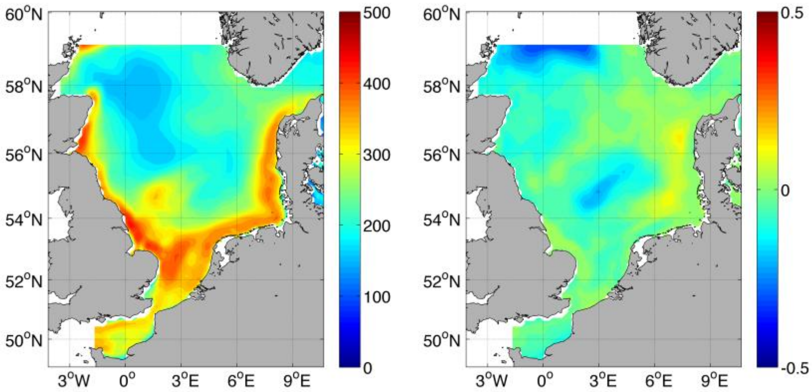


Figure 15. Annual mean map of net primary production (mgC m^{-2} day^{-1}) under present day climatic conditions (left) and fractional change in net primary production for the business as usual (BU) scenario (right) (with respect to present day conditions), climate change projection for the time period 2030-2040.

The projected changes in spatial pattern for zooplankton biomass (Fig. 16) basically follows what has been described for primary production, although the general impact seems to be larger. This is especially noticeable in the northern North Sea where the projected decrease in zooplankton biomass is up to 50%.

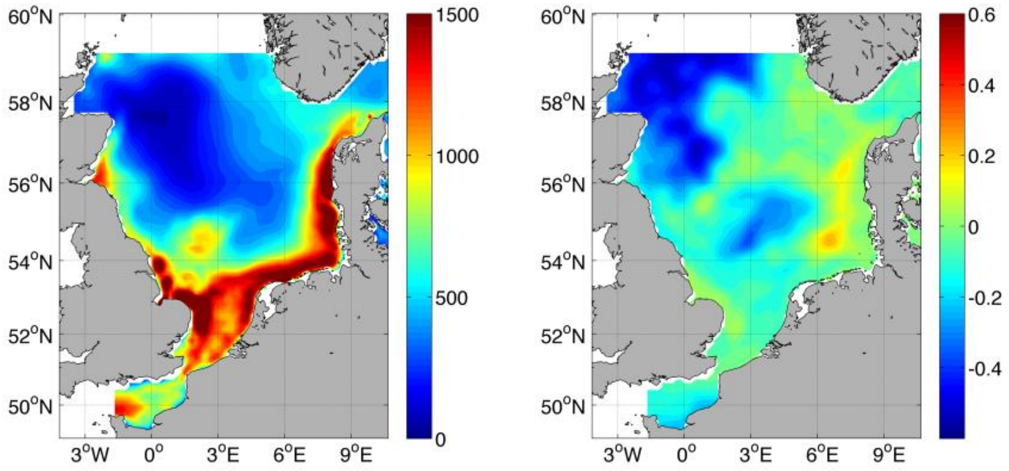


Figure 16. Annual mean map of simulated zooplankton biomass (mgC m^{-2} day^{-1}) under present day climatic conditions (left) and fractional change for business as usual (BU) scenario (right) with respect to present day conditions. The climate impact is projected for the time slice 2030-2040.

For the 2030-2040 time period the North Sea was projected to become generally more acidic (lower pH) with highest impacts along the southern and eastern coastline and in the Norwegian trench,

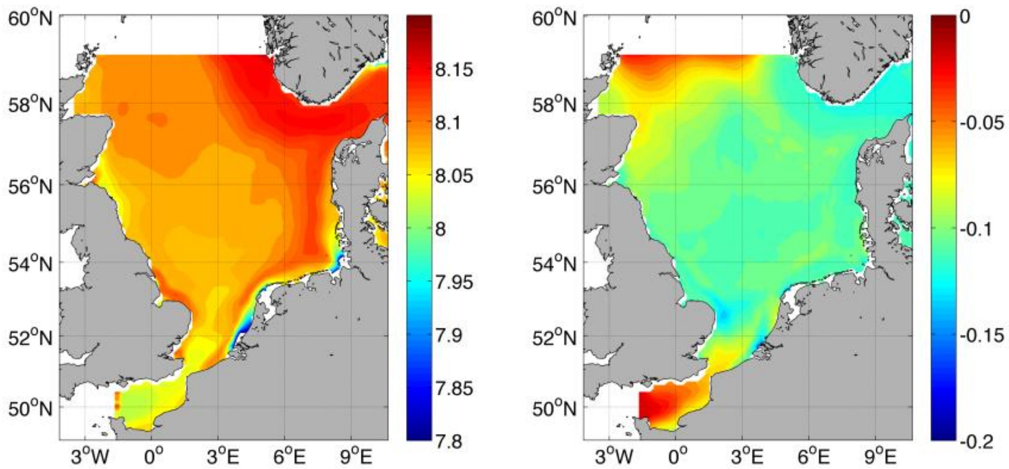


Figure 17. Annual mean map of simulated pH under present day climatic conditions (left) and total changes for the business as usual (BU) scenario with respect to present day conditions (right). The climate impact is projected for the time slice 2030-2040.

Multidriver scenarios vs baseline

The projected changes for the multidriver scenarios are discussed in comparison with the climate impact scenarios. In figures 18-20 the projected changes of the 2 multi-driver scenarios with respect to the climate-induced changes are shown. Both scenarios indicate small changes in primary projection when compared to the climate scenario. In the *World Market* scenario the additional nitrogen loads increase the coastal productivity in the southern North Sea slightly, while the reduced nutrient loads in the *Global Community* scenario amplifies the overall production decrease by reducing the locally positive climate response off the Jutland and Continental coast.

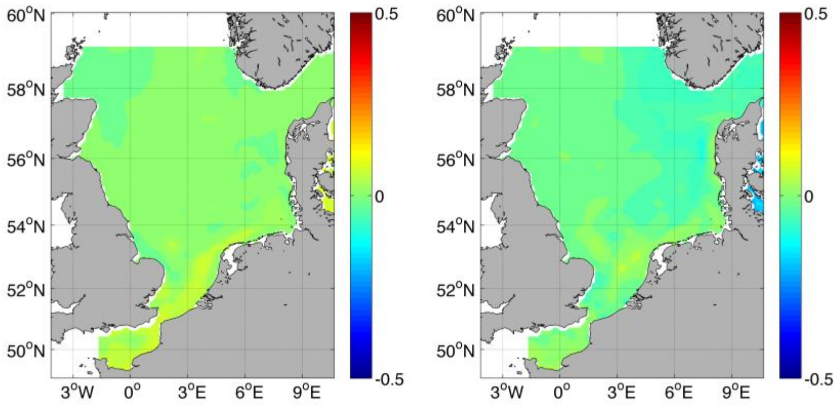


Figure 18. Annual mean maps of the fractional changes in net primary production (mgC m^{-2} day^{-1}) for the World Market (WM) scenario (left) and the Global Community (GC) scenario (right) with respect to the business as usual (BU) scenario. The climate impact is projected for the time slice 2030-2040.

Zooplankton biomass (Fig. 19) changes accordingly to primary production with a relatively strong decrease in the Southern North Sea and English Channel for the *GC* scenario.

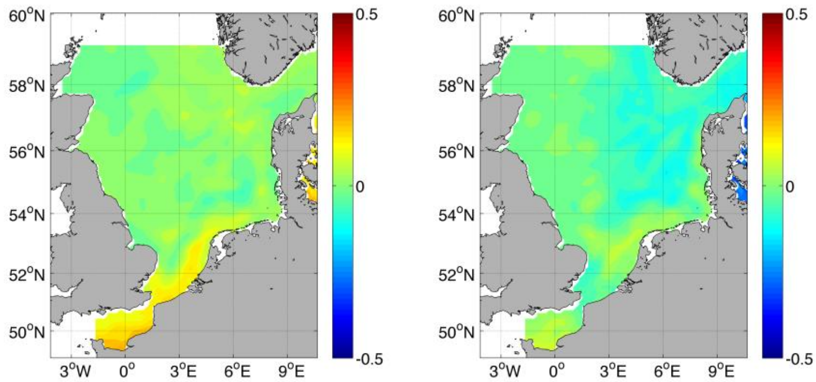


Figure 19. Annual mean maps of the fractional changes in zooplankton biomass (mgC m^{-2} day^{-1}) for the World Market (WM) scenario (left) and the Global Community (GC) scenario (right) with respect to the Business as usual (BU) scenario. The climate impact is projected for the time slice 2030-2040.

The response of pH to the changes in nutrient loads is negligible.

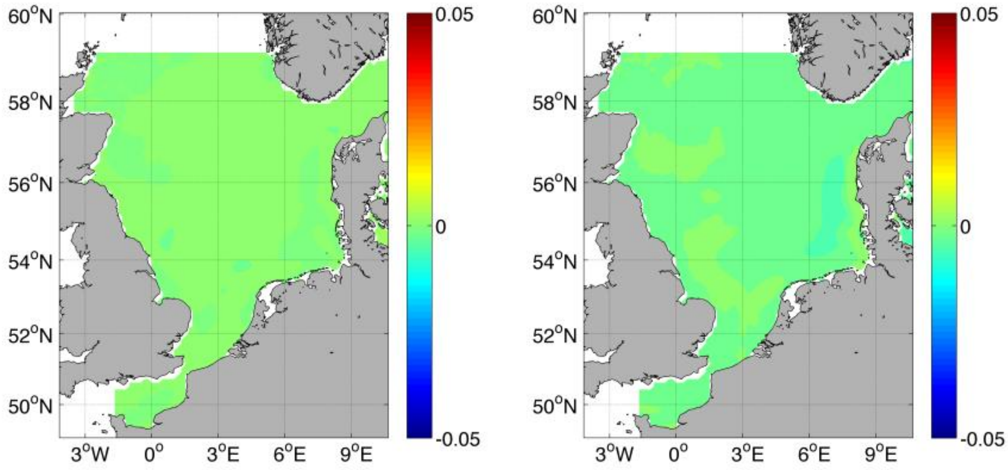


Figure 20. Annual mean maps of the total changes in pH for the World Market (WM) scenario (left) and the Global Community (GC) scenario (right) with respect to the Business as usual (BU) scenario. The climate impact is projected for the time slice 2030-2040.

2.1.3 Discussion and conclusion

Corroborating the findings from D4.1, the response of the North Sea to changes in nutrient loads is relatively small when compared to that of near term climate change signals. This can be explained by the short characteristic time scales of the North Sea, which prevents sustainable accumulation of land derived nutrients.

Nevertheless, the comparison between the two potential policy scenarios does show that different nutrient loads have consequences for the lower trophic level productivity of the North Sea ecosystem either attenuating (World Market) or amplifying (Global Community) the climate signal. The change appeares to be more relevant for the zooplankton compared to primary production and hence, might amplify upwards the trophic chain and more over impact survival of early life stages of fish (Beaugrand, Brander, Alistair Lindley, Souissi, & Reid, 2003; Daewel, Peck, & Schrum, 2011). Our modelling approach doesn't include an interactively coupled higher-trophic level approach therefore we chose not to consider additional fisheries scenarios. However, since the North Sea is generally described as 'bottom-up' controlled (Heath, 2005) we consider the assumption that the lower trophic level ecosystem dynamics in the North Sea will not significantly be highly impacted by changes in fishery efforts as robust. In conclusion, for the near future, the dominant future changes in the North Sea lower trophic dynamics is introduced by climate impacts. The latter is dominated by internal climate variability rather than by anthropogenic climate change, due to the short modelling time scale of only 10 years.

2.1.4 References

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Heath, M. (2005). Changes in the structure and function of the North Sea fish foodweb, 1973–2000, and the impacts of fishing and climate. *ICES Journal of Marine Science*, *62*(5), 847–868. doi:10.1016/j.icesjms.2005.01.023

Kalnay, E., Kanamitsu, M., Kistler, R., Collins, W., Deaven, D., Gandin, L., Iredell, M., et al. (1996). The NCEP/NCAR 40-year reanalysis project. *Bulletin of the American Meteorological Society*, *77*(3), 437–471. doi:10.1175/1520-0477(1996)077<0437:TNYRP>2.0.CO;2

2.2 Ecosim coupled to GOTM-ERSEM LTL model; combined climate change; land derived nutrient and fishing scenarios

2.2.1 Model Description

The linked model runs explore three aspects of environmental change: Effect of changes in fishing mortality to one based on putative MSY, a reduction in the level of shelf sea nutrients (specifically nitrate and phosphate) and long-term climate change. The order of significance of the effects of the three drivers is as above.

2.2.2 Results

Climate change has the least effect - between zero and 20% change in biomass, with the greatest effect on the highest trophic level species: sharks, rays and seabirds as well as hake and sandeels. The effect on invertebrates was least and benthic fish intermediate. The effect of climate change on pelagic fish was the most complex with sandeels greatly benefitting from global warming but Mackerel suffering a population decline as a result. These results are consistent with the results of figure 21 indicating an increase in large zooplankton biomass (mesozooplankton) in the North Sea area of less than 0.2, except that whereas purely LTL models, such as ERSEM have a fixed proportion death rate, the coupled model has an increasing predation rate on zooplankton resulting from increase in HTL predator population.

The effect of nutrient reduction was an almost universal reduction in populations of the highest trophic levels with the population levels of around 50% of the high nutrient level for seals, sharks and seabirds. Many commercial species such as Cod and various demersal flatfish showing a 60% to 70% level of biomass, but invertebrates show a small reduction and the Omnivorous zooplankton themselves show little change. These results illustrate that the production of zooplankton is to a large extent nutrient limited but that reduction in productivity at the lower trophic levels is balanced by reduction by predation from higher trophic levels. In other words the system is bottom up as far as nutrients are concerned.

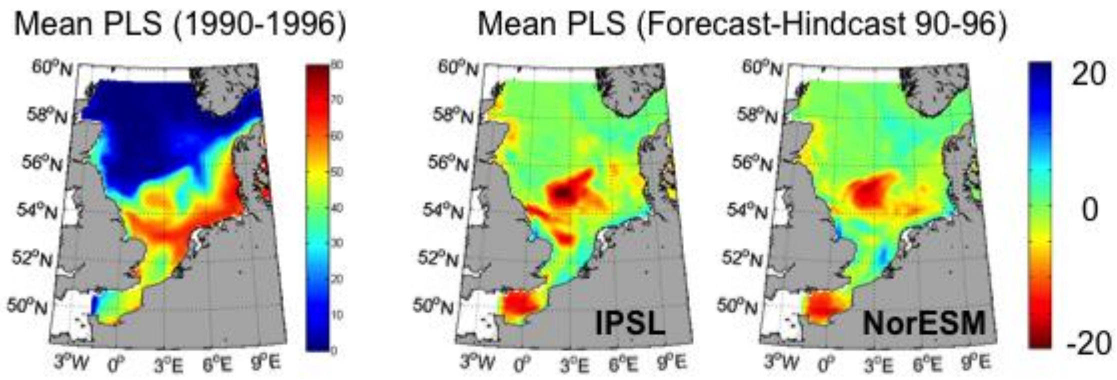
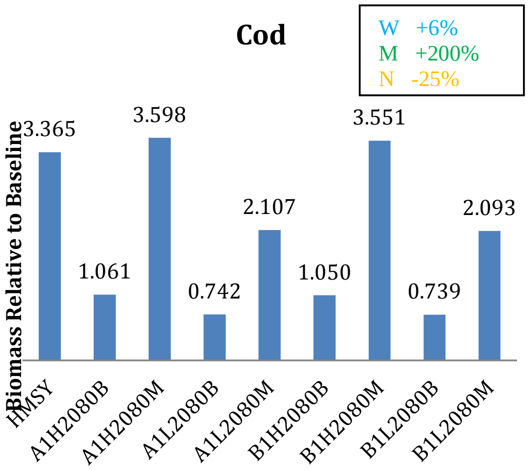
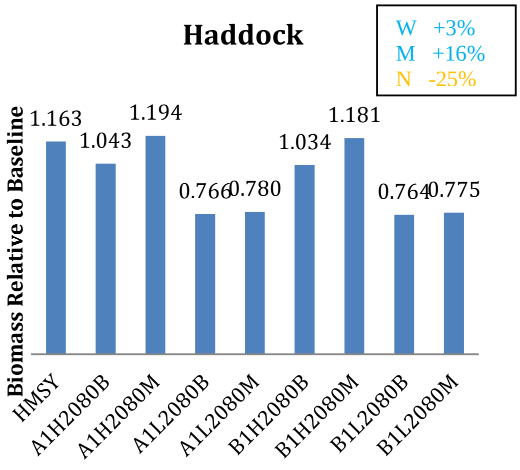
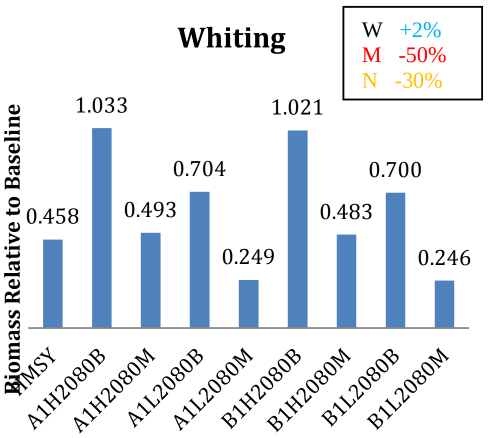


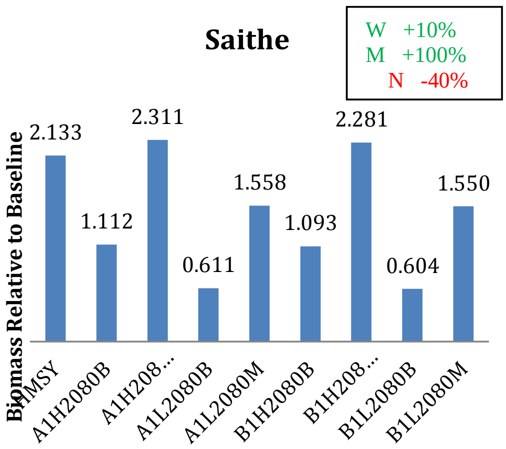
Figure 21. Average (1990-1996) annual PLS and projected changes in 2090-2096 (Forecast-Hindcast).

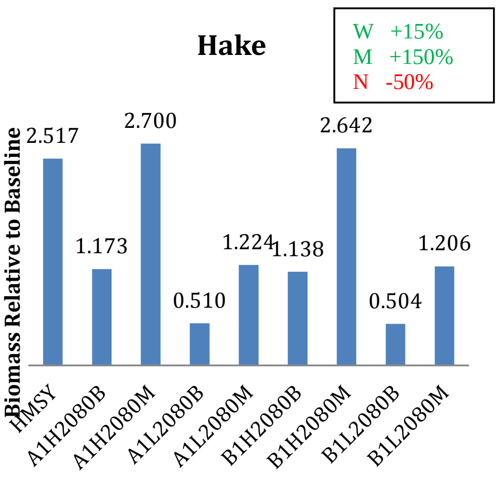
Change in fishing pressure to MSY has a significant long term positive effect on Cod, Saithe, Hake, Mackerel, Sand Eel as well as Catfish and, indirectly, Large Shark and Seals. Cod biomass is a factor of 3 higher (starting from a low baseline of current Cod stocks). Some species are negatively affected through predation / competition: Whiting, Blue whiting, Norway Pout, Herring and Sprat. Flatfish and invertebrates are moderately affected, typically by 20% or less compared to current fishing practices.

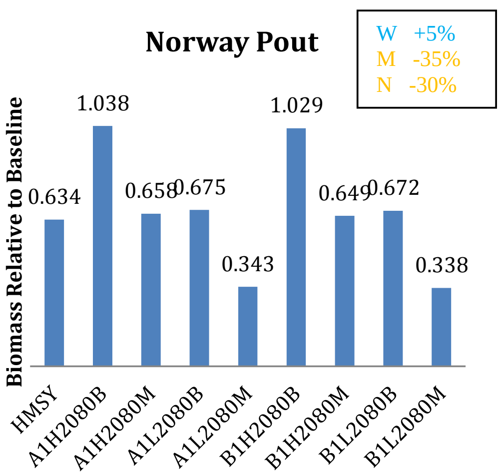

Cod
W +6%
M +200%
N -25%
Biomass Relative to Baseline
3.365
1.061
3.598
0.742
2.107
1.050
3.551
0.739
2.093
HMSY
A1H2080B
A1H2080M
A1L2080B
A1L2080M
B1H2080B
B1H2080M
B1L2080B
B1L2080M

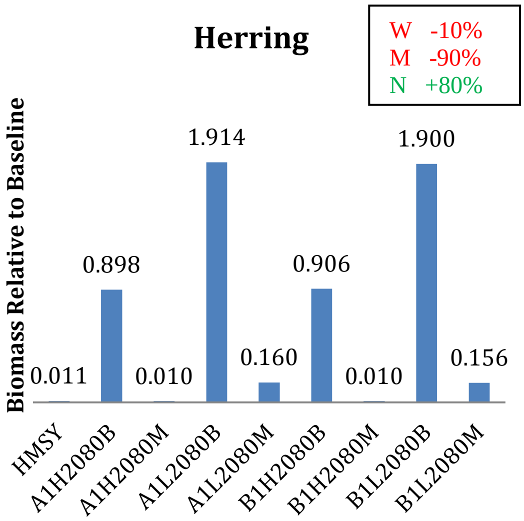

Haddock
W +3%
M +16%
N -25%
Biomass Relative to Baseline
1.163
1.043
1.194
0.766
0.780
1.034
1.181
0.764
0.775
HMSY
A1H2080B
A1H2080M
A1L2080B
A1L2080M
B1H2080B
B1H2080M
B1L2080B
B1L2080M

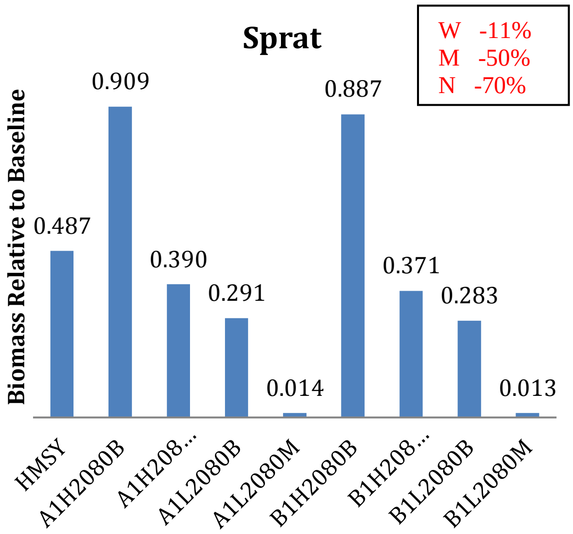

Whiting
W +2%
M -50%
N -30%
Biomass Relative to Baseline
0.458
1.033
0.493
0.704
0.249
1.021
0.483
0.700
0.246
HMSY
A1H2080B
A1H2080M
A1L2080B
A1L2080M
B1H2080B
B1H2080M
B1L2080B
B1L2080M

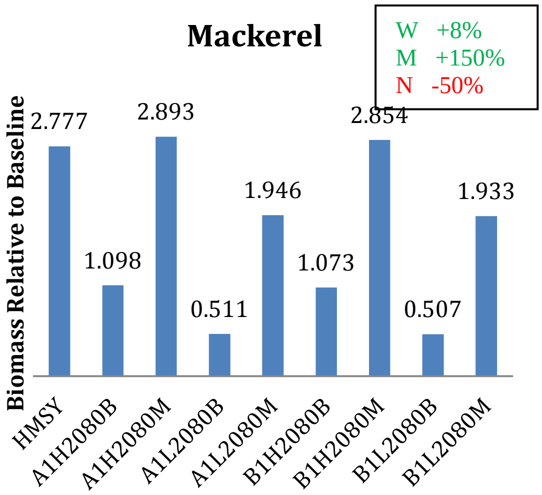

Saithe
W +10%
M +100%
N -40%
Biomass Relative to Baseline
2.133
1.112
2.311
0.611
1.558
1.093
2.281
0.604
1.550
HMSY
A1H2080B
A1H208...
A1L2080B
A1L2080M
B1H2080B
B1H208...
B1L2080B
B1L2080M

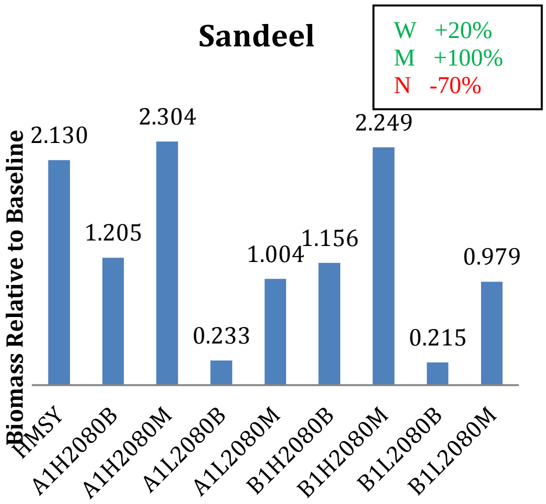

Hake
W +15%
M +150%
N -50%
Biomass Relative to Baseline
2.517
1.173
2.700
0.510
1.224
1.138
2.642
0.504
1.206
HMSY
A1H2080B
A1H2080M
A1L2080B
A1L2080M
B1H2080B
B1H2080M
B1L2080B
B1L2080M

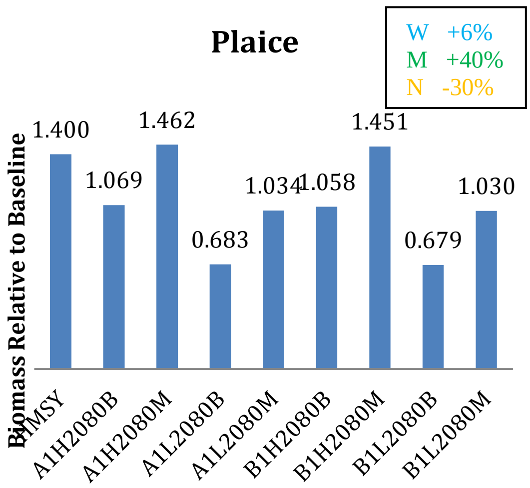

Norway Pout
W +5%
M -35%
N -30%
Biomass Relative to Baseline
0.634
1.038
0.658
0.675
0.343
1.029
0.649
0.672
0.338
HMSY
A1H2080B
A1H2080M
A1L2080B
A1L2080M
B1H2080B
B1H2080M
B1L2080B
B1L2080M

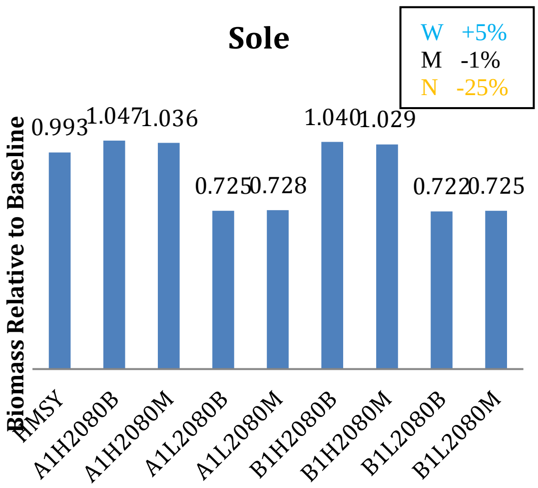

Herring
W -10%
M -90%
N +80%
Biomass Relative to Baseline
0.011
0.898
0.010
1.914
0.160
0.906
0.010
1.900
0.156
HMSY
A1H2080B
A1H2080M
A1L2080B
A1L2080M
B1H2080B
B1H2080M
B1L2080B
B1L2080M

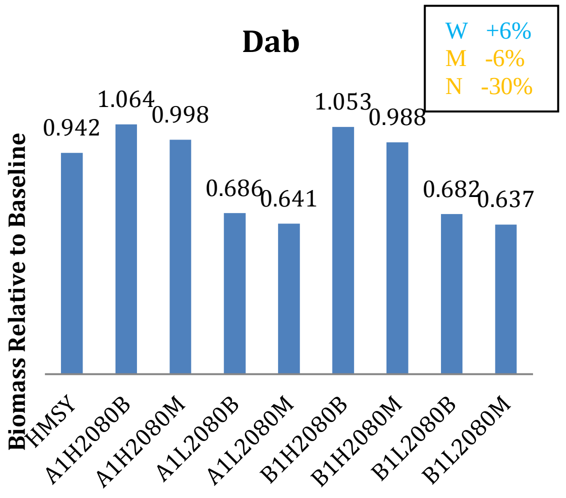

Sprat
W -11%
M -50%
N -70%
Biomass Relative to Baseline
0.487
0.909
0.390
0.291
0.014
0.887
0.371
0.283
0.013
HMSY
A1H2080B
A1H208...
A1L2080B
A1L2080M
B1H2080B
B1H208...
B1L2080B
B1L2080M

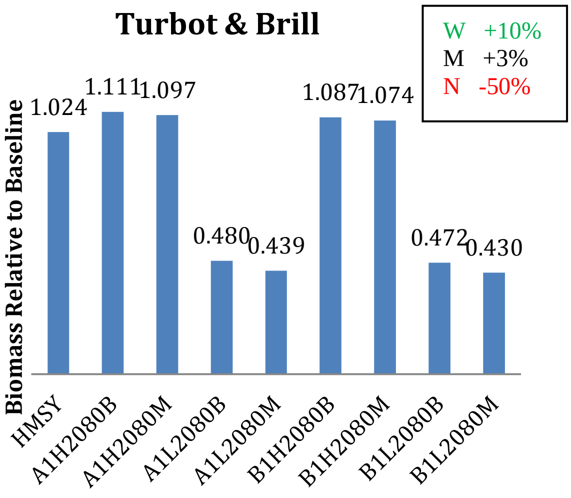

Mackerel
W +8%
M +150%
N -50%
Biomass Relative to Baseline
2.777
1.098
2.893
0.511
1.946
1.073
2.854
0.507
1.933
HMSY
A1H2080B
A1H2080M
A1L2080B
A1L2080M
B1H2080B
B1H2080M
B1L2080B
B1L2080M

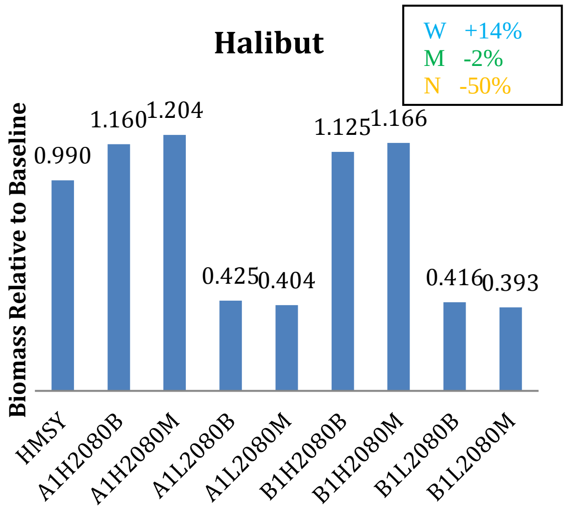

Sandeel
W +20%
M +100%
N -70%
Biomass Relative to Baseline
2.130
1.205
2.304
0.233
1.004
1.156
2.249
0.215
0.979
HMSY
A1H2080B
A1H2080M
A1L2080B
A1L2080M
B1H2080B
B1H2080M
B1L2080B
B1L2080M

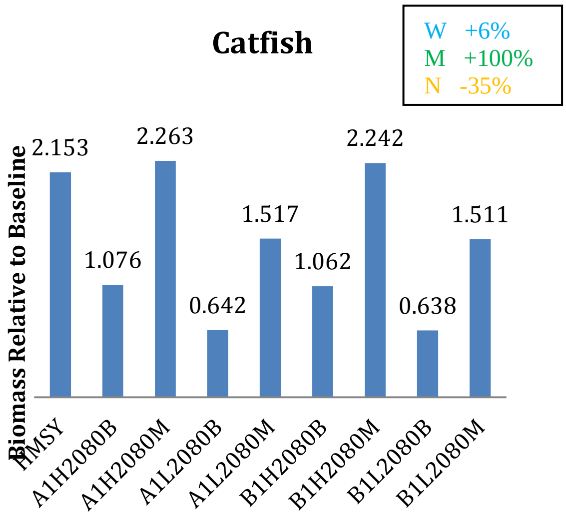

Plaice
W +6%
M +40%
N -30%
Biomass Relative to Baseline
1.400
1.069
1.462
0.683
1.034
1.058
1.451
0.679
1.030
HMSY
A1H2080B
A1H2080M
A1L2080B
A1L2080M
B1H2080B
B1H2080M
B1L2080B
B1L2080M

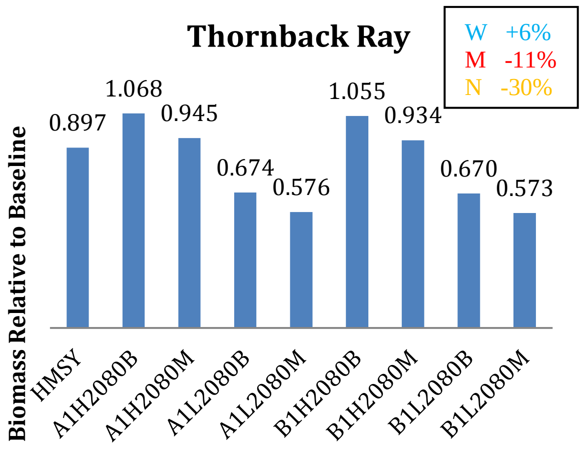

Sole
W +5%
M -1%
N -25%
Biomass Relative to Baseline
0.993
1.047
1.036
0.725
0.728
1.040
1.029
0.722
0.725
HMSY
A1H2080B
A1H2080M
A1L2080B
A1L2080M
B1H2080B
B1H2080M
B1L2080B
B1L2080M

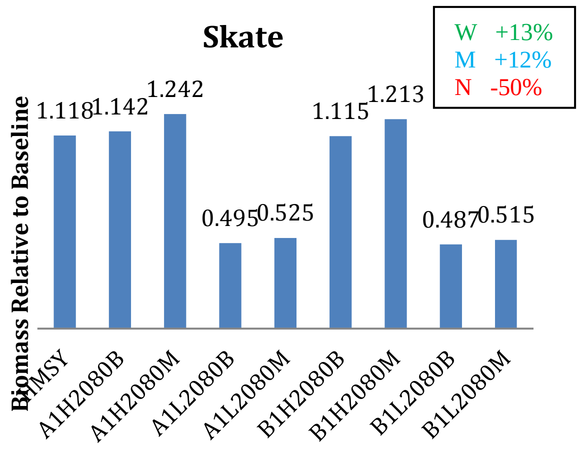

Dab
W +6%
M -6%
N -30%
Biomass Relative to Baseline
0.942
1.064
0.998
0.686
0.641
1.053
0.988
0.682
0.637
HMSY
A1H2080B
A1H2080M
A1L2080B
A1L2080M
B1H2080B
B1H2080M
B1L2080B
B1L2080M

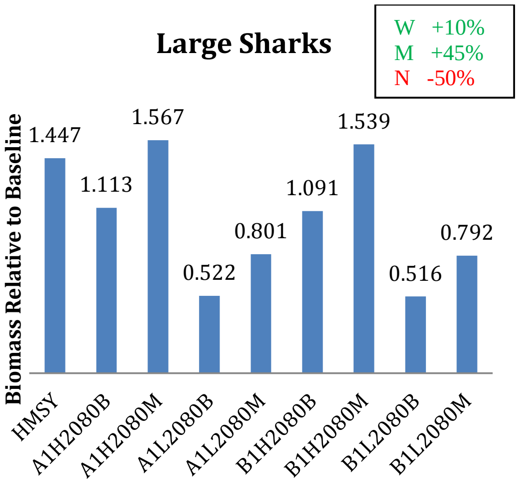

Turbot & Brill
W +10%
M +3%
N -50%
Biomass Relative to Baseline
1.024
1.111
1.097
0.480
0.439
1.087
1.074
0.472
0.430
HMSY
A1H2080B
A1H2080M
A1L2080B
A1L2080M
B1H2080B
B1H2080M
B1L2080B
B1L2080M

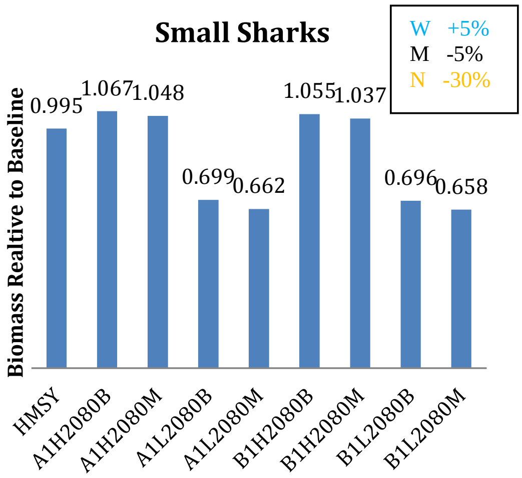

Halibut
W +14%
M -2%
N -50%
Biomass Relative to Baseline
0.990
1.160
1.204
0.425
0.404
1.125
1.166
0.416
0.393
HMSY
A1H2080B
A1H2080M
A1L2080B
A1L2080M
B1H2080B
B1H2080M
B1L2080B
B1L2080M

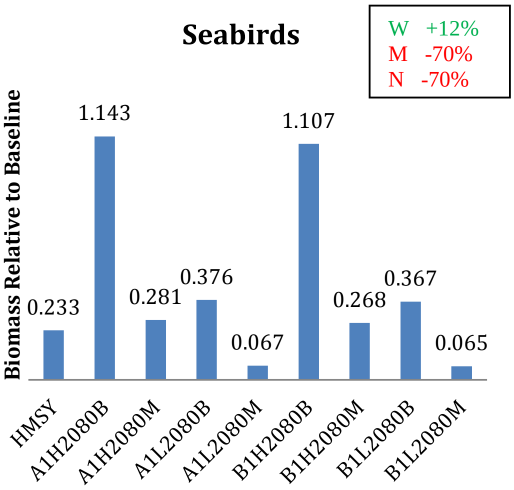

Catfish
W +6%
M +100%
N -35%
Biomass Relative to Baseline
2.153
1.076
2.263
0.642
1.517
1.062
2.242
0.638
1.511
HMSY
A1H2080B
A1H2080M
A1L2080B
A1L2080M
B1H2080B
B1H2080M
B1L2080B
B1L2080M

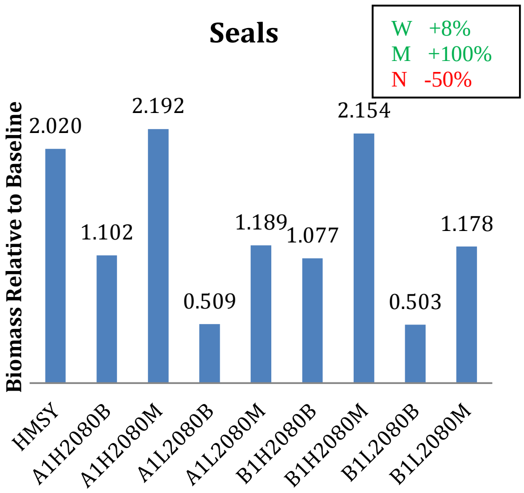

Thornback Ray
W +6%
M -11%
N -30%
Biomass Relative to Baseline
0.897
1.068
0.945
0.674
0.576
1.055
0.934
0.670
0.573
HMSY
A1H2080B
A1H2080M
A1L2080B
A1L2080M
B1H2080B
B1H2080M
B1L2080B
B1L2080M

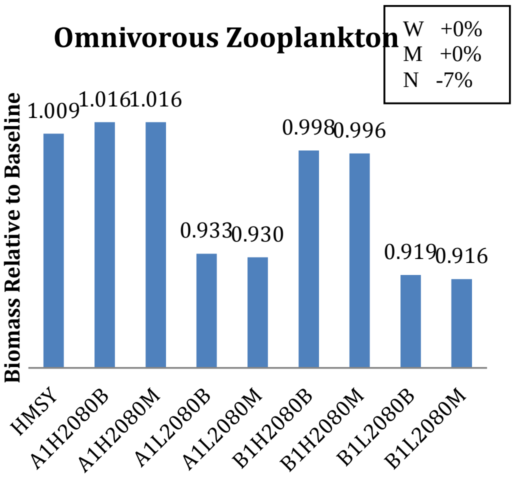

Skate
W +13%
M +12%
N -50%
Biomass Relative to Baseline
1.118
1.142
1.242
0.495
0.525
1.115
1.213
0.487
0.515
HMSY
A1H2080B
A1H2080M
A1L2080B
A1L2080M
B1H2080B
B1H2080M
B1L2080B
B1L2080M

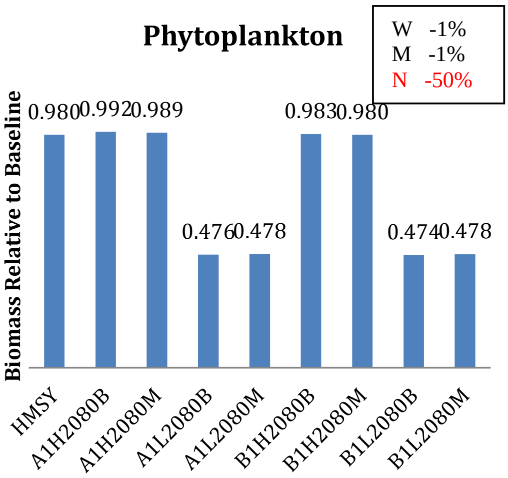

Large Sharks
W +10%
M +45%
N -50%
Biomass Relative to Baseline
1.447
1.113
1.567
0.522
0.801
1.091
1.539
0.516
0.792
HMSY
A1H2080B
A1H2080M
A1L2080B
A1L2080M
B1H2080B
B1H2080M
B1L2080B
B1L2080M


Small Sharks
W +5%
M -5%
N -30%
Biomass Realtive to Baseline
0.995
1.067
1.048
0.699
0.662
1.055
1.037
0.696
0.658
HMSY
A1H2080B
A1H2080M
A1L2080B
A1L2080M
B1H2080B
B1H2080M
B1L2080B
B1L2080M


Seabirds
W +12%
M -70%
N -70%
Biomass Relative to Baseline
0.233
1.143
0.281
0.376
0.067
1.107
0.268
0.367
0.065
HMSY
A1H2080B
A1H2080M
A1L2080B
A1L2080M
B1H2080B
B1H2080M
B1L2080B
B1L2080M


Seals
W +8%
M +100%
N -50%
Biomass Relative to Baseline
2.020
1.102
2.192
0.509
1.189
1.077
2.154
0.503
1.178
HMSY
A1H2080B
A1H2080M
A1L2080B
A1L2080M
B1H2080B
B1H2080M
B1L2080B
B1L2080M


Omnivorous Zooplankton
W +0%
M +0%
N -7%
Biomass Relative to Baseline
1.009
1.016
1.016
0.933
0.930
0.998
0.996
0.919
0.916
HMSY
A1H2080B
A1H2080M
A1L2080B
A1L2080M
B1H2080B
B1H2080M
B1L2080B
B1L2080M


Phytoplankton
W -1%
M -1%
N -50%
Biomass Relative to Baseline
0.980
0.992
0.989
0.476
0.478
0.983
0.980
0.474
0.478
HMSY
A1H2080B
A1H2080M
A1L2080B
A1L2080M
B1H2080B
B1H2080M
B1L2080B
B1L2080M

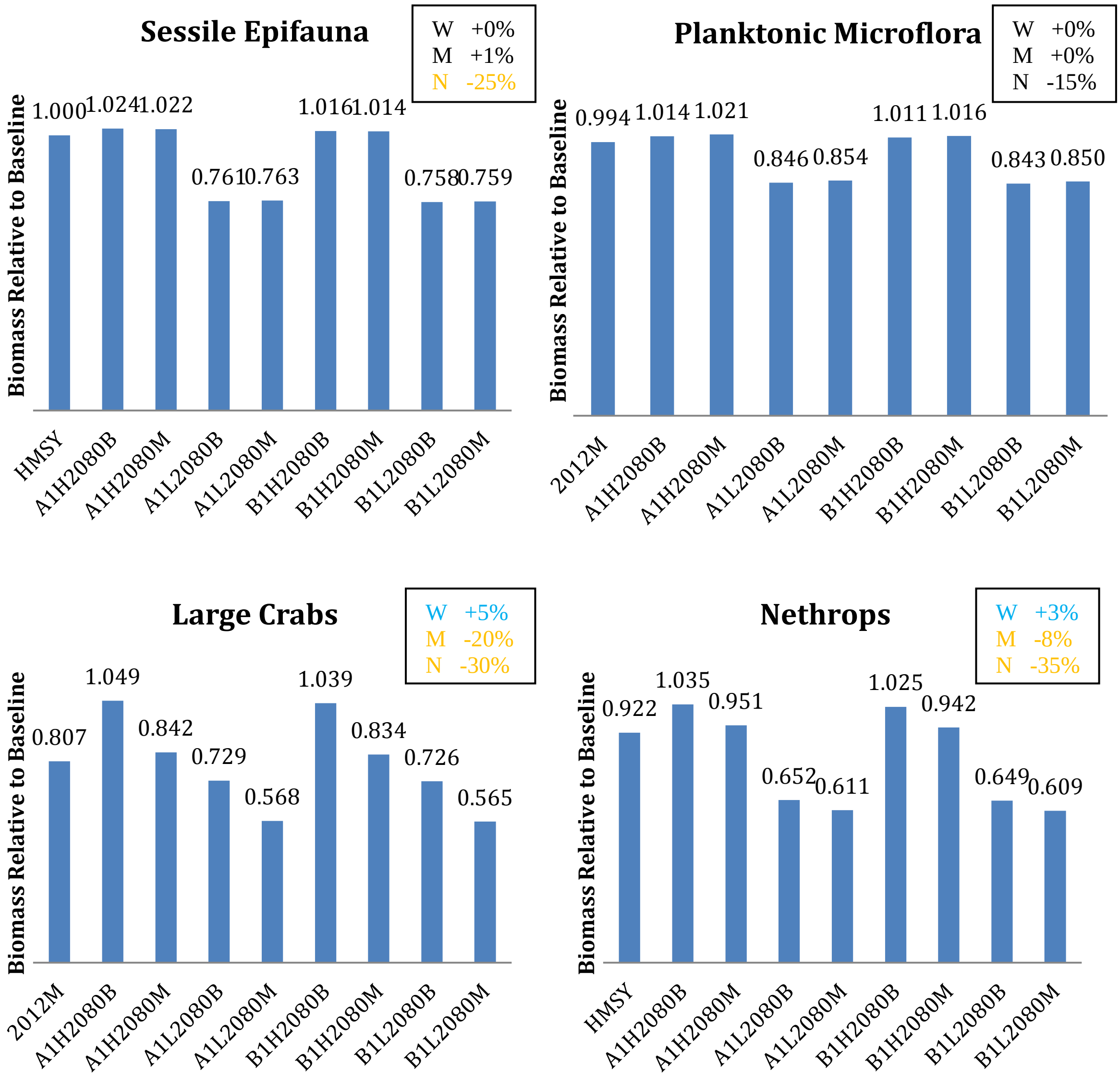


Figure 22: Effect of interaction of climate change, fishing and nutrient reduction scenarios on biomass relative to current baseline levels for a variety of higher trophic level species in the North Sea. Box indicates effect of warming (W) – 3.8 degrees scenario A1B1, switch to MSY (M) and nutrient reduction (N). The levels shown are for the effects separately.

The effects of combining the effects of nutrient reduction, changing the fishing pressure and introducing warming are largely additive with the observed effect of combing MSY fishing and warming very close to the effect of the calculated effect of the combination of the two effects in isolation (fig 23).

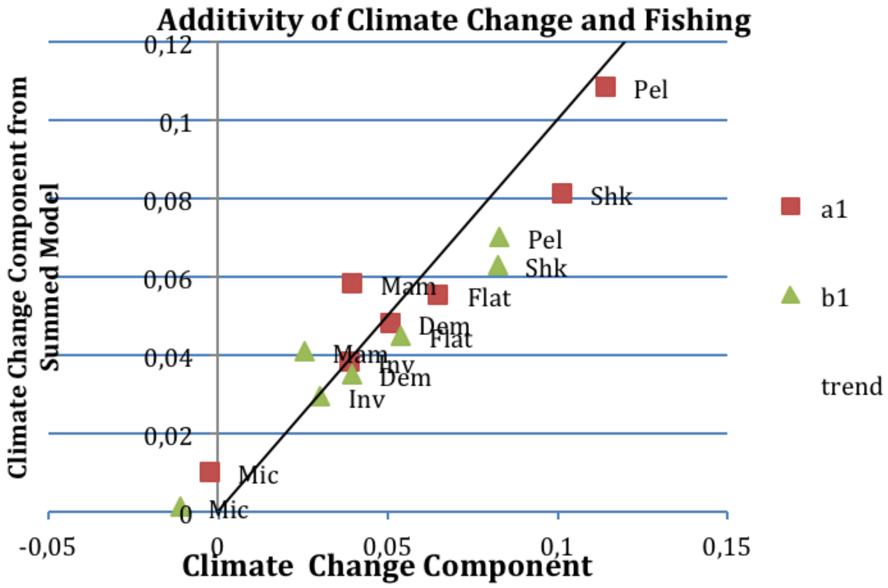


Figure 23. Effect of adding climate change and fishing changes. The effect of climate change in the summed model is compared with the effect from the climate change alone, for the climate change scenarios a1b and b1. A marker below the trend line indicates that the change in biomass in the summed model is less than that predicted from climate change alone. Combined groups are: Pel –pelagic (not sharks), Dem – demersal (not sharks or flatfish), Flat – demersal flatfish species (not sharks or rays), Shk – sharks and rays, Inv – invertebrates excluding plankton, Mic – Microbes and plankton.

2.2.3 Discussion

Higher trophic level in the North Sea

The model coupling results have indicated that changes in the environment and fishing pressure could have both a top down and bottom up effect on the North Sea food web. However, whereas the bottom up effect is concentrated up the food web, the top down effects are not transmitted to the microbial parts of the food web, or affect them only very marginally by less than 1%. Furthermore, the most significant effects are as a result of the changes in nutrients rather than the direct effect of changes in temperature. These results should not, however, be taken to be demonstrative of no effect of climate change on higher trophic levels, rather that the mechanisms of nutrient enrichment / depletion is unlikely to be the most significant one. Other possibilities might include effects on migration of HTL species, effects of shift in nutrient balance having an effect on the metabolism of the HTL species and direct effects of temperature on the metabolism of the HTL species themselves. Empirical evidence of shifts in population following decadal scale changes in temperature resulting from variation in North Atlantic Oscillation suggests other mechanisms are important. It should be noted that other work in the Meece project has focussed on the effect of environmental and lower trophic level conditions on the survival of fish larvae, however fish larvae in the Ecosim North Sea model are used simply as a food source and are not connected to the mature populations.

It would seem that there is the need to integrate other model components if we are to fully explore the consequences of climate change on HTL populations. One potential improvement is to replace the coupling

Physics Model -> Lower Trophic Level Model -> HTL food web

with

Physics Model -> Lower Trophic Level Model -> Individual based larval and Fish -> HTL food web

The Couplerlib system of managed coupling would be able to do this because it handles data translation, but a specific module for aggregating individual based model data into mean field representation would be required.

The possibility exists for direct incorporation of climatic effects into HTL models, specifically Ecosim. Currently Ecosim has a temperature and salinity variable which can be used to set optimal temperatures and salinities for survival. Potentially the plugin mechanism of model extension could be used to code explicit model relationships for predation and growth as well as survival. Similarly in a 2 dimensional Ecospace model, ocean flux predictions from the physics model could be combined with behavioural information on marine vertebrates to produce a detailed sub-model of migration and fluxes in space. However obtaining the data needed for an elaborate behavioural model in a large food web will be a considerable challenge.

2.2.4 Concluding remarks

The wider effect of changes to the North Sea food web is necessarily a complex emergent property of the interactions of the many groups. Modelling an entire system in this way with necessarily simplified models will not produce accurate predictive models for all groups, indeed it may not produce any meaningful predictions at all for some groups where the driving features of the group are not adequately represented by the model. For example although Baleen whales were included in the model, they have not been presented in the results because they are too wide ranging and too long lived to be anything other than a feeding sink for their food species, similarly fish larvae were not included because their population is only meaningful as a population stage in other species / groups. In general though there are some broad conclusions about some of the trends that might be experienced as a result of changes in production: The highest trophic level species respond positively to less fishing and more nutrients, whereas the effects on demersal and flatfish are smaller. Moving to an MSY based fishing approach clearly benefits the fish that are fished less whilst their competitors may be adversely affected. In other words, the fishing quotas of some groups that are being fished sustainably now may have to be revisited as a result of changes in population of competitors and predators. Smaller pelagic fish are the ‘closest’ trophically speaking to the plankton whose levels may change and are likely to see the most dramatic effects of any deliberate or inadvertent change in plankton composition.

3. Baltic Sea

3.1 Model Description

The LTL Model, ECOSMO (ECOSystem Model, Schrum, Alekseeva, & St. John, 2006) provides spatial-temporal information about the ecosystem state in term of physical properties (e.g. temperature, salinity, current field, turbulence, mixed layer depth) and lower trophic level ecosystem components (e.g. nutrient concentration, primary and secondary production, oxygen) to address fisheries impacts on the Baltic Sea ecosystem. ECOSMO is a coupled physical-biogeochemical model, with the hydrodynamics based on the HAMSOM (HAMburg Shelf Ocean Model; Schrum & Backhaus, 1999) including a free-surface 3D baroclinic coupled sea-ice model (fig 23). The bio-chemical sub-module (Fig 24) solves 12 state variables and resolves 3 nutrient cycles. Phytoplankton and zooplankton are each resolved with 2 functional groups, in addition the model uses 2 state variables for detritus and one for oxygen. The primary production in ECOSMO is limited by either the availability of the 3 macro nutrients (nitrogen, phosphorus and silicate) or light.

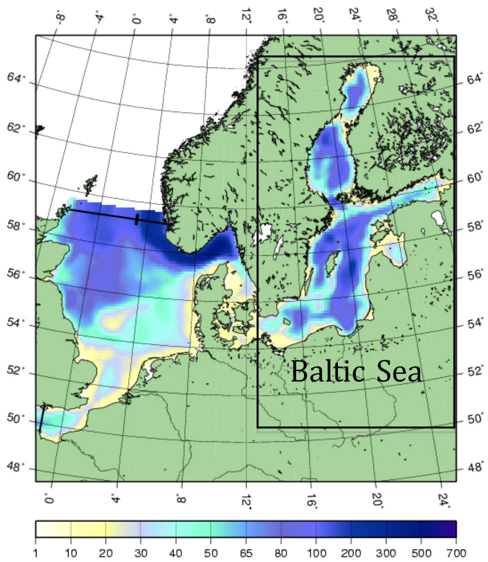
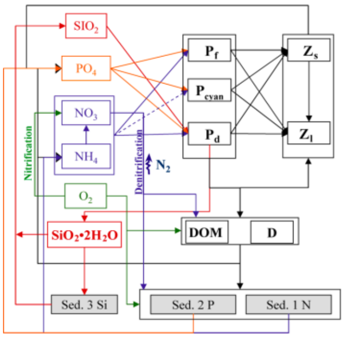


Figure 23: Model area and bathymetry [m].



P_f	Flagellates
P_{cyan}	Cyanobacteria
P_d	Diatoms
Z_l	large zooplankton
Z_s	small zooplankton
DOM	"dissolved organic matter"
D	detritus
Sed. 1	Silicate sediment pool
Sed. 2	Phosphate sediment pool
Sed. 3	Nitrate sediment pool

Figure 24: Schematic diagram of biological interactions in ECOSMO II.

<u>Scenarios: model setup and scenario definition</u>

Present Day (PD) reference for the time period 1980-1999 (outline of scenario, see D1.5)

A present day simulation (for outline of scenario see D1.5, additional and complementary information is provided in D3.4) was performed using atmospheric boundary conditions from the the IPSL-ESM A1B scenario.

Multi Driver scenarios

The multiple driver scenarios emphasize the combined effect of climate change and anthropogenic drivers like eutrophication on the respective marine ecosystem. The scenarios were defined for the time period 2030-2040 (D1.5). The reference baseline is a “business as usual” (BU) scenario with river nutrient supply assumed to be equal to the present day conditions, while atmospheric forcing and boundary conditions where adapted from the IPSL-ESM (IPCC-A1B scenario) downscaled with a delta-change approach (see D3.4).

As agreed in D1.5, the choice for the anthropogenic driver scenarios based on the results from the EU FP6 project ELME (European lifestyles & marine ecosystems). The chosen scenarios were “World Market” and “Global Community”. Our results from the anthropogenic driver sensitivity studies in D4.1 revealed that the parameterization in ECOSMO doesn’t allow for a quantitative assessment of fishery impacts on the ecosystem dynamics, we will therefore hereafter focus only on eutrophication impacts.

<u>Scenarios:</u>

World Market: The ELME results indicate an increase in both Nitrate & Phosphate loads basically driven by increased agricultural activity. (N & P: +20%)

Global Community: While agricultural activity keeps constant, both industrial discharge and UWWT (urban waste water treatment) decreases. This results in a significant decrease in Nitrate & Phosphate loads. (N&P: -50%)

Metrics considered (from D3.2)

- Surface temperature
- Surface salinity
- Surface nutrients
- Depth integrated phytoplankton biomass (small and large)
- Depth integrated zooplankton biomass (small and large)
- Benthic biomass
- Net primary production (net primary production)

Linkages with MEECE deliverables

Deliverable	Comments
D1.5	Outline of driver response scenarios (ELME)
D2.2	Details of carbon sub-model
D3.1	Outline of model scenarios
D3.2	Description of metrics to consider
D3.4	Details of the ECOSMO implementation for the Baltic Sea
D3.5	Atlas of marine ecosystem climate response
D4.1	Description of single driver experiments
D4.4	Atlas of marine ecosystem climate response

3.2 Results

Climate impacts → present day vs. baseline

Our projection for the time period 2030-2040 using the IPSL-ESM A1B scenario to the force ECOSMO shows that the SST in the Baltic Sea increasing by around 1.5-1.7 °C in the next 20 to 30 years compared to the reference period 1980-1999 (Fig. 25). This temperature increase is a spatially relative robust signal but with a slightly stronger warming in the Bothnian Sea. The projection suggests only small changes in sea surface salinity with a general decrease in the central Baltic Sea and the Gulf of Bothnia. Surface salinities in the Gulf of Finland and Riga were, in contrast, projected to be slightly higher than during the reference time period.

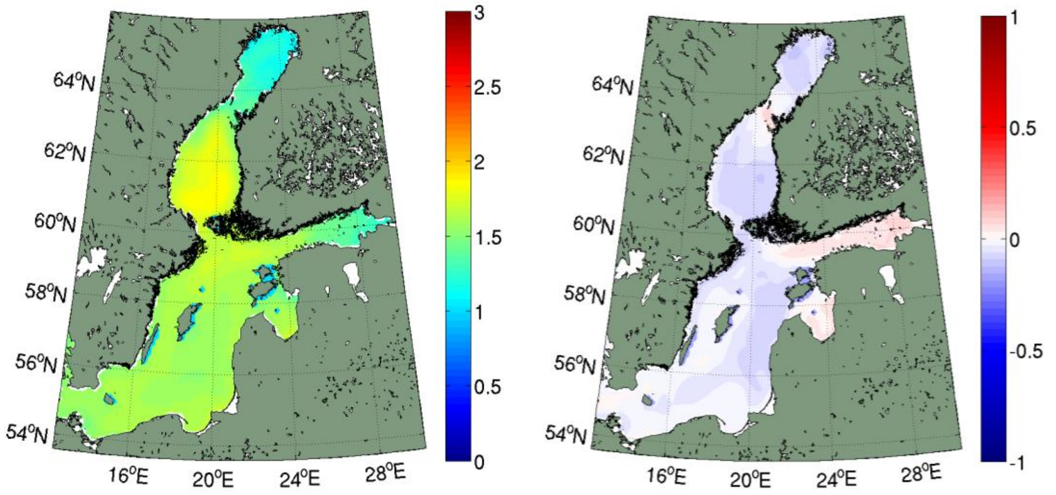


Figure 25. Physical parameters total change in average annual SST (left) and SSS (right) between future projection (2020-2049: IPSL-ESM) and present day reference (1980-1999).

The "climate-induced" changes in the Baltic Sea production (Fig. 26) in 2030-2040 when compared to 1980-1999 are highly inhomogeneous with clear increasing pattern in the coastal areas of the southern and eastern Baltic Sea but show, likewise, a slight decrease in the central Basins and in the Gulf of Bothnia. The increased coastal productivity can probably be assigned to changes in the wind field that allows an increased upwelling of nutrients to the surface at the southeastern coast of the Baltic Sea.

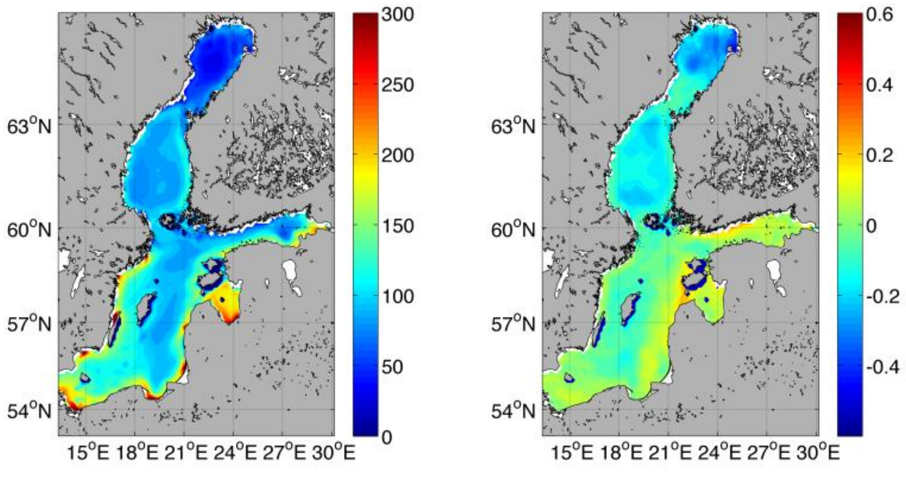


Figure 26. Annual mean map of net primary production (mgC m-2 day-1) under present day climatic conditions (left) and fractional change in net primary production for the business as usual (BU) scenario (right) (with respect to present day conditions), climate change projection for the time period 2030-2040.

Subsequent changes in zooplankton biomass (Fig. 27) only partially correspond with the changes in primary production and show a higher spatial diversity. The most pronounced increase occurs at the entrance to the Gulf of Riga, while in contrast the low zooplankton biomasses in the Gulf of Bothnia and in parts of the southern Baltic Sea are projected to decrease even further. Projected relative zooplankton biomass changes are significantly larger than projected primary production changes.

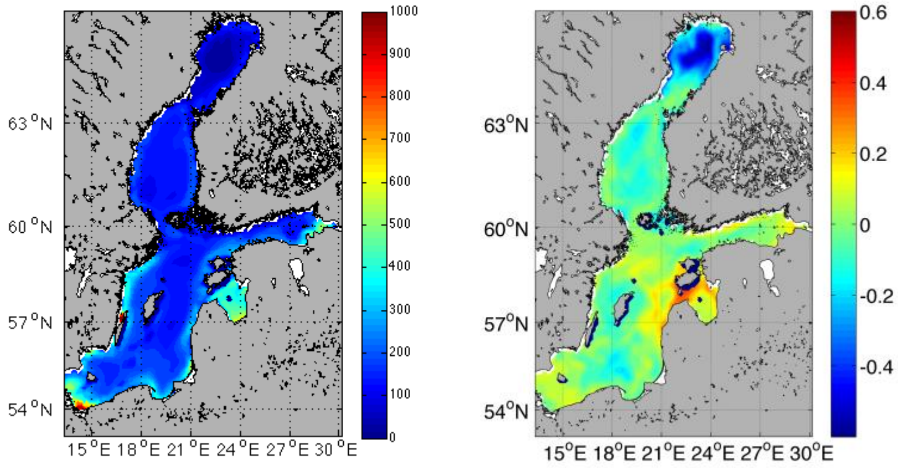


Figure 27. Annual mean map of simulated zooplankton biomass (mgC m^{-2} day^{-1}) under present day climatic conditions (left) and fractional change for business as usual (BU) scenario (right) with respect to present day conditions. The climate impact is projected for the time slice 2030-2040

Multiple driver scenarios vs baseline

The anthropogenic driver experiment in D4.1 shows a strong response of the Baltic Sea ecosystem to changes in the river nutrient supply. Eutrophication is one of the dominant processes important for the Baltic Sea ecosystem dynamics. The anthropogenic scenarios chosen are clear in this respect. Either river nutrient loads will increase (*World Market* scenario) resulting in an overall increase in Baltic Sea primary production and zooplankton biomass (Fig. 28 & 29) or nutrient loads will decrease (*Global Community* scenario) and thus diminish (if not repress) the effect of the atmospheric forcing in the coastal areas. In the central Baltic Sea and the Gulf of Bothnia we therefore expect a significant decrease in primary production under a *Global Community* scenario in 2030-2040. Additionally, the zooplankton biomass increase forced by changes in the atmospheric forcing was strongly reduced under the *Global Community* scenario.

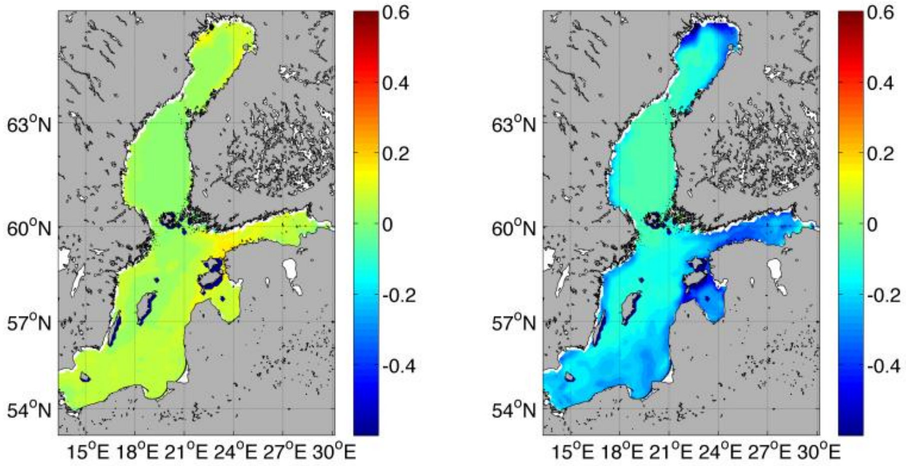


Figure 28. Annual mean maps of the fractional changes in net primary production (mgC m^{-2} day^{-1}) for the World Market (WM) scenario (left) and the Global Community (GC) scenario (right) with respect to the business as usual (BU) scenario. The climate impact is projected for the time slice 2030-2040.

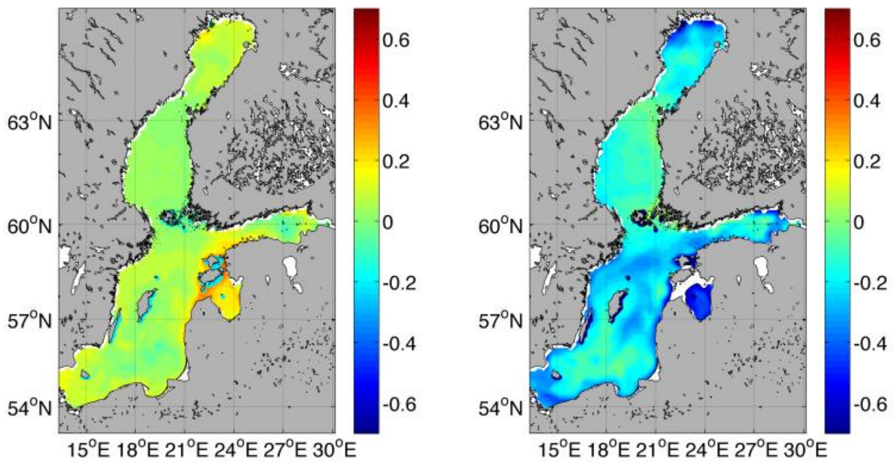


Figure 29. Annual mean maps of the fractional changes in zooplankton biomass (mgC m^{-2} day^{-1}) for the World Market (WM) scenario (left) and the Global Community (GC) scenario (right) with respect to the Business as usual (BU) scenario. The climate change is projected for the time slice 2030-2040.

In the climate scenario in D3.4 pH was shown to decrease with increasing atmospheric pCO_2 as assumed in the IPCC-A1B scenario. The changes in primary production during the considered anthropogenic scenarios have only small subsequent effects on the pH (Fig. 30). Only in the Gulf of Finland and Riga slightly larger effects were simulated with increasing pH under the WM scenario due to increasing primary production and the opposite response during the GC scenario indicating an amplification of the on-going ocean acidification.

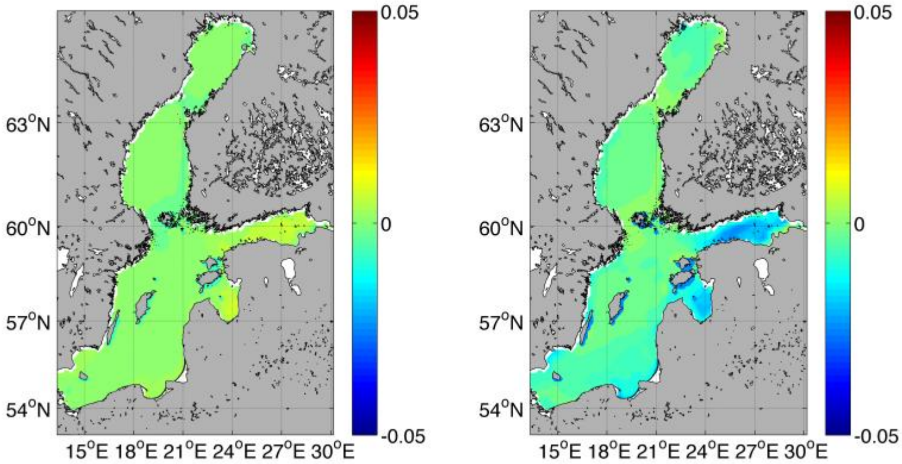


Figure 30. Annual mean maps of the total changes in pH for the World Market (WM) scenario (left) and the Global Community (GC) scenario (right) with respect to the Business as usual (BU) scenario. The climate impact is projected for the time slice 2030-2040

3.3 Discussion & Concluding remarks

In the Baltic Sea, eutrophication is a dominant process for changes in ecosystem productivity. Nonetheless, our model results indicate that the ecosystem response to changes in the atmospheric forcing is in the same order of magnitude. Thus, at least in a short-term perspective ecosystem relevant policies can have major effects on the future progression of the Baltic Sea ecosystem.

But, since the characteristic time scale of the Baltic Sea (30 years) is much longer than the simulated time period even though we started the simulation 10 year in advance, the scenarios consider only the instant response of the ecosystem to atmospheric changes rather than long-term climatic signals. Therefore, continuous long-term future projections would be necessary to account additionally for e.g. changes in the inflow to the Baltic Sea and to understand the actual effect of climate change on the Baltic Sea ecosystem.

3.4 References

Kalnay, E., Kanamitsu, M., Kistler, R., Collins, W., Deaven, D., Gandin, L., Iredell, M., et al. (1996). The NCEP/NCAR 40-year reanalysis project. *Bulletin of the American Meteorological Society*, *77*(3), 437–471. doi:10.1175/1520-0477(1996)077<0437:TNYRP>2.0.CO;2

4. Baltic Sea

4.1 Model Description

HTL – Climate and Fishing

Stochastic Multi Species model: SMS (Stochastic Multi Species model) (Lewy and Vinther, 2004) is a stock assessment model including biological interactions estimated from a parameterised size dependent food selection function. The model is formulated and fitted to observations of total catches, survey CPUE and stomach contents. Parameters are estimated by maximum likelihood and the variance/covariance matrix is obtained from the Hessian matrix. Once the parameters have been estimated, the model can be run in projection mode, using recruitments from stock recruitment relations and fishery mortality derived from an array of Harvest Control Rules. In the forecasts applied in MEECE, the recruitment sub-model has been extended in order to include ECOSMO II data on temperature in 10 m depth (for sprat), and cod reproductive volume. A simple non-linear model was fitted to the recruitment, spawning stock biomass and environmental data, and the parameter estimates were then used in predicting cod and sprat recruitment under environmental change. Together with herring, cod and sprat make up more than 90% of the fish biomass in the Baltic. Cod was chosen to represent the ‘large demersal’ component of the higher trophic levels (HTL), while sprat was chosen to represent the ‘small pelagics’ HLT component in the Baltic Sea. Both component are treated separately, because due to their predator-prey relationship and different recruitment processes, the differ to a large extent in their response to climatic changes, in some instances in opposite directions.

SMS is a stochastic model where the uncertainties on fishery, survey and stomach contents data are included. The parameters are estimated using maximum likelihood (ML) and the confidence limits of the estimated values are calculated by the inverse Hessian matrix or from the posterior distribution from Markov Chain Monte Carlo simulations. The approach contains sub-models for stock recruitment, food selection, predation mortality, fishing mortality and survey catchabilities. Further, in contrast to the fully age-structured MSVPA, SMS is a semi age-length structured model where the stomach content observations and the food selection model are length based. This allows for more realistic food selection models and the use of the originally sampled length based stomach data. Catch data models are kept age-structured as length-structured data are not available for the cases considered.

The Baltic multispecies assessment process started about 20 years ago and presently the following data (catch, mean weight, proportion mature and food ration) by age group, quarter and year are available for the Baltic Sea.

Baltic Main Basin combined subdivisions (ICES WGSAM Report 2010):

- Years 1974–2009
- Cod in Subdivisions 25–29+32
- Sprat in Subdivisions 25–32
- Herring in Subdivisions 25–29+32 (i.e. including the Gulf of Riga)
- A total of 55000 cod stomachs sampled in the period 1977–1994

Input data to SMS are given by quarter of the year. This time step has also been used by ICES SGMAB (ICES, CM 2005/H:06) and input including catch numbers, mean weight at age, proportion mature and food rations were as far as possible copied from this SG. Survey CPUE data were copied from ICES single species assessment data. Stomach content data, 1977–1994 have previously been compiled for use in the age-based MSVPA and are used by SGMAB. SMS uses stomach data by size classes, however, and a recompilation of the “raw” stomach data are now available on the standard ICES format. During the re-compilation of data, errors were spotted in the old data compilations and some of the methods previously used were rejected.

SMS can fit the catch at age, survey CPUE and recruitment sub-models reasonably well, but the model has limited ability to predict the stomach contents. Further analysis of the residuals from the stomach contents observations showed a distribution of residuals for the named prey species, with an excess of large positive residuals (higher observed than expected stomach contents). The distribution of “other food” residuals has an overrepresentation of negative residuals. The residuals of named prey species seem independent of the predator-prey size ratio, indicating a good fit to the size model. When the residuals are plotted against the size of the prey, there seems, however, to be an overweight of positive residuals for the smallest prey of all the prey species. This indicates that more small preys are found in the stomachs than expected from the model.

Ecopath with Ecosim (EWE): We used delta-approach using food-web model constructed at Ecopath with Ecosim software developed by Tomczak at al. (2012) and carefully tested by Niiranen et al. (2012). The model was forced and calibrated by observed data. At version by Nirranen et al. 2012 primary production forcing was applied additionally. For model details see 2.2.

For MEECE delta approach, original model was recalibrated with ERA40 hindcast forcing and lower trophic level biomass data, derived from ECOSMO model output and represents analogues to observed environmental forcing and group biomasses.

Delta approach as applied in SMS and EwE

ECOSMO forcing data from the control run and IPSL simulations were applied to force the models, but additionally two fisheries scenarios were applied, representing long term average of fishing mortality (F) value for all species and F_{msy} adopted from WGBFAS ICES (2011):

A: (1970 – 1999) control run, average F (1974-2006)

B: (1970 – 1999) control run, F_{msy} (2011)

C: (2070 – 2099) simulation run, average F (1974-2006)

D: (2070 – 2099) simulation run, F_{msy} (2011)

Values of fishing mortality F applied for delta approach:

Cod F: average (1974-2006) –> 0.87; F_{msy} –> 0.3

Herring F: average (1974-2006) –> 0.18; F_{msy} –> 0.16

Sprat F: average (1974-2006) –> 0.23; F_{msy} –> 0.35

Combination of scenarios applied:

Delta (s): Δ=A-B; A-C; C-D; B-D

4.2 Results

SMS Results

Traditionally, in SMS the reproduction of the cod and sprat stocks for forecast runs is estimated using the relationship between spawning stock biomass and recruitment at age 0. However, in MEECE this relationship has been extended to account for the impact of temperature and, in the case of Baltic cod, reproductive volume calculated by ECOSMO.

Cod

Assuming F_{msy} fisheries management instead of historical average fisheries yielded higher cod spawning stock biomass in predictions assuming the ECOSMO (control) run using 1970-1999 data), Fig. 31 panel AB. Using the 2070-2099 ECOSMO time slice evoked much greater variability in cod SSB (pane AC in Figure 31). The peaks in scenario C are higher than in scenario A. This is probably because in scenario A cannibalism is dampening oscillations, whereas in scenario the stock increases form almost extinction, and the size structure does not contain cannibals. The reason that the SSB faces almost extinction is in the changed environmental conditions, which although leading to few high recruitments, contain mostly very weak recruitments. Panel CD in figure 31 shows, that this tendency is hardly counteracted by applying F_{msy} fisheries management instead of the (higher) traditional fishing pressure. This environmental effect on cod recruitment in these simulations dominates cod SSB becomes also visible when comparing scenarios B and D (Figure 31). However, cod reproductive volume was not significant in the recruitment model, thus refining the recruitment regression might modulate this result.

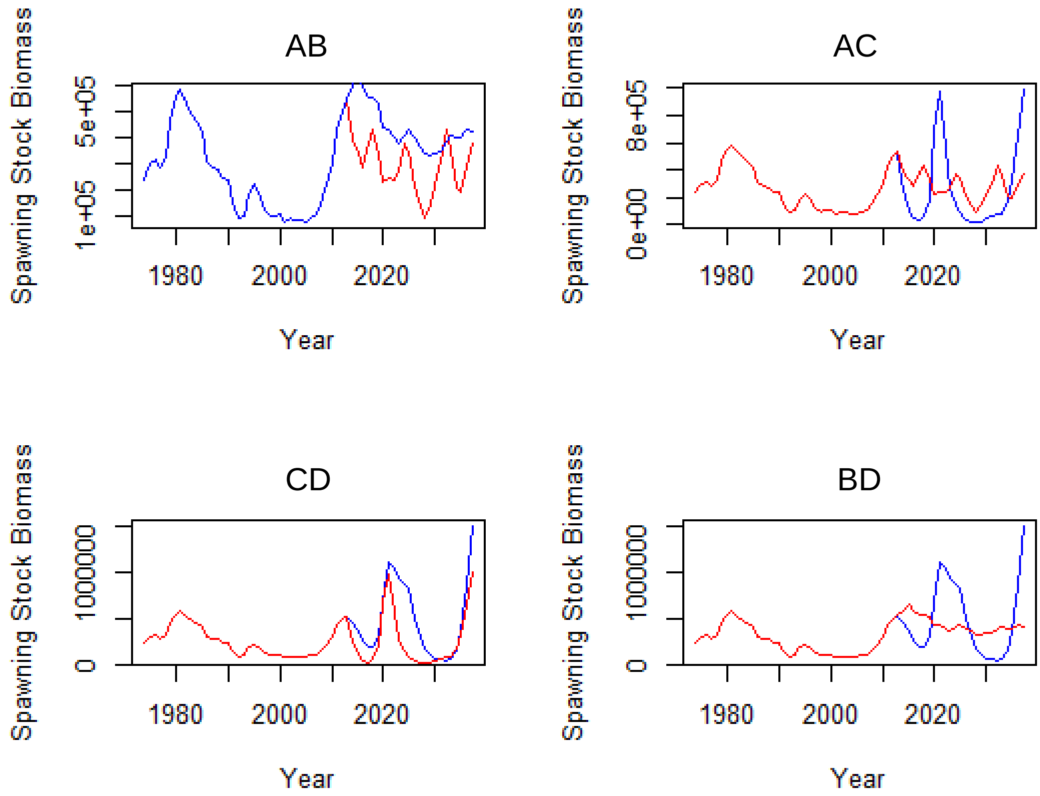


Figure 31. Time slices simulations for cod. Up to 2009 the runs are identical. Apparent differences are due to scaling of the y-axis (Recruitment). In panel AB, the scenario A (Ecosmo run 1970-1999; historical average fishing pressure) is plotted in red, and scenario B (Ecosmo run 1970-1999; maximum sustainable yield fishing pressure) is plotted in blue. In panel AC, scenario A is plotted in blue and scenario C (Ecosmo run 2070-2099; historical average fishing pressure) is plotted in red. In panel CD, scenario C is plotted in red, and scenario D (Ecosmo run 1970-1999; maximum sustainable yield fishing pressure) is plotted in blue.

While the projected environmental conditions clearly are hampering successful cod recruitment, the contrary is the case for sprat. Fishing regime has no major effect on sprat biomass (Figure 32, panel AB), however, when 2070-2099 conditions are assumed instead, sprat spawning stock biomass is predicted to increase markedly (Figure 32, panel AC). The increase is almost independent of the fishing regime (Figure 32, panel CD), but under F_{msy} exclusively driven by the environment (panel BD in figure 32).

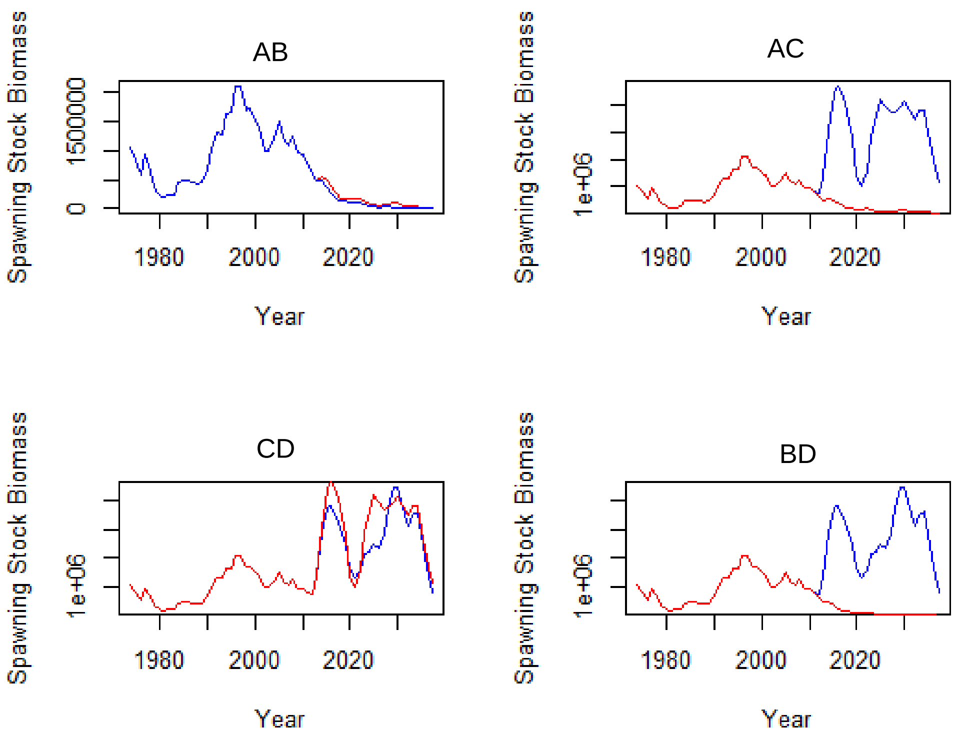


Figure 32: Time slices simulations for sprat. Up to 2009 the runs are identical. Apparent differences are due to scaling of the y-axis (Recruitment). In panel AB, the scenario A (Ecosmo run 1970-1999; historical average fishing pressure) is plotted in red, and scenario B (Ecosmo run 1970-1999; maximum sustainable yield fishing pressure) is plotted in blue. In panel AC, scenario A is plotted in blue and scenario C (Ecosmo run 2000-2040; historical average fishing pressure) is plotted in red. In panel CD, scenario C is plotted in red, and scenario D (Ecosmo run 1970-1999; maximum sustainable yield fishing pressure) is plotted in blue.

Box plots of the scenario comparisons are presented in figure 33.

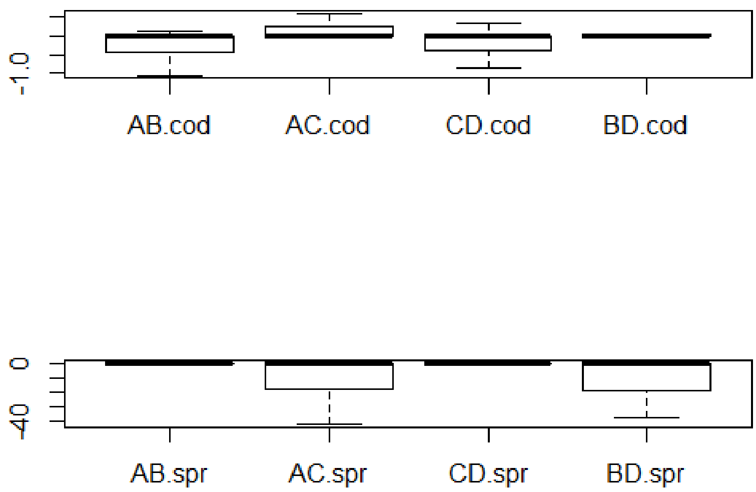


Figure 33: Scenario comparison according to the delta method. Solid bars indicate the median, the boxes comprise the 0.50 and 0.75 percentiles. Whiskers reach out to 2 standard deviations.

5. Bay of Biscay

5.1 Science questions addressed for the region

Marine ecosystem functioning and impact of fishing is still not totally understood. Because trophic interactions between species play an important role on the dynamics of the fish communities, fishing pressure has non-linear effects on the ecosystem. A new management method that takes into account the effects of fishing together with the natural population dynamics in the Bay of Biscay is developed. Using a multi-species end-to end model, the fishing effects on the most important pelagic species of the Bay of Biscay have been quantified for present day conditions and future scenarios. In addition to the reference state, two fishing mortalities have been simulated: fishing mortality consistent with achieving Maximum Sustainable Yield (Fmsy) and the precautionary reference point for fishing mortality (Fpa). Variations in fish stock biomasses have been analysed for each of the simulated scenarios.

5.2 Models used

Both Lower Trophic Level and Higher Trophic Level models used for the D4.3 are described in D2.3, D3.4 and D4.1:

- LTL Models: ROMS-$N_2P_2Z_2D_2$ (Bay of Biscay) / ERSEM (North European Waters)
- HTL Model: OSMOSE

Indeed, as the climatic scenarios simulations were not available with ROMS-$N_2P_2Z_2D_2$ for the period 2030-2040, we plan to use the outputs of ERSEM model for this period. The both outputs of LTL models ROMS-$N_2P_2Z_2D_2$ and ERSEM are used as input for the HTL model OSMOSE.

Scenarios runs

- Simulations using ROMS-$N_2P_2Z_2D_2$ model outputs as input for OSMOSE

  CNTRL 1980-2000 (presented in D3.4)

  CNTRL + fishing scenario Fmsy

  CNTRL + fishing scenario Fpa

  A1B 2080-2099 (presented in D3.4)

  GC (A1B 2080-2099 + fishing scenario Fmsy)

  WM (A1B 2080-2099 + fishing scenario Fpa)

- Simulations using ERSEM model outputs as input for OSMOSE

  CNTRL 1980-2000 (presented in D3.4)

  A1B 2030-2040 (presented in D3.4)

GC (A1B 2030-2040 + fishing scenario Fmsy)

WM (A1B 2030-2040 + fishing scenario Fpa)

Fishing scenarios have been run using different Annual Fishing Mortalities F (Table 5).

- **F(ref)** refers to the estimated mean fishing mortality between 1998-2002.
- $\mathbf{F_{pa}}$ is defined as precautionary fishing mortality
- $\mathbf{F_{MSY}}$ is defined as the level of fishing mortality that achieves maximum sustainable yield (MSY) over the long term based on growth and natural mortality rates, the selection pattern of the fishery and recruitment changes associated with the level of adult biomass (stock-recruitment relationship).

Table 5: Annual fishing mortality in the OSMOSE model for each species, for the reference simulation and the fishing scenarios simulations. As the F_{MSY} and F_{pa} values for Atlantic Bluefin Tuna and Albacore were not easily available, we have used same values as for the reference simulation.

Species	F(ref)	GC - F_{MSY}	WM - F_{pa}
Anchovy	0.68	0.63	1.1
Sardine	0.22	0.15	0.26
South Hake	0.25	0.21	0.40
North Hake	0.25	0.21	0.40
Horse Mackerel	0.08	0.14	0.25
Atlantic Mackerel	0.20	0.21	0.23
Atl. Bluefin Tuna	0.25	=	=
Atlantic Albacore	0.24	=	=
Blue Whiting	0.29	0.18	0.32

Metrics considered

- Considered variables

All results about LTL variables (SST, circulation, nutrients, phytoplankton and zooplankton) have been presented in the D3.4. In the WP4, the focus is on HTL variables as the anthropogenic driver is “fishing”.

HTL variables:

- Total fish biomass for each considered species, averaged over the domain (in tons)
- Annual mean biomass distribution for each species (in tons)

- Statistical tests for sensitivity

No statistical tests done.

Table of linkages with MEECE deliverables

Deliverable	Comments
D1.2 IPSL model outputs	Used as forcing conditions for the scenarios simulations
D1.4 New model parameterizations	c. Fisheries: OSMOSE parameterization for F_{MSY} and Fpa
D1.5 & D1.6: Driver envelope scenarios	Hindcast + present day climate + future climate (A1B1 - IPSL-CM4) Fishing scenarios F_{MSY} and Fpa
D2.3 OSMOSE model	OSMOSE model implemented in the Bay of Biscay
D3.1 Common set of forcing scenarios	Has been followed as possible
D3.2 Common set of metrics	Has been followed as possible
D3.4	Climate simulations presented in this deliverable
D3.5	Atlas: LTL model results
D4.1	Fishing scenarios presented in this deliverable
D4.4	Atlas: HTL model results

5.3 Results

LTL – demonstration of spatial and temporal sensitivity

As the considered anthropogenic driver for the Bay of Biscay is “Fishing”, the scenarios have impacts only on the fish community (OSMOSE is 1-way coupled to ROMS-$N_2P_2Z_2D_2$). Thus, no sensitivity analysis has been undertaken for the LTL system. All the results of the LTL models (environment and plankton system) are presented in the deliverable D3.4.

HTL - demonstration of spatial and temporal sensitivity

Period 2080-2099: far future climate vs. fishing scenarios

The changes in fish biomass applying F_{MSY} (GC) and F_{pa} (WM) annual fishing mortalities, for the period 2080-2099 (simulations A1B) are shown on Figure 34, and the variations in % in table 6.

The variation of total biomass between the two periods (1980-2000 and 2080-2099) is of 4.6% (%A1B/CTRL). Fishing mortalities in these two simulations are identical, thus, the variation is caused by changes in the plankton field. The anthropogenic scenario Global Community (F_{MSY}) outputs show a 4.9% increase of the total fish biomass compared to CNTRL run, a similar value than the future climate scenario A1B with no modification of F. Thus, the variation of fishing mortality from F(ref) to F_{MSY} has little effect on the total biomass. However, all the species do not react in a same way: anchovy and sardine slightly increase, while both northern and southern stock of hake increases considerably. In contrast, mackerel and horse-mackerel suffer a modest biomass decrease. Indeed the F_{MSY} values for anchovy, sardine and hake are lower than the F(ref) values used for CNTRL and A1B runs, whereas are slightly higher for mackerel and horse-mackerel. GC is a scenario with reduction in fishing pressure on anchovy, sardine and hake.

The anthropogenic scenario World Markets (F_{pa}) outputs reflect a positive variation of the total biomass of 8.7% in comparison with the CNTRL run. In particular, hake biomasses increase 33.6% and 67.5% in comparison to the CNTRL run (southern and northern stocks, respectively). Sardine and Atlantic mackerel biomasses undergo also a considerable increase of 15.9% and 14.2% respectively, whereas anchovy biomass decreases by 1.9%. The F_{pa} values (used for WM run) are higher than the F(ref) values (used for CNTRL run) for all the species. Thus, the WM scenario is a stronger fishing pressure scenario, and the response of the fish stocks is strongly non-linear.

Comparing the A1B, GC and WM scenarios, the anchovy stock as well as hake stocks, show a favourable evolution for the climate scenario 2080-2099, in particular when F_{MSY} is used as fishing mortality. Atlantic and horse mackerel decrease their biomass in the future scenario, with more pronounced decrease if F_{MSY} is used instead of F(ref). When fishing mortality is set to F_{pa}, horse mackerel biomass accentuates the loss of biomass, but Atlantic mackerel shows a positive evolution. As for this species, the F_{pa} value (WM) is similar to the F(ref) and Fmsy values, the Atlantic mackerel appears to take advantage of the horse-mackerel lower biomass as they are competitive species.

Table 6: Variation of the biomass of each species and total stock for i) the climate (A1B) simulation comparatively to the CNTRL one (column 2, also in D3.4) and ii) the multi-drivers simulations comparatively to both climate (A1B-2080-2100) and CTRL simulations -(columns 3-6).

Each cell of the table is highlighted with a specific colour: red for decrease of more than 10%, light orange for decrease of 1 to 10%, light green for increase of 1 to 20%, green for increase of more than 20%. Cell in white represent a variation of less than ±1%.

	%A1B / CNTRL	**%GC / A1B**	**%GC / CNTRL**	**%WM / A1B**	**%WM / CNTRL**
Anchovy	120.5	103.0	124.1	81.5	98.1
Sardine	114.8	103.8	119.1	99.6	114.2
South Hake	174.2	142.0	247.4	76.7	133.6
North Hake	144.2	122.9	177.2	116.0	167.3
Horse-Mack.	95.0	95.6	90.8	82.3	78.1
Atl. Mackerel	91.5	90.7	83.0	126.6	115.9
Total stock	**104.6**	**100.4**	**104.9**	**103.9**	**108.7**

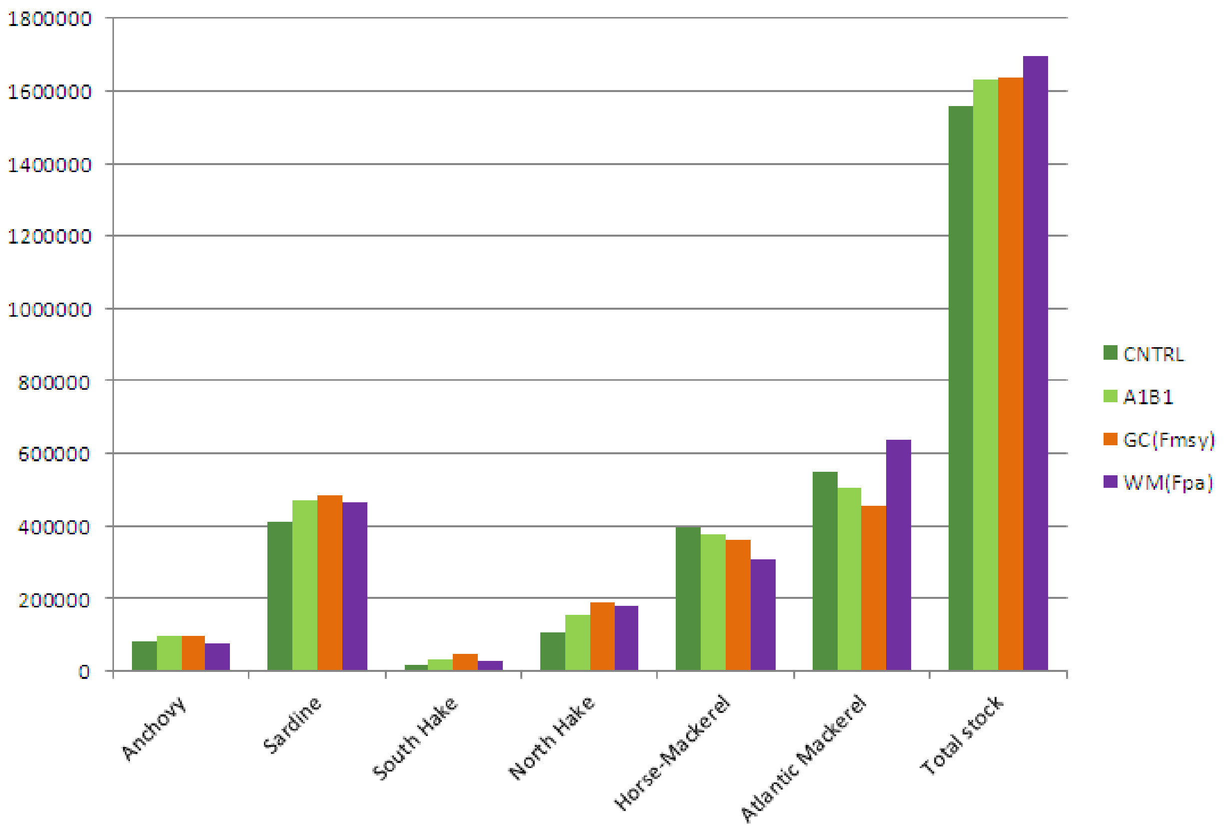


Figure 34: Total biomasses of the 6 species taken into account in OSMOSE for the Bay of Biscay for: the CNTRL simulation (1980-2000), the A1B simulation (2080-2099), the "Global Community" simulation (2080-2099 + F_{MSY} scenario) and the "World Market" simulation (2080-2099 + F_{pa} scenario). The results are shown over a climatologic year.

Period 2030-2040 (using ERSEM model outputs as input)

This study is in progress, in collaboration with J. Holt and S. Wakelin for the ERSEM outputs, and P. Verley to modify the OSMOSE model.

5.4 Discussion and conclusions

Impact of fishing pressure for several periods

The F_{pa} and F_{MSY} scenarios do not have the same impact following the input plankton prey fields. Indeed, the results are different, sometimes reversed, if the fishing scenarios are applied to different periods: near past (CNTRL 1980-2000) and far future (A1B 2080-2100) simulations (Table 7).

The F_{pa} scenario results show reversed results following if it is applied to the near past period (1980-2000) or to the far future period (2080-2099). Thus, the plankton prey input fields seem to impact the fishing scenario response of fish biomass. Thus, this shows the importance to couple dynamically (2-ways) the HTL model OSMOSE to the LTL model. Indeed, as the fish biomass do not respond by directly following the plankton prey fields, it is crucial to take into account (i) the impact of the variability of these plankton prey fields, and thus (ii) the impact of HTL to LTL.

Table 7: Variation of the total stock (total biomass) for the climate, fishing and multi-drivers simulations.

Climate / **Fishing**	**CNTRL (1980-2000)**	**A1B 2030-2040**	**A1B 2080-2099**
F(ref)	-	*in progress*	+4.55% (/ CNTRL)
WM – Fpa	-8.10% (/ CNTRL)	*in progress*	+3.93% (/ A1B)
GC - F_{MSY}	+2.12% (/ CNTRL)	*in progress*	+0.36% (/ A1B)

Access to Biscay Model results

- Access to model results: MEECE Atlas
- Model state variables available (in relation with WP4: anthropogenic drivers)
- Temporal frequency : mean values for the climatologic year
- No spatial availability: mean distribution (surface or depth integrated)
- Data format : cvs
- Condition for data transfer: Marina Chifflet: mchifflet@azti.es – ftp transfer