EURO-BASIN
BASIN SCALE ANALYSIS, SYNTHESIS AND INTEGRATION

SEVENTH FRAMEWORK PROGRAMME

Final Scientific Report & Publishable Summary

Contents

Executive Summary

EURO-BASIN (European Basin-scale Analysis, Synthesis & Integration) was part of a joint EU / North American research initiative involving on the EU side, twenty four institutes from nine European nations. This FP7-ENV-2010 project was funded under the Work Programme topic: ENV.2010.2.2.1-1 North Atlantic Ocean and associated shelf-seas protection and management options commencing December 31st 2010 and ending December 31st 2014.

EURO-BASIN was designed to improve the understanding of the variability, potential impacts, and feedbacks of global change and anthropogenic forcing on the structure, function and dynamics of the ecosystems of the North Atlantic Ocean and associated shelf seas and on their capacity to provide services. The overarching goal of EURO-BASIN was to develop understanding and strategies to improve and advance ocean management (ecosystem approach). EURO-BASIN was focused on key processes and organisms, while maintaining a connection to key trophic interactions and their importance for exploited resources within a changing climate. Following this strategy the program created understanding and simulated the population structure and dynamics of broadly distributed, and biogeochemically and trophically important plankton and fish species in order to resolve the impacts of climate variability on marine ecosystems and the feedbacks to the earth system. Process understanding and simulation tools developed and applied within EURO-BASIN identified the following key issues, which are essential for environmental management and governance, development of policy and identification of societal challenges.

- The overall potential economic rent for the fishing industry in the North Atlantic is estimated to be € 12.85 billion, which highlights the loss of potential when compared with the current estimated profits of only € 0.63 billion. Furthermore our studies have shown that the availability of fisheries resources is more sensitive to governance changes than to climatic change, at least at the horizon of 2040. This provides economic justification for maintaining or restoring fish stocks to above their MSY biomass levels. These conclusions are consistent with similar global scale studies.

- Observed and simulated future distributions of key species and their habitats indicate that we can expect significant changes in the biogeography of the North Atlantic Ocean over the next century when compared with present the present day. As a result of these changes adaptive management strategies are necessary involving the nations bordering the Atlantic to cope with the changing distributions of the fish stocks of the region.

- By the end of the century significant reductions in both secondary production and carbon export will occur due in part to reductions in primary production. This implies that less energy will make is way up the food webs toward fish, birds and mammals with potentially major consequences for biodiversity. It also indicates that ability of the North Atlantic to sequester anthropogenic carbon may be impaired, potentially exacerbating global warming.

- The regime shift analyses performed on North Atlantic ecosystems revealed two clear periods of change, specifically the 2020s and 2040s. The results suggest that the changes in the abiotic and lower trophic level dynamics as a result of "business-as-usual" emission scenario will be linked to new states in the North Atlantic fish communities. The major change predicted (>2040) suggests that the shift will strongly benefit species that are adapted to higher temperatures while traditional species such as herring and cod will have difficulties in keeping their population sizes at historical levels. This implies that commercial fisheries operations and management will need to adapt there harvesting strategies to account for the changing fish community in order to preserve stocks and the biodiversity of the system.

2.0 Project Context & Objectives

Evidence that climate change is strongly affecting the structure and functioning of the marine environment is mounting and projected impacts suggest more dramatic changes in ecosystem productivity and services will occur in our lifetime. The interplay between climate, marine ecosystems and human activities fundamentally affects not only the North Atlantic-Arctic system, but also the entire earth system. Much scientific effort has been invested to build the existing knowledge base of this system, but it remains rudimentary in many aspects that are requisite to deliver predictive capacity and long-term forecasting. Predictive capacity and long-term forecasting are essential for addressing key scientific, environmental, governance, policy and societal challenges that we are already facing, and which are guaranteed to multiply in the near future.

To foster predictive capacity, long-term forecasting, and the ecosystem approach for the management of the ecosystems of the North Atlantic, EURO-BASIN assembled and analyzed existing databases on key North Atlantic plankton and fish species as well as performing extensive field, laboratory and mesocosm studies. The results from these activities were analyzed and new knowledge on the processes, both physiological and abiotic influencing the vital rates, distribution and role of key ecosystem and biogeochemical players in ecosystem structuring and functioning were established. These studies generated vital rate parameterizations and process understanding that were used to advance the EURO-BASIN suite of predictive modeling tools employed by the partners to simulate the dynamics of North Atlantic ecosystems and their key players.

EURO-BASIN employed these new and extended existing modeling tools to describe, understand and predict the impact of climate change and variability and mans activities (fisheries) on marine ecosystem structure and function in the North Atlantic Ocean and shelf seas. To achieve this Euro-BASIN took a basin-scale modelling approach, simulating the response of marine ecosystems using coupled physical-biogeochemical-MTL models via both re-analysis forced simulations and climate-scenario forced simulations. The models served to integrate knowledge and thereby extend our understanding of the potential impacts and feedbacks of global change and anthropogenic forcing on ecosystem structure, production of exploited fish stocks, sequestration of carbon, and the abundance of key species.

With this as the background, the overarching scientific objectives of EURO-BASIN were to understand and predict the population structure and dynamics of key plankton and fish species of the North Atlantic and shelf seas, and assess the impacts of climate variability on North Atlantic marine ecosystems and their goods and services.

In order to achieve these objectives EURO-BASIN had the following goals.

1) To resolve the influence of climate variability and change, for example changes in temperature, stratification, transport and acidification, on the seasonal cycle of primary productivity, trophic interactions, and fluxes of carbon to the benthos and the deep ocean.

2) To identify how life history strategies and vital rates and limits of key ecosystem and biogeochemical players contribute to observed population dynamics, community structure, and biogeography?

3) To assess how the removal of exploited species influences marine ecosystems and sequestration of carbon?

4) To improve the science basis for ecosystem based management targets outlined in the EC Common Fisheries Policy (CFP), the Marine Strategy Framework Directive (MSFD), the European Strategy for Marine and Maritime Research (COM(2008)534) and the Integrated Maritime Policy for the European Union (COM(2007)575).

3.0 Highlights from the EURO-BASIN Scientific and Technical Objectives

The major issue facing resource managers dealing with the renewable resources of the North Atlantic in the light of climate change is developing the understanding, management tools and impetus to sustainably manage the ecosystems providing these resources. To this end

EURO-BASIN was focused on the furthering our ability to understand and manage the fisheries resources of the North Atlantic as well as the benefits stemming from the North Atlantic Biological Carbon Pump. This summary is structured around the key outcomes from EURO-BASIN that buttress our ability to manage this system and the advances in process understanding, which has and will strengthen our ability to manage these systems. The primary focus of this summary is to highlight contributions furthering and fostering our ability to develop ecosystem based management strategies for the ecosystems of the North Atlantic. EURO-BASIN has made significant advances in process understanding across a broad spectrum of marine science, however not all will be presented in this summary. For further details on specific activities we refer the reader to the Deliverables of the project.

3.1 EURO-BASIN: Advancing Ecosystem-Based Management of the North Atlantic

Marine ecosystems are under pressure from two fundamental forces: on the one hand global environmental change is directly and indirectly affecting the distribution and productivity of marine species, with consequences for the availability of fish resources and carbon sequestration. On the other hand economic globalization is affecting the decisions that North Atlantic societies make in relation to the goods and services we obtain from the marine environment. Overfishing combined with environmental stressors have resulted in changes in fish communities, the quality of marine ecosystems and their ability to provide services of both economic and environmental importance to mankind. The interplay between these drivers, economic sustainability and profitability and the desire to maintain a healthy marine ecosystem (the later in the EU defined partially by the Marine Strategy Framework Directive and its focus on environmental quality) ultimately determine environmental quality and the ability of the systems to provide services. Ideally the impacts of exploitation and maintenance of environmental quality should be governed by an ecosystem based management strategy, which balances these goals.

Notably in order to bring more attention to the need for an ecosystem based management strategy, EURO-BASIN examined the status of the management of the fisheries resources of the North Atlantic based on their present and potential economic production. Furthermore, EURO-BASIN provided an economic evaluation of the Biological Carbon Pump in the North Atlantic under present and future conditions. This evaluation strategy provides an economic stimulus for supporting the implementation of an ecosystem based management strategy in the North Atlantic. Furthermore EURO-BASIN examined the present status and potential future evolution of ecosystems of the North Atlantic under climate change based on the MSFD descriptors D1 Biodiversity, and D4 Food webs. Thereby, highlighting the environmental consequences of management choices and climate change on ecosystem quality.

3.1.1. Economic impetus for Ecosystem based Management: The economic loss due to sub-optimal fisheries management in the North Atlantic

The overall potential economic rent for the fishing industry in the North Atlantic is estimated to be € 12.85 billion (Fig. 1), which compares with the current estimated profits of only € 0.63 billion. This not a surprise, as it is accepted that world's fisheries are not generally exploited at their biological or their economic optimum. EURO- BASIN scientists explored the conditions under which European fisheries in the North Atlantic achieve its maximum potential economic rent. The analysis involved estimating plausible Maximum Sustainable Yields (MSY) from catch data, taking into account a range of intrinsic growth rates and pristine biomasses. Given that not all species can achieve MSY at the same time due to competition for space and food, the catch data was added for "pelagic fish stocks" and "bottom-dwelling fish stocks". The analysis concluded that to maximize the profits of North Atlantic fisheries (MEY in Fig. ***3.1.1.1***) total fish biomass would have to be rebuilt to 108 Mt (about 2.4 times more than present) by reducing current total fishing effort by 53%. Stochastic simulations were undertaken to estimate the uncertainty associated with the analysis, given a range in the value of the economic loss to North Atlantic fisheries in a range of 2.5 and 32 billion of euro. This provides economic justification for maintaining or restoring fish stocks to above their MSY biomass levels. Our conclusions are consistent with similar global scale studies.

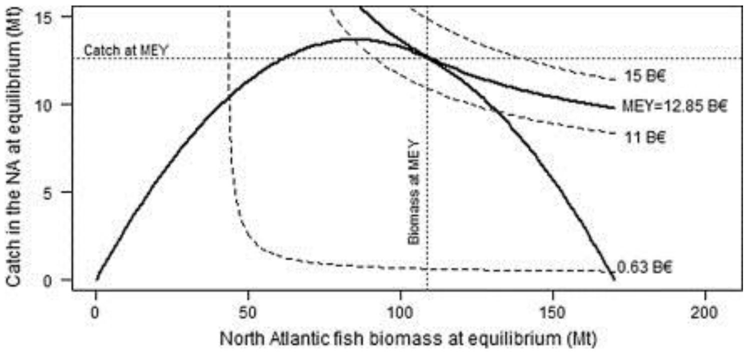


***Figure 1** Graphical estimation of North Atlantic fisheries maximum economic yield. The crossing point between different potential profit trajectories (iso_Ψ) and the biomass-catch equilibrium curve determines the catch and biomass level that will lead to Maximum Economic Yield (MEY). The MEY for North Atlantic fisheries is B€ 12.85. The iso_Ψ = 0.63 B€ corresponds to profits in 2010.*

3.1.2 Estimating changes in the distribution and production of fish stocks in the North Atlantic, based on climate change projections.

In order to conduct the analysis the partners had to predict the distribution and production of key fish stocks based on climate projections. Currently, this ability relies on dynamic bio-climate models (DBEM), which describe habitat preferences for each species and combines future habitat predictions with population models that incorporate environmental and ecosystem production changes in response to climate change. The novelty that EURO-BASIN wanted to add to this research involved the incorporation of competitive interactions between species in the projections, in addition to habitat preferences and ecosystem changes. The first analysis included an assessment of how important are trophic interactions in determining distribution and production changes. The results indicated these are significant. For example, Fig.3.1.2.1 shows that for a specific "ocean cell" (0.5°x0.5°) the inclusion of competition (SS-DBEM) constrained the biomass that the ocean cell could host compared to the model without competition (NSI-DBEM).

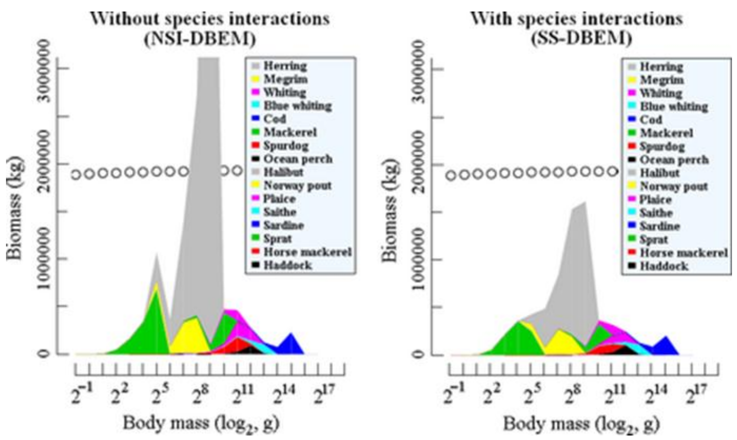


Figure 2 Species biomass by body mass class supported in a single coastal cell (30′ × 30′), used as an example. Open circles represent the biomass that can be supported in this cell using only the size-spectrum component of the model

One of the expected consequences of climate change in the North Atlantic is the reduction of sea ice, warming of sea water, and as a result the expansion of species distributions towards the North Pole. Comparing the distributional shifts of the community (all, bottom-dwellers, pelagic species) between models with or without competition over the period 1970-2010 demonstrated that the former predicted latitudinal shifts up to 40% smaller than the latter (Table 1). Latitudinal shifts over the period of study ranged between 1.2-1.8 km/year, consistent with observations.

Table 1 Average distributional shift of fish species in the North Atlantic between 1970 and 2004 based on two different ecosystem models (Geophysical Fluid Dynamic Laboratory Earth System Model, GFDL; and European Regional Seas Ecosystem Model, ERSEM). Figures in brackets indicate the reduction in estimated migration by using the SS-DBEM model, which incorporates not just habitat preferences per species but also ecological interaction between species.

	Latitudinal shift in species distribution (km/decade)		
	All species	***Bottom-dwellers***	***Pelagic species***
GFDL input model	13.7 (17.9%)	12.6 (10.6%)	18.4 (29.2%)
ERSEM input model	15.7 (13.3%)	15.3 (-0.7%)	16.9 (40.1%)

Having developed the techniques to a satisfactory level EURO-BASIN could use the models to project relative changes of potential catches for 26 commercial fish species in the North Atlantic at yearly temporal resolution (from 1996 to 2060) and 0.5 x 0.5 spatial resolution.

In order to explore and understand the tension between these forces we constructed a bio-economic model including 19 fish stocks, 11 fishing systems, 4 aquaculture systems, 12 fish commodities, 11 geographical areas, 22 political nodes, 23 trade systems and 67 markets. The important concept in this modeling approach is that of “network equilibrium”. Under this principle the volumes and prices on nodes, the flows between nodes on links and the quantified relationships between prices and flows (e.g. cost and price functions) need to be equilibrated. This equilibrium is defined as a set of values for prices and flows such that, locally, basic economic relationships (for example, the law of supply and demand, or production constraints) are satisfied.

The model was fed with information on expected biomass, distribution and potential catch for the species considered between 2010 and 2040. To obtain this information we used outputs from WP6, which provided biochemical projections in the North Atlantic ecosystem according to three greenhouse gas emission scenarios. On the governance level, scenarios were defined (Baseline, Fortress, Free trade, Global Commons) which linked governance objectives and globalization implications.

The results provide a number of outputs to assess in comparing global futures. An example of output is provided in Fig.3.1.2.2, where trends in a particular variable (total fish biomass) are presented for 2010-2040, divided by ICES fishing areas (I-XIV).

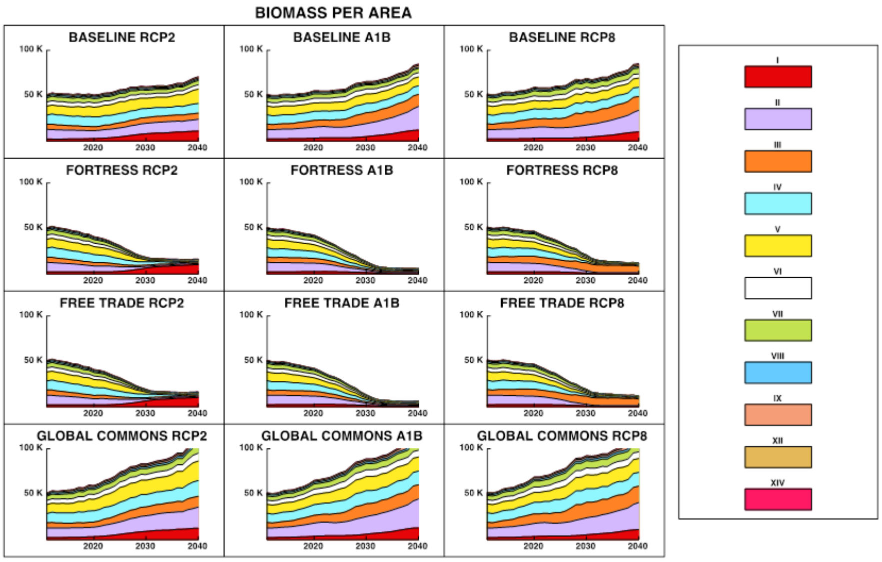


Figure 3 Time series of estimated trends in total fish biomass in the North Atlantic, broken down into ICES sub-areas, for three emission and four socio-economic scenarios. Values indicate no changes (1), >double (2) or < half (0.5) by 2040, referenced to the present.

The trends are driven by a combination of 3 greenhouse gas emission pathways and corresponding ecosystem chance (vertical) and 4 governance scenarios (horizontal), thus resulting in a 4x3 matrix with differential outcomes in terms of resource sustainability. The main conclusions are:

1. The system is more sensitive to governance changes than to climatic change, at least at the horizon of 2040.

2. Climate changes tend to result in a latitudinal drift of populations towards northern parts of the basin.

3. An important driver of change for the future of the North Atlantic and the European fishing fleet appears to be the interplay between wild fisheries and aquaculture.

4. That restrictions to international trade are not as important as are relaxations of protection means such as total allowable catch limits.

The scenarios demonstrate that the viability and profit of fisheries industries is highly volatile across scenarios. The method, the modeling choices and the results provided contribute to discussions on the implementation of a future European policy combining environmental and socio-economic considerations, and highlight the importance of involving all stakeholders in defining these policy changes.

3.1.3 Valuing the Biological Carbon Pump.

Becoming more topical in our understanding of the economic services provide by the oceans is their ability to sequester greenhouse gas materials. Anthropogenic drivers, particularly fossil-fuel combustion, deforestation and land-use change drive the recent increase in atmospheric concentrations of CO_2 (IPCC AR5). The global biosphere buffers these increases by absorbing emissions through biological processes. The ocean is a major repository of anthropogenic carbon, both inorganically and organically through photosynthetic processes. A fraction of this organic carbon is further transferred to the deep ocean and sequestered for thousands of years. The importance of the ocean biological pump is such that it is estimated that without it the present day atmospheric concentrations of CO2 would be 50% higher (Parekh *et al.*, 2006). Model projections indicate that the rate of carbon uptake by the oceans will decrease over the 21st century, largely as a result of saturation. Little effort has been devoted to understanding the economic cost of such reduction. The ocean sink is a regulatory ecosystem service linked to the provision of an equitable climate. This service has an economic significance, which is often poorly represented in the development of policy and management narratives. Monetary and non-monetary valuation can facilitate this narrative by allowing a comparison with other natural service provision, or with mitigation and adaptation interventions.

We estimated changes in C fluxes in the NA based on two biochemical models: ERSEM and MEDUSA (Fig.*4*). Simulations were forced with two different IPCC AR5 Representative Concentration Pathways of greenhouse gas emissions, RCP 2.6 and RCP 8.5.

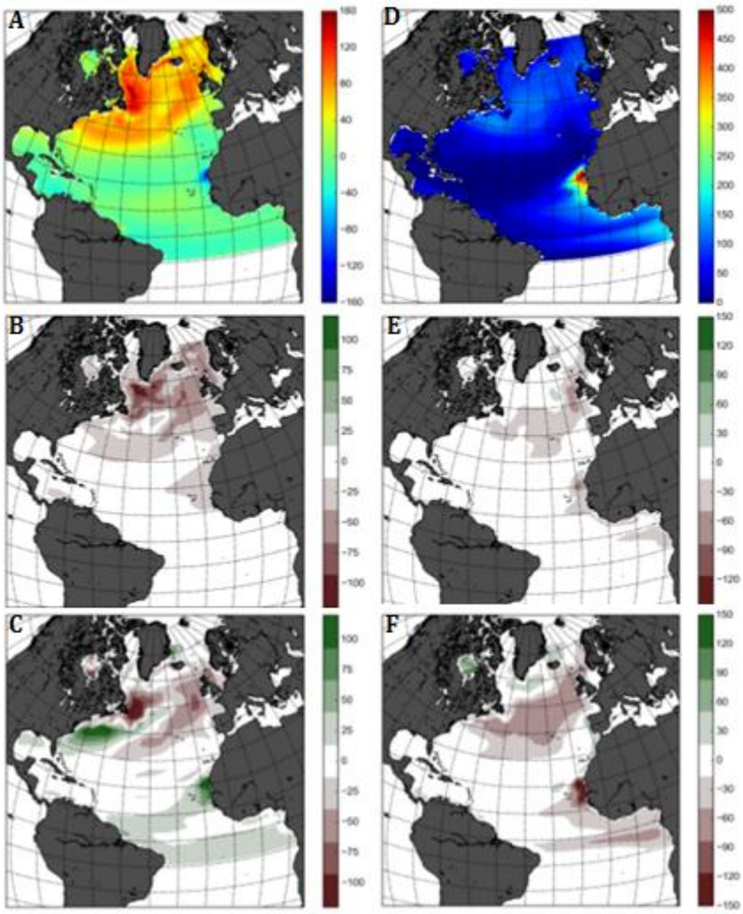


Figure 4 Carbon fluxes in the North Atlantic, according to MEDUSA (1°x1° resolution). (A) Present Surface fluxes (average 1990-2009), and (B, C) changes in 2090-2099 referenced to present, according to IPCC RCP 2.6 and RCP 8.5 emissions scenarios (in %). (D) Fluxes at 500m deep (1990-2009), and (E, F) changes in 2090-2099 referenced to present, according to IPCC RCP 2.6 and RCP 8.5 emissions scenarios (in %). Positive values indicate positive C uptake to the ocean (A, D) and increases in uptake (B, C, E, F), respectively.

Monetary value of carbon export at 500m was greater in the low emission scenario than the high emission scenario (Fig. *3.1.3.1.*). The decadal differences in the value are 5.8% (2010s), 14.1% (2020s), 27.7% (2050s) and 78.8% (2090s). Furthermore, the ERSEM sensitivity analysis showed that it was possible to set parameter values for a fish-dependent mortality term a proxy for differential fish biomass, which gave stable model behavior. The ERSEM sensitivity analysis showed that the POC at the sea floor was reduced by up to 2-3% and inter-annual variability was increased with the introduction of plankton natural mortality. Looking at fish biomass estimates, an increase of POC sinking from fish due to fish natural mortality could be less than 1% of fish biomass. Modeled fish catches represent an insignificant percentage of carbon in relation to POC sinking in the NA, but this removed fish cannot be considered permanently sequestered for valuation purposes. However, fish could play an important role through fecal pellet production, which is not considered in these models. This preliminary investigation, using a very simple forcing based on data for one fish type, indicates that top-down forcing may affect model estimates of carbon cycling.

3.1.4 Consequences of climate change in the North Atlantic based on the changes in Descriptors from Marine Strategy Framework Directive (MSFD)

The North Atlantic Basin scale climate forced modelling work undertaken in EURO-BASIN can be related to two descriptors D1 Biodiversity, and D4 Food Webs. It should be noted that this pair of descriptors are closely linked and are often grouped together for the purpose of implementation. D1 requires that Biological Diversity is maintained and that the quality and occurrence of habitats and the distribution and abundance of species are in line with prevailing physiographic, geographic and climatic conditions. The Biodiversity Descriptor D1 is characterised by it broad biological and geographical scope. This requires a multi species and multi habitat approach coupled with a robust assessment of human pressures (and impacts) on these components in order to achieve GES. D1 is subdivided into a number of topics areas as follows; fish, mammals, birds, plus pelagic and benthic habitats. The work reported here can be specifically related to pelagic habitats and fish.

For pelagic habitats, the targets and indicators all focus on plankton, which plays a crucial role in the pelagic food-web and the whole marine ecosystem. Changes in plankton are driven by climate are also affected by human pressures, particularly eutrophication and fishing. The targets and indicators are designed to identify changes in plankton caused by human pressures, and require that the distribution, structure, condition and abundance of the plankton community 'are not significantly adversely influenced by anthropogenic drivers'. For reference maps of the annual mean primary production for the present day and mid-century are shown in Fig. 5. Time-series analysis of the model primary production provides a decomposition of the harmonic components and extracts the linear trends. In the northern part of the basin the variably in PP is dominated by the 12 month harmonic (Fig. 6) with a significant contribution from the 6 month harmonic (Fig. 7). The linear trends are mostly decreasing (with some exceptions) across the region in the present day. A decreasing trend in primary production is very noticeable to the west of the British Isles by mid-century. This is marked by a decrease in the influence of the 12 harmonic and an increasing tin the 6 month harmonic (Fig. 6 and Fig. 7), which may be attributable to changes in seasonal stratification. The sub-tropical gyres and equatorial regions show large areas of increasing primary production in both time slices (Fig. 5). While these regions have a significant signal, there is also considerable influence of modes of variability longer than 5 years. The changes in the harmonic composition of the seasonal cycles of PP are indicative of changes bulk phytoplankton phenology, i.e. the timing and magnitude of plankton bloom and the length of the growing season.

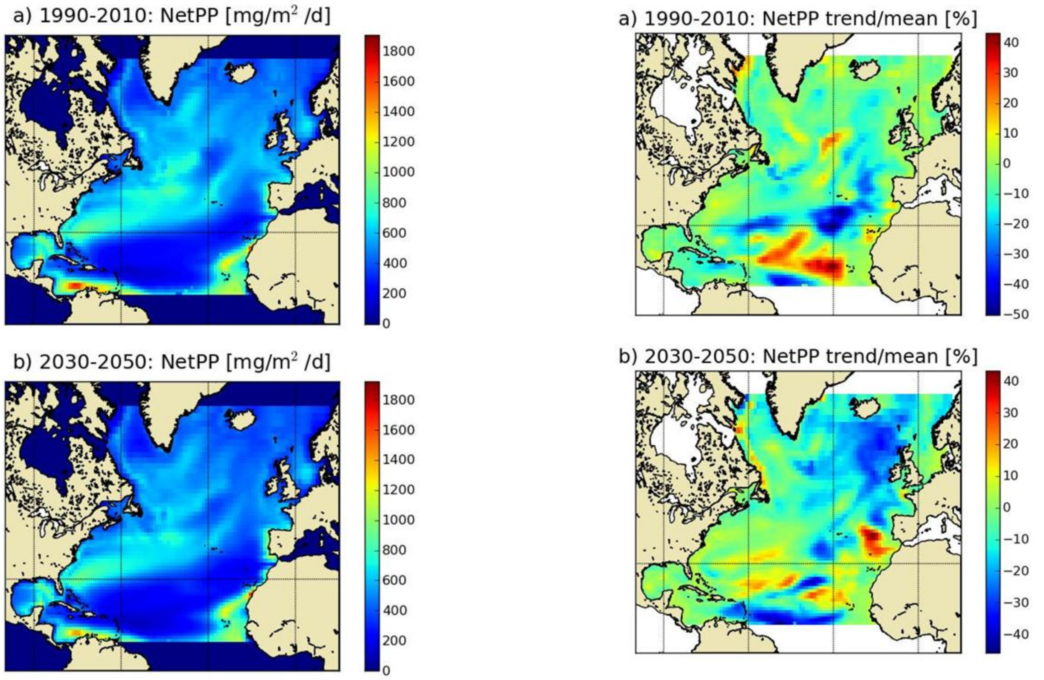


Figure 5 Net primary production from the ERSEM-NEMO climate forced model run. Left column shows the annual mean net primary production depth integrated over the water column for the periods 1990-2010 (top) and 2030-2050 (bottom). Right column shows the % trend *in annual mean net primary production depth integrated over the water column for the periods 1990-2010 (top) and 2030-2050 (bottom).*

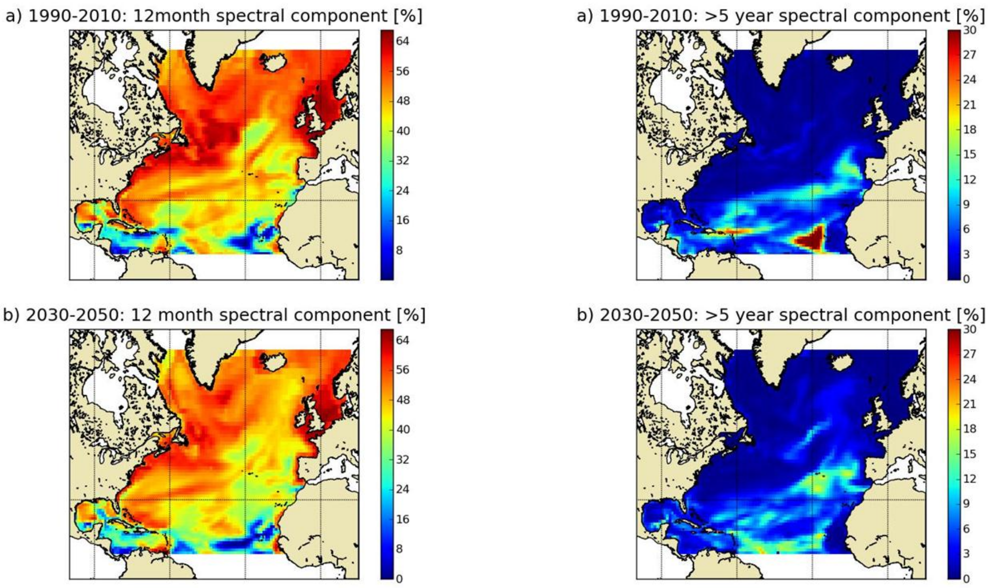


Figure 6 Net primary production from the ERSEM-NEMO climate forced model run. Left column shows the % of the total signal attributed to the 12 month spectral component for the periods 1990-2010 (top) and 2030-2050 (bottom). Right column shows the % of the total signal attributed to the >5yr spectral component for the periods 1990-2010 (top) and 2030-2050 (bottom).

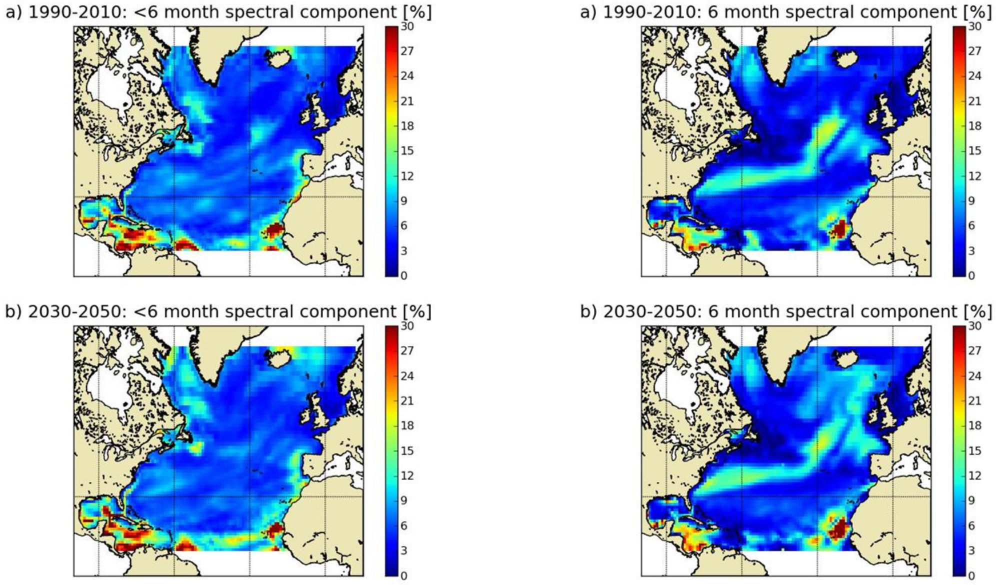


Figure 7 Net primary production from the ERSEM-NEMO climate forced model run. Left column shows the % of the total signal attributed to spectral components of < 6 months for the periods 1990-2010 (top) and 2030-2050 (bottom). Right column shows the % of the total signal attributed to the 6 month spectral component for the periods 1990-2010 (top) and 2030-2050 (bottom).

Figure 8 shows a phenological based Biogeography of the North Atlantic, achieved by applying a Self-Organising Map (SOM) to the results of the harmonic analysis. This illustrates projected changes in the phytoplankton phenology as a present day and a mid-century climatology for each biome, thus illustrating the changes in phenology over the next decades. These changes will impact the distributions of phytoplankton along with its community structure and condition, all of which are indicators for assess pelagic habitat. Consequently the future assessment of GES for pelagic habitats will need to be able take account of such changes if we are to correctly maintain it in the future.

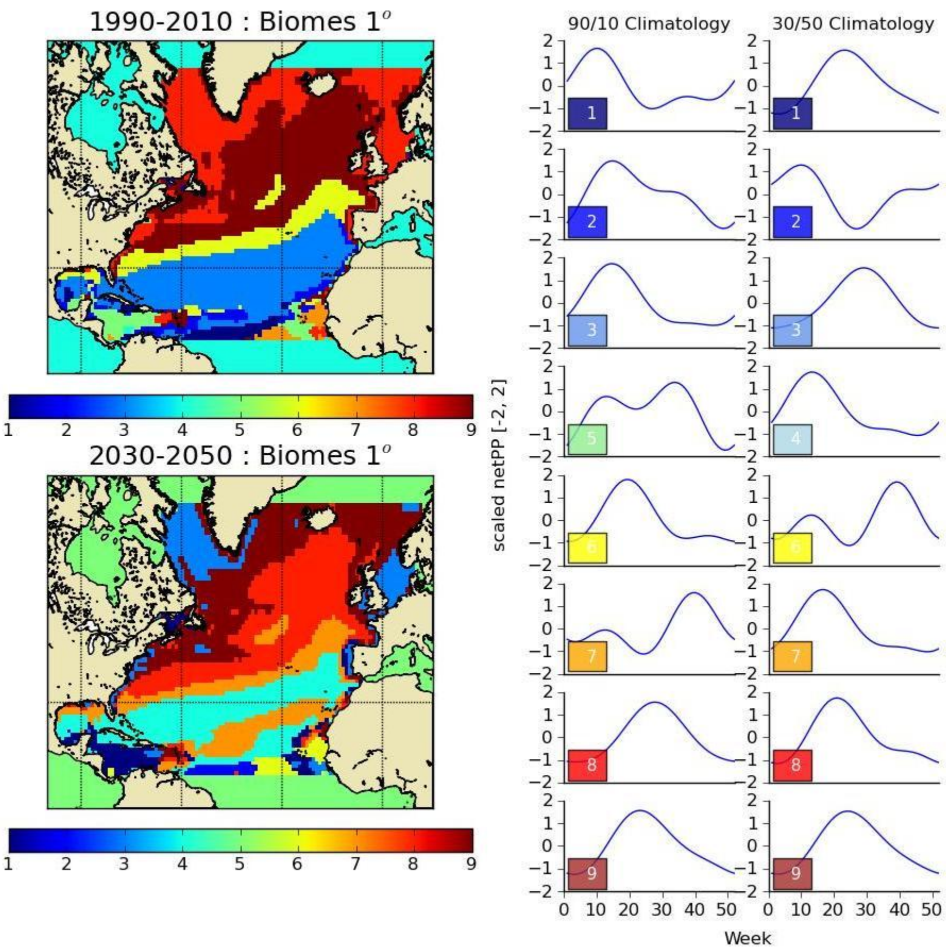


Figure 8 Phenological Biogeography of the N Atlantic: Upper left panel present day, lower left panel 2030-2050. Right hand panel show the climatological primary production signal for each biome.

In terms of fish biodiversity indicators, the requirement is that at the scale of the MSFD sub-regions distribution of sensitive fish species is not significantly impacted by human activities and that the geographic and depth distribution of sensitive fish should meet individual indicator targets in a statistically significant proportion of species monitored. The biogeographic analysis of fish habitat reported in D6.8 provides information on the impact of climate change on fish habitats. A classification has been developed based on environmental indicators relevant to the describing the distributions of fish habitats and hence by inference fish populations, (see D6.8 for details). The changes to the distribution of these habitats under the impact of climate change (RCP8.6 scenario; Fig. 9) indicates that we can expect significant changes in the biogeography of the N Atlantic Ocean over the next century when compared with today.

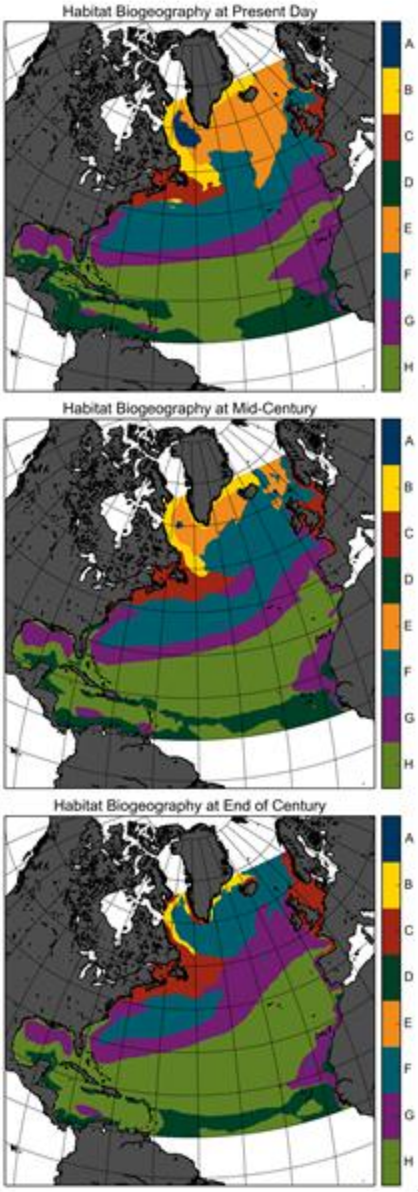


Figure 9 Evolution of Ecosystem Function Regimes under Future Conditions – Top: Present Day; Centre: Mid-Century; Bottom: End of Century. The 8 emerging classes of the habitat classification are described by the following features: Class A: This regime situated in the centre of the Davis Strait subject to strong overturning is characterised by mixed-layer depth that substantially higher than anywhere else in the North Atlantic. Nitrogen supply is high fuelling a strong bloom that occurs in summer and waters are cold and rich of oxygen. Class B: Along the coast of Greenland and North East Canada waters are even colder and richer in oxygen. Nutrient levels and oxygen are somewhat lower than in class, leading to lower but still substantial levels of primary production. The regime is subject to large ranges of pH and salinity. Class C: The shallow coastal waters of Northern Europe and the mid-latitudes of the North- American East coast form a regime of a much longer growing season with intermediate levels of production. The range of temperature in the annual cycle is huge compared to other regimes, also the other indicators show substantial variation. Surface waters are comparatively fresh. Class D: The tropical water of class D extending from the Caribbean over the Equatorial Current to the Mauritanian upwelling show modestly high levels of production all year round. Temperatures are high and show only little variability as does pH. The mixed layer depth is shallow in this stratified regime leading to low levels of nitrogen and oxygen. Class E: The deep and cold oceanic cold waters of the sub-arctic region show a strong seasonal cycle with a marked spring bloom. Waters are comparatively strongly mixed with a high supply of surface nitrogen and oxygen and relatively high changes of pH throughout the year. Class F: The oceanic mid-latitude regime around the Gulf Stream shows a similar primary production pattern with the bloom occurring a little earlier. The mixed layer depth is still substantial, nutrient and oxygen levels are little lower. Class G: The intermediate regime between the productive mid-latitude area and the oligotrophic gyre is comparatively warm and stratified leading to even lower nitrogen and oxygen conditions. The seasonal cycle is still strong under a large range of temperatures, while the ranges of salinity and pH are much lower. Class H: The warm, saline waters of the oligotrophic gyre are characterised by strong stratification, low nitrogen and oxygen availability and leading to low productivity with few variations during the year.

At mid-century the overturning regime (A) in the Davis Strait has disappeared, the sub-polar regime (E) has reduced to the waters around Southern Greenland and the coastal sub-arctic regime (B) is restricted to a narrower band attached to the coastline with respect to present day conditions. The continental mid-latitude biome (F) stays in place until the middle of the century, while the tropical class extends in the oceanic part and reduces in the Caribbean part. The intermediate regime between oligotrophic gyre and the mid-latitudes extend towards the Gulf of Biscay and the French Atlantic coast, while the waters off the Western Coast of the peninsula turn oligotrophic.

Towards the end of the century also the sub-polar regime has essentially vanished, while the coastal sub-arctic regime is further restricted towards the coast. The continental mid-latitude domain now extends northward by about half a degree until the end of the century. The tropical regime does not show any significant changes with respect to the mid-century state.

The oceanic mid-latitude regime extends over the hole sub-arctic region and is itself replaced by the an extension of the intermediate class in larger sections of the Eastern part of the Gulf Stream, that splits the former mid-latitude regime into a Western part south of the Gulf Stream and a Northern part that is now sub-arctic. The oceanic gyre continuous its northward extension around the South Western European continental shelf reaching the Gulf of Biscay, leaving only a narrow strip of coastal water in intermediate conditions around the Iberian Peninsula.

The consequences for the distributions of fish in the North Atlantic could be highly significant. By the middle of this century we would expect to see significant northward movement of warm water biomes. By 2100 we might expect the current cold water biomes of the north Atlantic to have almost completely disappeared, suggesting that fish species found in the N Atlantic may be very different in the future. This in turn may have significant consequences for the biodiversity of bird and mammals. This presents a significant challenge for policy and management to define and implement GES. Under climate change use of fixed geographical baselines is problematic and future definitions of GES will have to be flexible enough to take account of biogeographic change.

The food web descriptor covers all elements of marine food webs, to the extent that they are known, occur at normal abundance and diversity and levels capable of ensuring the long-term abundance of those species and the retention of their full reproductive capacity. Emphasis is placed on the functional aspects of marine food webs (particularly energy transfer) and levels of productivity. There is not currently enough known about energy transfer between trophic levels and species interaction to meaningfully cover these within the targets for this Descriptor. In the medium term a pragmatic approach is proposed, which focuses on the abundance, distribution and productivity of key species and trophic groups within the food web, hence there is significant overlap with the biodiversity descriptor. Ecosystem models provide a tool though which we can explore the consequences of changes in energy transfer on foodwebs. Signal-effect amplification analysis allows us to illustrate the ecosystem response to climate change at different levels of ecosystem function. Three pairs of cause (or signal) and effect (or response) indicators are analysed:

- Sea Surface Temperature –> Net Primary Production illustrating **Metabolic Amplification** with the underlying hypothesis that in synergistic change conditions the temperature effect on metabolic processes dominates stimulating the system to increased (decreased) production in a warmer (colder) ambient.

- Net Primary Production -> Secondary Production illustrating **Trophic Amplification** where in synergistic conditions the system is bottom-up controlled with primary production fuelling secondary production while in antagonistic conditions the system is top down controlled with secondary production reducing the autotrophs and therefore their production.

- Net Primary Production -> Carbon Export illustrating **Amplification of the Biological Pump**.

Figure 10 gives an overview of the three pairs of amplification indicators for mid-century and end of century in form of geographical maps showing the spatial distribution of the categories of response (i.e. various strengths of amplification or attenuation).

For metabolic amplification the bulk of points in both time slices show significant attenuation of variable degree of the temperature increase which is mostly antagonistic (i.e. the metabolic effect of temperature rise is restrained by the effect of increased stratification lowering production). Some occurrences of synergistic response occur in the Canary Current, in the Sargasso Sea, the Gulf of Mexico and along the Newfoundland coast. Trophic Amplification is largely characterised by bottom-up controlled decreases (i.e. reductions in primary production are associated with reductions in secondary production). This is marked by comparable occurrences of attenuation and amplification of up to factor two where causal change is significant. Amplification of the biological pump is dominated by synergistic decrease with a tendency towards amplification except for a patch of synergistically attenuated increase emerging towards the end of the century off West Africa and along the Moroccan coast.

The work suggests based on our model projections that the by the middle of this century large areas of the N Atlantic will show significant antagonistic responses of primary production to SST which exceed the current natural variability, but that with the exception of the region to the west of the British isles and south of Iceland, the trophic and biological response lies within the present day variability. By the end of the century we are seeing significant synergistic responses of both secondary production and carbon export to reductions in primary production; to the north of the sub-tropical gyre with an amplification effect over large part of the domain (i.e. the reduction in the response is larger than the reduction in the signal). This implies that less energy will make is way up the foodwebs toward fish, birds and mammals with potentially major consequences for their biodiversity. It also indicates that ability of the N Atlantic to sequester anthropogenic carbon may be impaired.

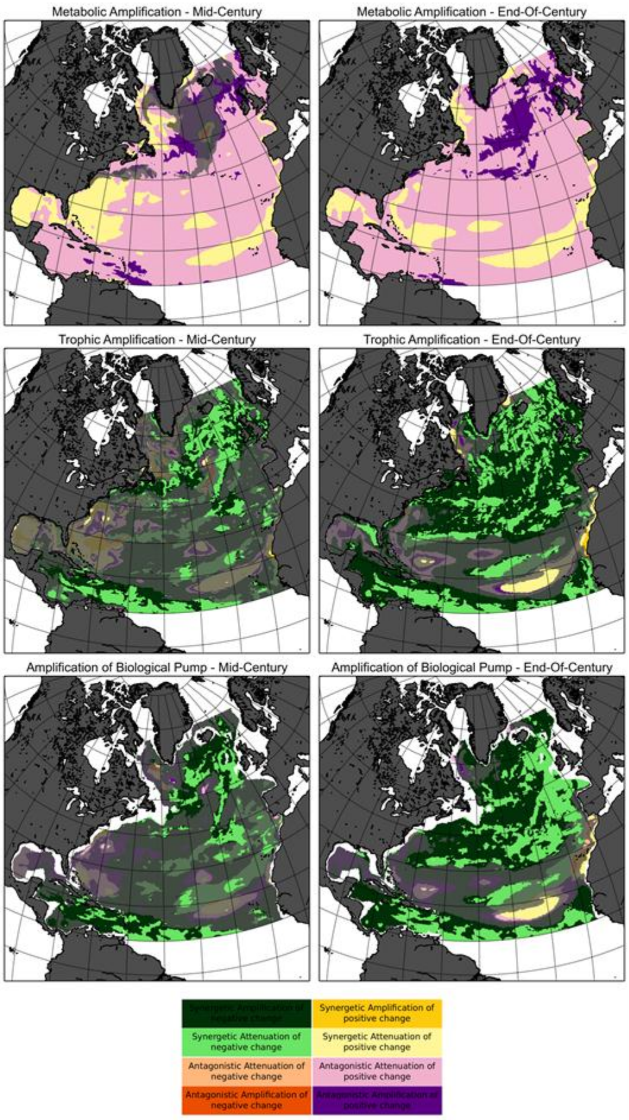


Figure 10 Propagation categories for the hindcast ensemble on the base of the local amplification indices. Top to bottom: Metabolic Amplification, Trophic Amplification, Amplification of the biological Pump. Left: Mid-Century changes, Right: End-Of-Century changes.

Figure 10 Propagation categories for the hindcast ensemble on the base of the local amplification indices. Top to bottom: Metabolic Amplification, Trophic Amplification, Amplification of the biological Pump. Left: Mid-Century changes, Right: End-Of-Century changes.

3.1.5 Regime shifts: Climate Change and management actions.

Statistical analyses performed on outputs of the EURO-BASIN models were used to extract the main modes of variability and to derive integrative indicators of ecosystem change, ecological and key species status. Employing these indicators, future North-Atlantic marine ecosystem regime shifts were explored using scenario projections made by (i) ERSEM-NEMO and MEDUSA-NEMO simulating the NPZD components and physical oceanographic variables, and (ii) SS-DBEM simulating future trajectories of relative fish biomass of key commercial fish species with fishing mortality and competition (species interactions). Principal Component Analysis (PCA) of the modelled indicator outputs provided a means of identifying potential ecosystem regime shifts and relating them to patterns of variability in their indicators. The regime analyses performed revealed 2 clear periods of change, specifically the 2020s and 2040s (Fig. 11) . The results suggest that the changes in the abiotic and lower trophic level dynamics as a result of "business-as-usual" emission scenario (represented by ERSEM) are linked to new states in the North Atlantic fish communities. The major change (>2040) suggests that the shift will strongly benefit species that are adapted to higher temperatures while traditional species such as herring and cod will have difficulties in keeping their population sizes at historical levels. This implies that commercial fisheries operations and management will need to develop adaptive management strategies in order to maintain the biodiversity and economic services provided by North Atlantic ecosystems.

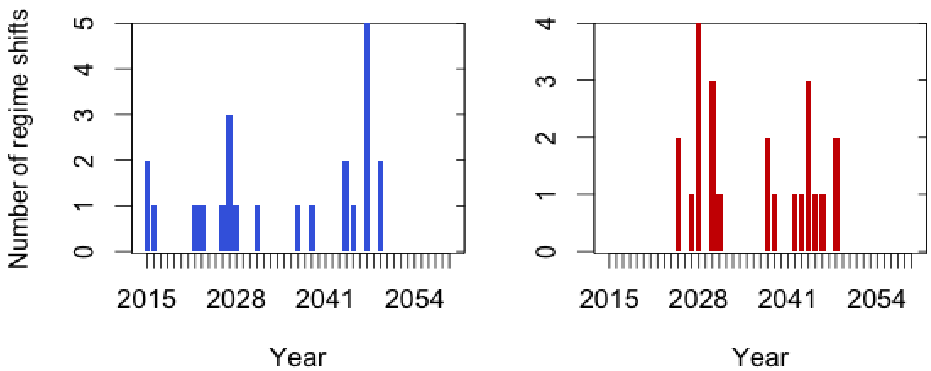


Figure 11 Frequency of ecosystem regime shifts derived by Constrained Clustering of ERSEM-NEMO (blue) and SS-DBEM (red) output variables for all ICES areas.

3.1.7 Consolidating and Integrating long-term observations from databases

Understanding the future requires identifying the key processes influencing the properties of ecosystems in the past. In support of the development of this understanding, the European Framework Program and other European and International Programs call for integration of marine scientific data through several initiatives addressing for example standard vocabularies, data infrastructures, multidisciplinary research, and Networks of Excellence. While scientific research and data management both increase their capacity for integration, the lack of interactions between the two undermines our overall capacity to integrate long-term observations. The first method proposed by EURO-BASIN to integrate scientific data was to archive and publish data in an international database (PANGAEA). This method was successfully implemented with the publication of over 150 datasets. Data publications at PANGAEA are citable digital entities (DOI); acknowledge funding from the European Commission Grant Agreement 264 933 to FP7 project EURO-BASIN; are monitored by the EC research output reporting mechanism (OpenAire); and when appropriate, are linked to related scientific literature by cross-referencing DOIs between data and journal publishers. The second method fostered by EURO-BASIN to integrate scientific data was to publish the successfully completed deliverables in the online peer-reviewed journal Earth System Science Data (ESSD). This method was successfully implemented with the publication of eight papers in a special issue entitled “EURO-BASIN data compilations for an integrated analysis of living resources in the North Atlantic Ocean”.

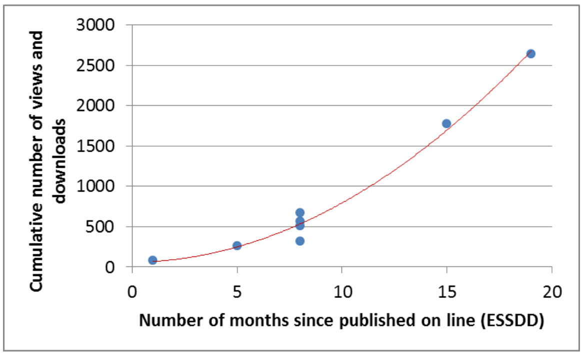


Figure 12 Cumulative number of views and downloads of the eight EURO-BASIN data papers with respect to the number of months since they are published on line, Earth System Science Data Journal.

EURO-BASIN Data were manually curated, archived in a certified relational database (ICSU World Data Centre) and published in Open Access by PANGAEA, Data Publisher for Earth and Environmental Science. EURO-BASIN data publications: (1) are citable and provide credits to the authors; (2) acknowledge funding from the European Commission Grant Agreement 264 933 to FP7 project EURO-BASIN; (3) are monitored by the EC reporting mechanism for Open Access research (OpenAire2020); (4) are assigned DOIs and will thus be included in future research performance metrics; (5) and in the meantime, are manually linked (cross-referenced) to related scientific literature.

3.2 EURO-BASIN: Advances in Process Understanding

Marine ecosystems are complex networks of organisms interacting either directly or indirectly while under the influence of the physical and chemical properties of the medium they inhabit. The interplay between these biological agents and their abiotic environment results in complex non linear responses to individual and multiple stressors, influenced by feedbacks between these organisms as well as their abiotic environment. Critical for furthering our ability for managing these systems is identifying the key processes impacting upon the services provided by these systems and integrating these processes into predictive modeling tools to assess the future state of the system, its services as well as assessing the potential impact of management actions. In this section we highlight some of process understanding developed in the EURO-BASIN program as well as some of the outputs from the modeling activities incorporating this knowledge in the project. These models were central in the development of the management understanding presented in the previous section.

3.2.1 Processes impacting upon the efficiency of the biological pump.

Within the North Atlantic there are significant uncertainties regarding how deep particle flux is mediated with a significant role proposed for bio-mineralizing protists in the large autumn and spring fluxes of material which reaches the deep ocean. The possibility that changes in predation pressure may have seriously impacted deep flux is therefore open. A particular feature of the work in EURO-BASIN was to evaluate the role of zooplankton on deep carbon flux. During the EURO-BASIN cruise Meteor M87 in the Iceland Basin and Norwegian Basin, a study of small and large sinking particles between 50-650 m was performed. The measured pre-bloom fluxes were of similar magnitude to bloom and post-bloom export and largely comprised of small particles (<0.5mm). Our data provides evidence that small particles are being exported to > 500 m (Fig. *3.2.1.*1) via 'detrainment', which occurred during a period of intermittent destabilization of the water column. Our findings contradict the traditional view that pre-spring bloom export is negligible.

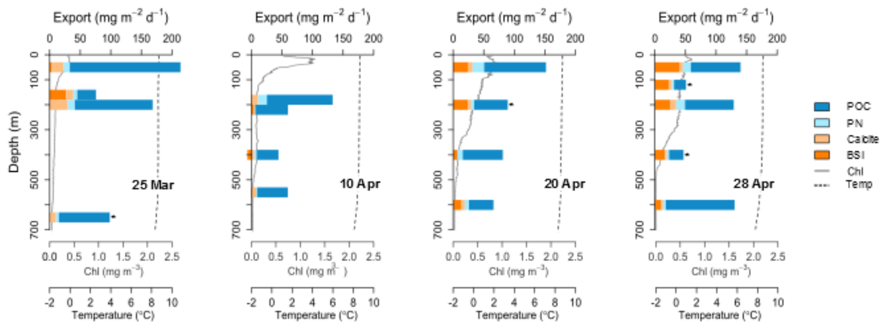


Figure 13 Flux profiles of small sinking particles in the Iceland Basin during Meteor M87. Fluxes of particulate organic carbon (deep blue), particulate nitrogen (light blue), calcite (light orange) and biogenic silica (deep orange) were measured during four visits between 25 Mar – 28 Apr 2012. Average chlorophyll and temperature during each visit based on CTD profiles are shown by grey solid line and black dashed line, respectively.

Complimenting such work on the magnitude and timing of export, research into the influence of zooplankton on the BCP EURO-BASIN examined zooplankton interactions with sinking material. Results from another mesocosm experiment showed that calanoid copepods are typically only able to feed on small suspended particles and will therefore not contribute to degradation of sinking aggregates, but will instead enhance vertical transport by re-packaging their food into fast-sinking fecal pellets. In contrast, harpacticoid copepods and Oncaea spp. are only able to feed on aggregates, and will therefore mainly contribute to degradation of sinking particles (Fig. 14).

As an example of the potential importance of zooplankton in influencing the BCP, results from the Meteor and James Cook EURO-BASIN cruises as well as from Greenland work show fast and large fluctuations in the abundance and community composition of zooplankton, often with a dominance of particle-colonising copepods such that it appears clear that a community dominated by particle-degraders can consume most of the sinking particles before they leave the euphotic layer.

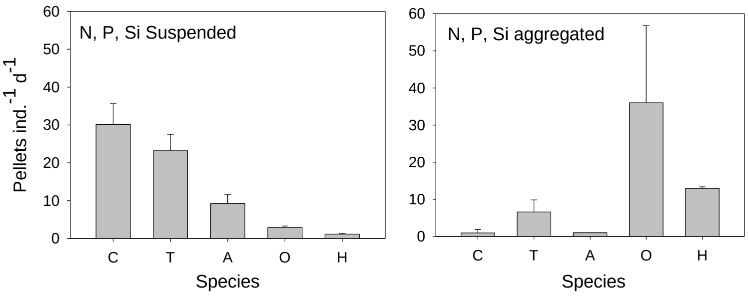


Figure 14 Pellet production of copepods in a diatom dominated mesocosm (enriched with N, P, Si; mean +/- SD).

EURO-BASIN provided new observations of particle aggregation, flux and disintegration were combined with existing data to generate a new flux algorithms suitable for inclusion in large scale numerical models. These were tested in simple one dimensional models and then implemented in large scale models. The performance of these new algorithms was tested via reference validation datasets. (Fig. *3.2.1.*3) This enabled modeling experiments predicting the likely response of the BCP and hence ocean CO^2 storage relative to climate change.

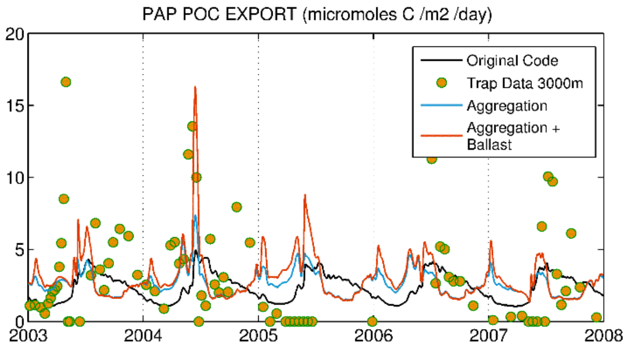


Figure 15 POC export at PAP station. Lines indicate model results and the circles indicate trap data at 3000 m. Black line is the original implementation. Blue line denotes that addition of aggregation rates as a function of mixing in the water column. Red line denotes additional ballasting formulation together with the aggregation formulation.

Figure 16 shows that the export carbon flux at 1000 m has generally increased mostly in the sub polar gyre. This result is rather surprising, as increased grazing pressure on particles, along with decreasing grazing on small phytoplankton, might be expected to favour remineralisation and reduce export towards the deep ocean. This is driven by a large increase of Primary Production in the sub-polar gyre, whereas the sub-tropical gyre is characterized by a decrease (not shown). This behaviour results from the very large increase of small phytoplankton which is not grazed by microzooplankton in the sensitivity run, increase which occurs mostly in the sub polar gyre, at the expense of diatoms (not shown). As small phytoplankton can be grazed only by large zooplankton, even though diatoms are less abundant, large zooplankton increases, mostly in the sub – polar gyre, which explains the resulting increase in export production at 1000 m. Although underlying hypothesis of this sensitivity experience is extreme, as not all the small zooplankton is going to change in small copepod Microsetella, it nevertheless shows that biodiversity modified by climate change can play a major role in the ocean carbon fluxes, and that feedbacks controlling the behaviour of the marine ecosystem can give unexpected results.

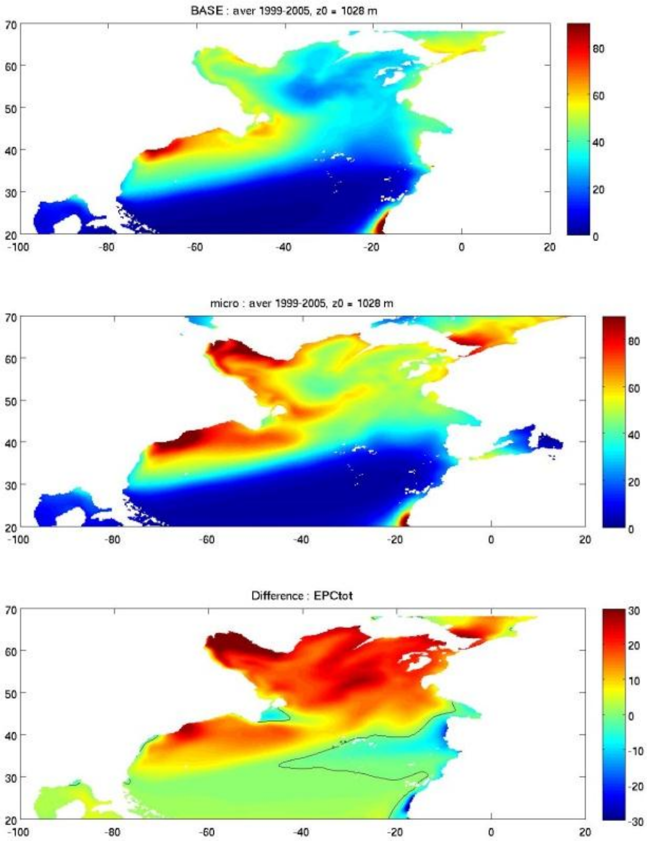


Figure 16 Export production at 1000 m. Upper: standard simulation; middle: Microsetella simulation; bottom = difference.

3.2.2 Resolving and predicting habitats utilized by key biogeochemical and ecosystem species.

Zooplankton

Reliable future scenarios of marine ecosystems, their key species and their ability to sequester carbon and support exploitable resources such as fish stocks, are dependent upon our ability to model the evolution of the abiotic and biotic habitats which they inhabit. As a precursor to model development, EURO-BASIN performed retrospective analyses and field studies on different scales (e.g. basin, meso and small scale) of key ecological and biogeochemical species and trophic positions in relation to oceanography (e.g. sea temperature, salinity, stratification and advective regime) and seasonality of the systems. In the last decade, the analysis based upon Continuous Plankton Recorder (CPR) survey in the eastern North Atlantic Ocean detected one of the most striking examples of marine poleward migration related to sea warming. We studied the poleward shift of zooplankton species (Calanus finmarchicus, C. glacialis, C. helgolandicus, C. hyperboreus) for which distributional changes have been recorded in the North Atlantic Ocean, and to assess how much of this shift was triggered by sea warming, using Generalized Additive Models (GAMs). To address the objectives, the population gravity centre of observed data were compared with that of a series of simulation experiments: 1) a model using only climate factors (i.e. niche-based model) to simulate species habitat suitability, 2) a model using only temporal and spatial terms to reconstruct the population distribution. Our findings show that only C. finmarchicus had a consistent poleward shift, triggered by sea warming, estimated in 8.1 km per decade in the North Atlantic (16.5 per decade for the Northeast), which is substantially lower than previous works at assemblage level and restricted to the Northeast Atlantic. On the contrary, C. helgolandicus is expanding in all directions, although its northern distribution limit in the North Sea has shifted northward. C. glacialis and C. hyperboreus, which have the geographic centres of populations mainly in the NW Atlantic, showed a slight southward shift, probably responding to cool water penetrating southward in the Labrador Current. Our approach, supported by high model accuracy, shows its power in detecting species latitudinal shifts, and identifying its causes, since the trend of occurrence observed data is influenced by the sampling frequency, which has progressively concentrated to lower latitudes with time

Using the aforementioned study as a basis, EURO-BASIN developed statistical-based habitat models for 14 copepod species in the North Atlantic Ocean, to evaluate the impacts of future climate change in community structure, diversity, distribution, and phenology of zooplankton community. Our projections for the end of the century indicated that copepod community is expected to respond substantially to climate change: a poleward latitudinal shift of 8.7 km/decade on average for the overall community with an important species range variation (-15 to 18 km/ decade), the species seasonal peak is expected to occur 12-13 days earlier for C. finmarchicus and C. hyperboreus, and important changes in community structure are also expected (high species turnover between 43 and 79% at the south of the Oceanic Polar Front; 4). These changes might lead to alterations of the future North Atlantic pelagic ecosystem (Fig. *3.2.2.1*)These analyses allowed us to understand the environmental envelopes in the past in which maintained the key species and different ecosystem and biochemical services, which the North Atlantic provides. Based on these findings EURO-BASIN developed habitat and process models for monitoring and predicting the future changes in key species and food web biogeography due to prominent ecosystem drivers thereby developing indices of the physical characteristics of key species and food web habitats for assessing the past, present and future states of marine ecosystems and their services.

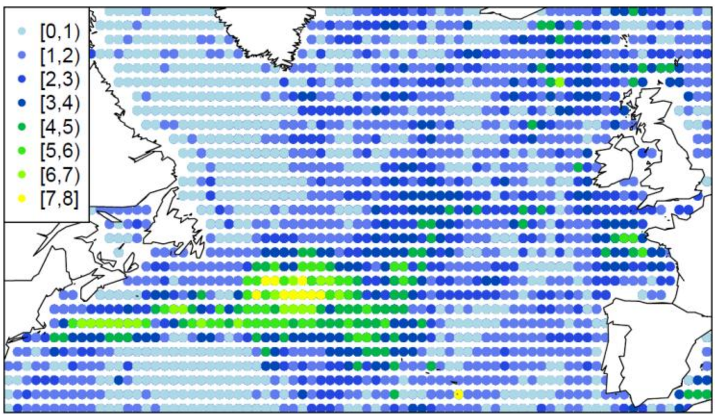


Figure 17 Species turnover (number of zooplankton species that will either locally colonize or extinct) by 2080-2099 under a climate change scenario. This is based on habitat models of 14 zooplankton species

Calanus Spp.

Furthermore EURO-BASIN characterized population genetic structures of keystone species, important for biogeochemical and trophic functioning using novel molecular approaches (temporal sampling in combination with genome scans), as well as to determine their evolutionary responses to climate change.

Two key players in the Arctic marine ecosystem are the Calanoid copepods, *Calanus finmarchicus* and *C. glacialis*. Although morphological very similar these sibling species have different life cycles and play differing roles in the Arctic pelagic marine ecosystem. Considering that the distribution of *C. glacialis* corresponds to Arctic water masses and *C. finmarchicus* to Atlantic water masses the species are frequently used as climate indicators. Consequently, correct identification of the two spp. is essential if we want to understand climate impacted changes on *Calanus* dominated marine ecosystems such as the Arctic. During EURO-BASIN we made a comparison of two different morphological characteristics, one traditional and one novel, used to separate 300 live adult females of *C. glacialis* and *C. finmarchicus* from Disko Bay, western Greenland. The results were verified genetically by molecular makers (both mtDNA and nuclear Fig. *3.2.2.2)*

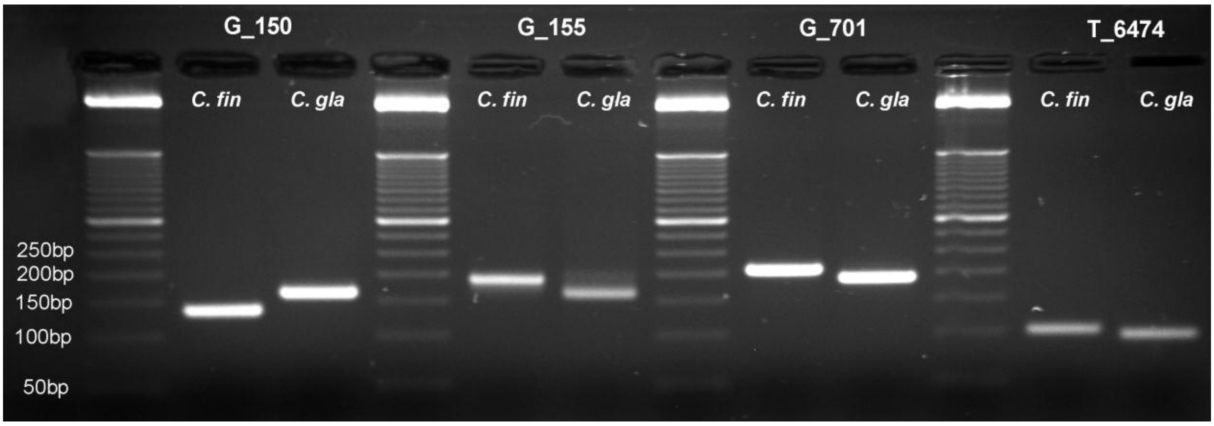


Figure 18 Calanus species identification using a 2.7% agarose gel and 4 InDels markers

Molecular identification confirmed that live females of the two spp. from Greenlandic waters can easily be separated by the red pigmentation of the antenna and somites of *C. glacialis* in contrast to the pale opaque antenna and somites of *C. finmarchicus Fig. 19* (Nielsen et al 2014*)*.

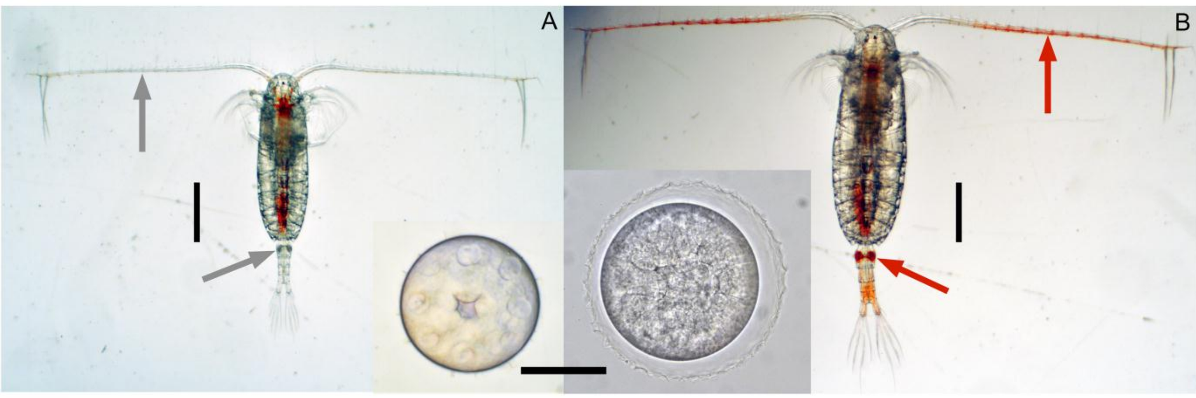


Figure 19 A key result of EURO-BASIN was a genetic validation of morphological criteria applied for years to separate the closely related Calanus spp. C. finmarchicus and C. glacialis. A) *C. finmarchicus* and B*) C. glacialis*. The black scale 1 mm and 0.1 mm for female eggs, respectively. This makes it possible to identify live females and much easier to conduct experiments with females of the two co-occuring species.

Top Predators

Considered together and from a north Atlantic basin-wide perspective, the biotic and abiotic factors affecting abundance and spatial distributions of large highly migratory predators and their prey species are poorly known and a major source of uncertainty in management. EURO-BASIN developed and applied new modeling tools that improved our understanding of factors influencing the distributions of these key species. Modern end-to-end biogeochemical-based trophic were to simulate the spatial dynamics of fish populations in interaction with their environment while new IBM based models that account for adaptive foraging behavior of predators to spatial variations in prey abundance and lifecycle closure were applied to understand the spatial dynamics, habitat utilization and trophic controls of predators on prey populations throughout the north Atlantic.

As an example, for North Atlantic albacore, the potential impact of climate change was simulated with the SEAPODYM model and environmental forcing variables provided by the Earth Climate model IPSL-CM4 under the IPCC A2 scenario (close to the AR5- RCP8.5 scenario). According to this model, after the mid 2060s, the conditions defining the suitability and extension of the albacore spawning ground, particularly ocean productivity and temperature, become more favorable north of 30°N while decreasing more rapidly in tropical waters, leading to a decrease in abundance of the population which is predicted to reach its lowest level (0.4 Mt) in 2100. At that time immature and mature albacore are predicted to have shifted to the north of the basin (Fig. 20). Using the same model, changes in habitat suitability for Blue fin tuna were predicted, accounting for temperature effects as well as prey availability (Fig. 20). In tropical areas a deterioration of habitat quality is predicted with an improvement in northern areas (e.g. around Iceland). By 2050, the total area in the western Atlantic suitable for bluefin tuna feeding and growth is predicted to have been reduced by 80% in comparison to 1950.

Generally the models are becoming increasingly able to use process knowledge (e. g., in relation to migration behaviour, growth and mortality rates) to estimate how spatial distributions of fish and the locations of their trophic impacts will change under scenarios of climate change and exploitation. The trophic impacts of the fish species considered here (albacore, bluefin tuna, mackerel, herring, blue whiting) differed by several fold, with impacts being greatest for the smallest species which have the highest biomasses. At present biomass levels, the cascading effects to low trophic levels due to predation by the small zooplanktivore species are larger than those due to predation by the tunas because of damped trophic effects progressively farther down food webs. This result is not likely to change under climate change scenarios.

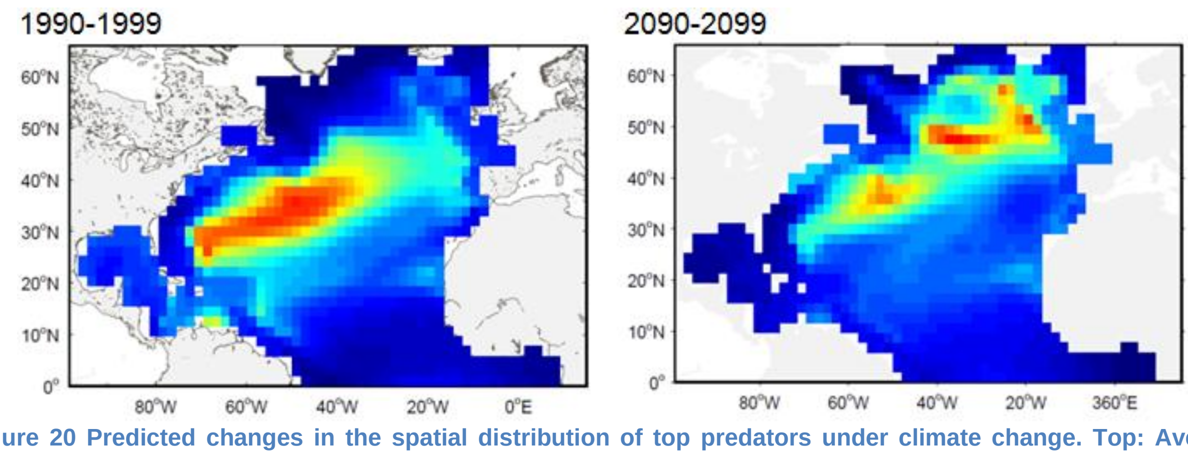


Figure 20 Predicted changes in the spatial distribution of top predators under climate change. Top: Average distribution of young immature albacore tuna (3 months to 4.5 yrs) in 1990-99 and 2090-99 without fishing. Bottom: Suitability of bluefin tuna feeding habitats in 2000 and 2099

3.2.3 Processes influencing biomass production and flow.

Primary production ultimately supports the growth of pelagic species, enters the dissolved organic matter (DOM) pool, or sediments to support the benthos. Sedimentation as the principal mechanism in transporting organic material to the benthic communities, acts either directly as intact phytoplankton cells or as fecal pellets and amorphous detritus. The division between all these fates, and indeed the magnitude of primary production, depends greatly on climatic and metrological conditions. Thus shallowing of the mixing depth coupled with a deepening of the critical depth initiates the spring bloom. While the timing of the spring bloom can be critical for higher trophic levels, especially as linked to match-mismatch of prey and predator. Central to our understanding of the biological carbon pump, which is expected to be of increased importance in a high CO_2 ocean, and the production of higher trophic levels is the role of phytoplankton. In the North Atlantic phytoplankton blooms form an important feature of the annual dynamics of the phytoplankton community and can contribute significantly to carbon export. Recent EURO-BASIN winter and spring observations in the northern North Atlantic have identified significant phytoplankton biomass and primary production in the absence of stratification. Deep convection, frequently occurring in the area has been suggested to sustain low primary production during winter by frequently returning plankton cells to the euphotic zone, a mechanism that has gained support from both model studies and field measurements. Based on these new data and Individual Based phytoplankton modelling inside EURO-BASIN a holistic model of the winter and spring dynamics of phytoplankton biomass and particle flux was developed by the partners. (Fig. 21)

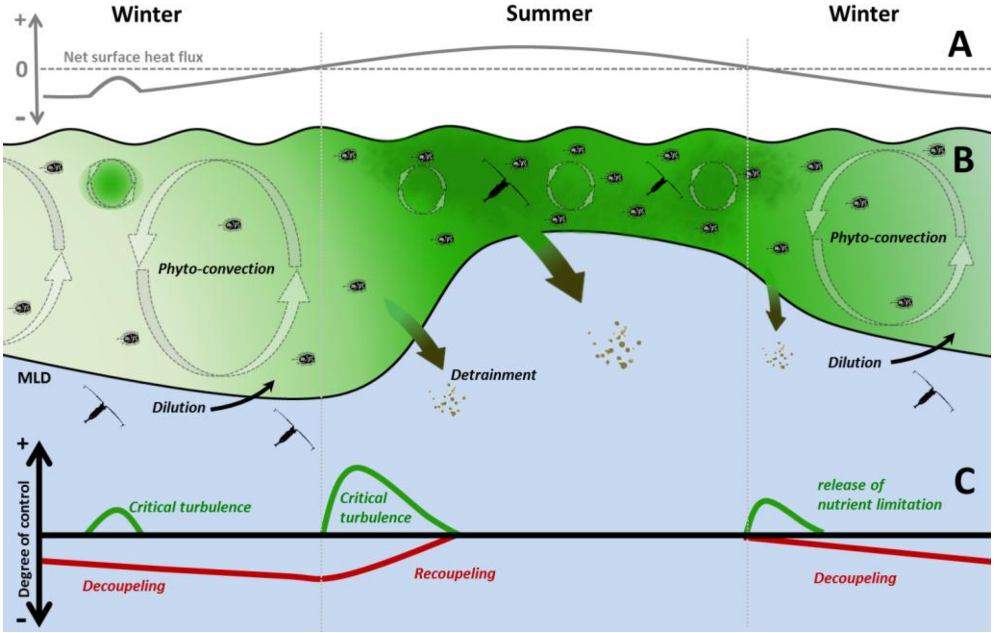


Figure 21 Conceptual model of the physical and biological controls and their impacts on the seasonal cycle of phytoplankton in the open subarctic North Atlantic. (A) Net surface heat flux (B) During winter, mixed layer deepening causes the Dilution of plankton leading to a *Decoupling* of grazers from phytoplankton. During this period phytoplankton are sustained by *Phyto-convection* and in combination with ephemeral periods of *Critical Turbulence* result in positive net growth. In early spring the shutdown of deep convection leads to a light driven increase in surface growth. Subsequently re-stratification results in further enhanced growth conditions i.e. the Critical Depth Model; the *Detrainment* of phytoplankton below the surface mixed layer; and a *Recoupling* with

grazers, resulting in a close coupling of biotic and abiotic controls to mixed layer dynamics as observed during summer. In autumn the *releases of nutrient limitation* due to mixed layer deepening lead to specific growth controlled period before returning to winter conditions. Meso-zooplankton (symbolized by copepods) remain in diapause below the convective mixed layer during winter and migrate into the surface ML in spring. (B) Impact of abiotic (green) and biotic (red) controls on net phytoplankton growth relative to the mixed layer driven dynamics.

Trophodynamic modelling

The traditional description of the marine planktonic food web is shown schematically in Fig *3.2.3.2*. This also represents the basis of model descriptions used for simulations of biogeochemical cycling through to end-to-end models for fisheries. However, the vast bulk of eukaryote (protist) “phytoplankton” and 1/3[rd] of the “microzooplankton” in the photic zone are mixotrophs. Where planktonic mixotrophs are defined as protists capable of photoautotrophy as well as heterotrophy in a single cell. A mathematical model was constructed which explored the consequences

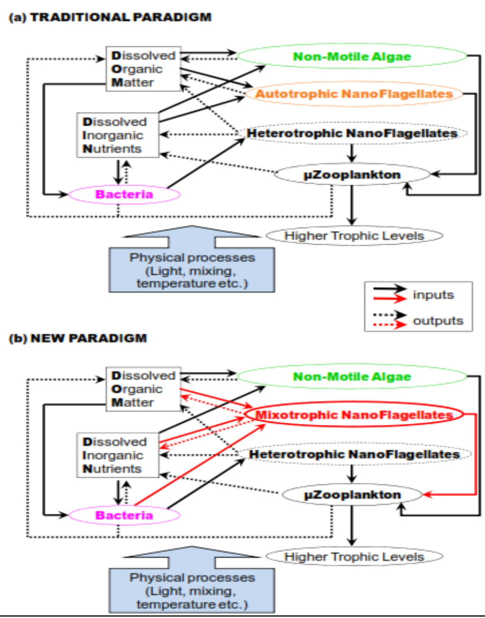


Fig. 1. Schematic representing the two alternate food web structures. In the traditional paradigm (A) the physiology of the photoautotrophic flagellates (ANFs) is similar to that of the nonmotile microalgae (NMA); neither are mixotrophic. Inorganic nutrients for the support of primary production are regenerated via bacteria, heterotrophic nanoflagellates (HNFs) and phagotrophic microzooplankton (µZ). In the new paradigm (B), the ANFs are replaced with mixotrophic nanoflagellates (MNFs), conforming to our present understanding of protist physiology. The MNFs are capable of eating bacteria (red-lined arrow), and hence deriving nutrients for the support of their growth, and of their primary production, directly rather than (for ANFs in panel A) via the activities of HNFs +µZ. Dashed arrows indicate functions contributing to nutrient pools. See also Fig.2. *(image reproduced from Fig.2 in Mitra et al. 2014)*

of modelling interactions excluding mixotrophy, versus that of including mixotrophy. The model developed is based on a acclimative variable stoichiometric (C,N,P) construct. An important additional realisation is that our previous expectations of mixotrophy in these organisms was incorrect. That expectation (and as mirrored in earlier models of mixotrophy) was of a shared acquisition of nutrients through both phototrophy and phagotrophy. The reality seems to be that non-C nutrients are primarily sourced through phagotrophy, and the balance of C comes through phototrophy. Thus physiology in mixotrophs is synergistic, not additive as previously expected. This has two important consequences: (i) experiments on mixotrophy need to consider multi-nutrient types (i.e., not just C or N), and (ii) models describing the base of planktonic food webs must be multi-nutrient and variable stoichiometric.

Transferring Biomass to Depth: The lipid shunt

A model on overwintering *Calanus finmarchicus* across the North Atlantic was constructed based on different copepod sizes, abundance and lipid content at different overwintering temperatures calculating carbon loss due to respiration. The conceptual model is presented in Fig. 22. Using this model, we investigated the sequestration of carbon by this annual migration in the deep basins of the North Atlantic and estimate an annual flux of 1 to 4 gCm-2 by this mechanism, an amount that is comparable to sequestration. The export flux of POC is much greater than the active transport of lipids by overwintering copepods. However, much of the POC flux is attenuated as it sinks to depth. At overwintering depths (> permanent pycnocline; 600-1400 m), the lipid transport and the sequestration flux are comparable (2 to 6 gC m-2 yr-1). A significant portion of this is respired at depth (44%-93%). The lipid pump, representing the difference between what descends in the autumn, and what ascends to the surface in spring, is conservatively estimated at (1 to 4 gC m^{-2} yr^{-1}), other sources of loss such as predation notwithstanding. The transport of lipids to depth and their respiration represents a shunt in the biological pump; the nutrients associated with lipid accumulation remain in surface waters, while respired carbon associated with their use over winter, is sequestered at depth.

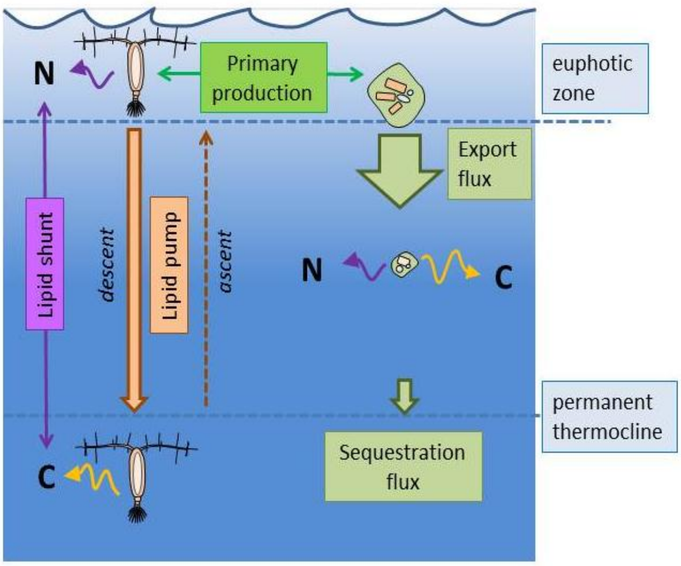


Figure 22 The lipid pump component of the biological pump, and the lipid shunt.

3.2.4 Estimating the extent of predatory restructuring of food webs

Blue Whiting

A number of activities addressed predation controls on food webs. Daily ration (food consumption) by blue whiting was estimated using a gastric evacuation model evacuation rates for all prey types. At present it has not proven possible to conduct gut-evacuation rate experiments on blue whiting in the laboratory. Such experiments are essential in order to accurately characterise the feeding physiology of a species which shows the estimated total consumption of zooplankton prey material by blue whiting, according to geographic area and by quarter between 1984 and 2011. As might be expected given the rapidly expanding stock size during this period, the amount of material consumed increased rapidly in the mid 1990s, especially in the northernmost region (Fig. 23*.* area 3). The overall peak in food consumption was attained in 2006 but declined thereafter. The peak in food consumption occurred slightly earlier in area 3 (the north) compared to Fig. 23*.* area 2 (the central region). The amount of zooplankton estimated to be consumed in each quarter of the year was broadly equal, however it is not known whether blue whiting cease feeding during the spawning period, as is the case for certain gadoids (e.g. cod), but not in others (e.g. haddock).

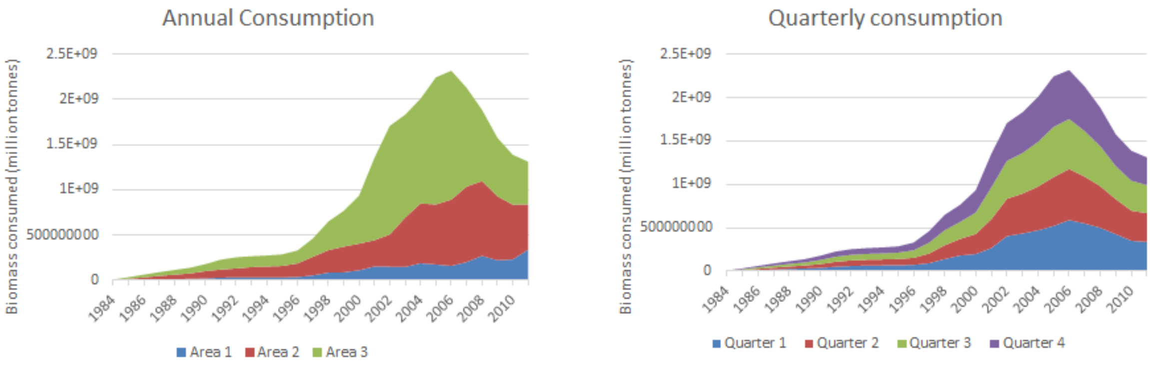


Figure 23 Estimated biomass of zooplankton material consumed by blue whiting between 1984 and 2011, according to geographic area (left) and by quarter (right).

This estimate suggests that many billions of tonnes of zooplankton are consumed by blue whiting in the north Atlantic. This value seems unfeasibly high (and is almost certainly not realistic) hence further checking will be necessary to determine what is possible given the availability and turnover of prey resources in each of the regions, and whether or not the estimates have simply been inflated by the overly-high population estimates. Blue whiting do range over a huge geographic area of the ocean that spans all of ICES sub-areas I–IX, XII, and XIV, but it unlikely that the ecosystem could sustain the level of predation suggested here.

Bluefin Tuna

Habitat modeling activities in EURO-BASIN allowed an estimation of the spatial distribution of bluefin tuna in the different feeding areas. Thus it was possible to estimate the direct trophic impact of bluefin tuna on prey populations. This has been done by assuming that bluefin tuna have a daily ration of 4% body weight / day (Tiews, 1978). The estimated prey consumption, and therefore the trophic impact of the species, differs substantially among the different regions (Fig. 24).

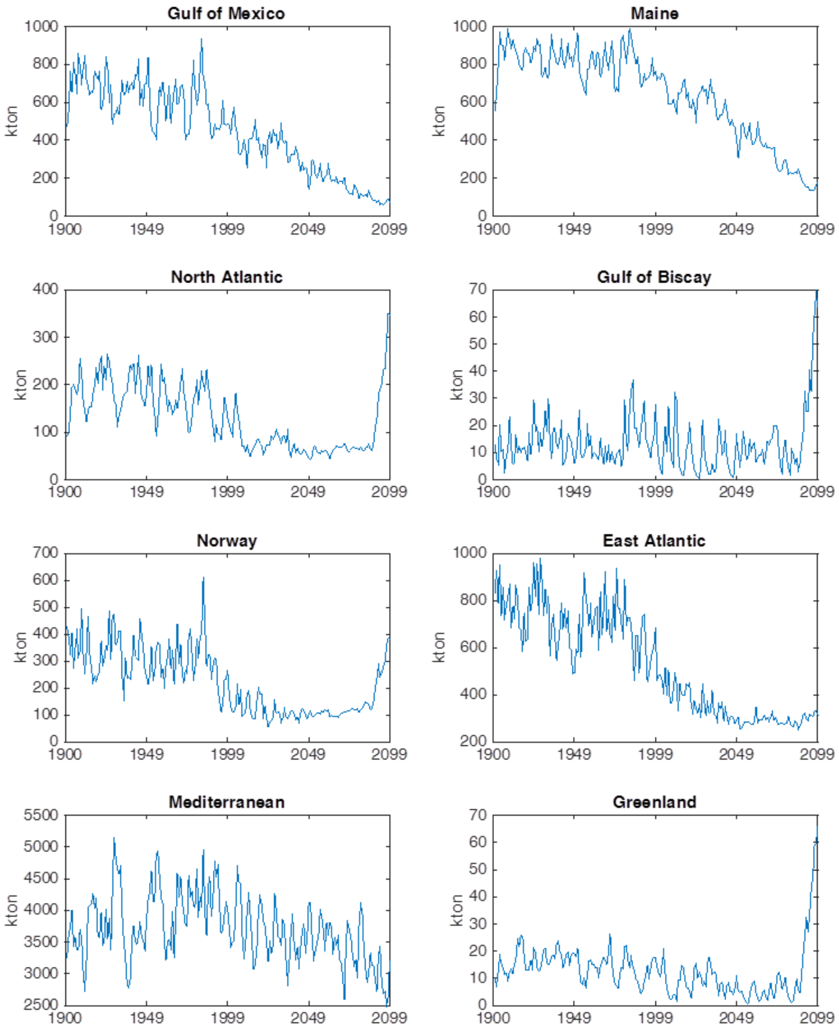


Figure 24 Yearly total consumption (kton) of tuna in different habitats under past and future climate, and with fishing at F = 0.7. The total consumption is calculated using the 5 age classes in the migration model, corresponding to weights (w, Kg): 1, 30, 100, 200, 500. The model for each habitat provides the total number of fish (N) in each class, then the daily consumption is calculated according to Overholtz 2006: $C=0.123\sum_{i}^{5} n_i w_i^{0.8}$ and the value is multiplied by the number of days in each month and summed over each year.

3.2.5 Simulating Climate Change Impact and variability, and anthropogenic activity on marine ecosystem structure and function in the N.Atlantic Ocean and shelf seas.

The goal of the integrative modelling was to describe, understand and predict the impact of climate change and variability and mans activities (fisheries) on marine ecosystem structure and function in the North Atlantic Ocean and shelf seas. To achieve this Euro-BASIN took a basin-scale modelling approach, simulating the response of marine ecosystems using coupled physical-biogeochemical-MTL models via both re-analysis forced simulations and climate-scenario forced simulations.

Three different ecosystem models were coupled to the same circulation model and the results spanning the 1980 – 2010 period analysed. This analysis shows that the models are consistent and agree globally with observations for the well constrained fluxes, such as Net Primary

Production. The future projection ensemble for the lower trophic level of the North Atlantic delivers a consistent picture of expected ecosystem changes under the atmospheric conditions described by the AR5 RCP8.5 scenario of largely unmitigated climate change. Increases in temperature and decreases in average wind speeds lead to a reduced supply of surface nitrate and consequently reduced biomass and productivity of autotrophic, heterotrophic plankton across the basin (see Table 2). This is most distinct in absolute terms from mid-latitudes upwards. This signal propagates further through the system impacting on the fish populations that result significantly reduced as shown in the projection for micronekton presented. Also the capacity of the North Atlantic to export carbon to the deep ocean by means of the biological pump is reduced significantly.

Table 2 Bulk Changes of Key States of the North Atlantic Ecosystem under AR5 RCP8.5 scenario.

	Present Day State	Mid-Century Change	End-of-Century Change
Sea Surface Temperature [°C]	18.89	1.13	3.56
Mixed Layer Depth [m]	52.64	-9.68	-16.2
Dissolved Inorganic Nitrogen [mmol/m^3]	1.79	-0.42	-0.89
Diatom Chlorophyll-a [mg/m^3]	0.09	-0.01	-0.04
Non-Diatom Chlorophyll-a [mg/m^3]	0.21	-0.02	-0.05
Surface Phytoplankton [mgC/ m^3]	25.72	-2.08	-6.26
Surface Zooplankton [mgC/ m^3]	17.92	-1.75	-5.58
Epipelagic Micronekton[gC/m^2]	22	-2.0	-8.0
Deep Mesopelagic Micronekton[gC/m^2]	26	-2.0	-6.0

The results above from the lower trophic level ensemble are complemented by a projection for the mid-trophic level, or more specifically micronekton. These results were obtained from the Spatial Ecosystem and Population Dynamics Model (SEAPODYM, Lehodey et al., 2014), forced by data of the IPSL global coupled ocean atmosphere model under an AR4 A2 scenario similarly to the RCP 8.5 corresponding to largely unmitigated climate change conditions. Total biomass decreases significantly from present day conditions, a consequence of the overall reduction of primary production and plankton biomass (Figure 25). In both cases the decrease is amplified in the second half of the century with a decrease of around 10% in the epipelagic and 8% in the deep mesopelagic zone at mid-century while at the end of the century the biomass reduction reaches levels of 35% for the epipelagic and 25% for the deep mesopelagic zone.

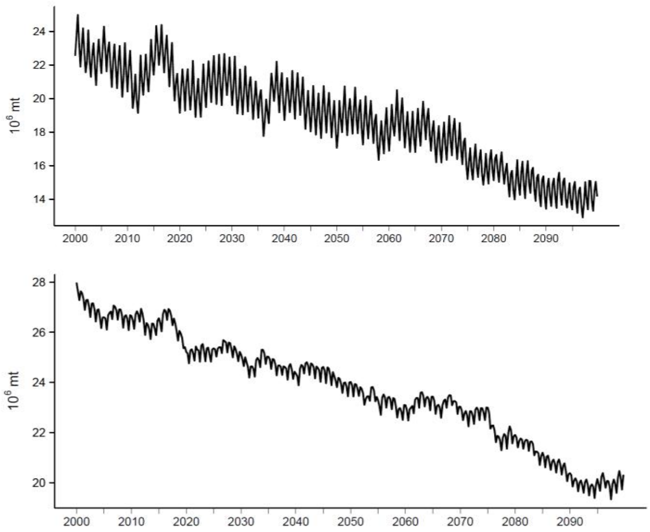


Figure 25 Future Changes of North Atlantic Micronekton – Top: Epipelagic; Bottom: Deep Mesopelagic

In addition we reviewed the key biophysical interactions effecting lower trophic level ecosystems in the North Atlantic, and its adjoining shelf seas. These relate to the diverse range of mixing and transport environments present, and highlight the need for both adequate resolution and process representation when modelling this region. We go on to present a first set of results from a new configuration for the northern North Atlantic using the NEMO-ERSEM model (NNA). While there have been earlier studies with eddy permitting models including ecosystems in this region, this is the first, as far as we are aware, that brings together eddy resolved open-ocean physics, tides and advanced mixing models appropriate for multiple boundary layers. This represents a substantial step beyond the current state of the art, to give significant insight into the biophysical dynamics of the region and to inform future model development.

Our primary point of comparison here is between BASIN 1/4o model and the NNA 1/12o model. This is significant because BASIN represents the emerging state-of-art model that will define the next generation of Earth Systems Models, for example to be used in global configurations in the next CMIP5 process (in the UK this will be UKESM1). NNA represents a generation beyond that, which we imagine could occupy this position in 2020. A basic comparison with climatological observations has been provided (e.g. Fig. *26*). The key facets of the comparison between the two configurations are as follows. In the open-ocean, the NNA model produces significantly deeper mixed layers depths, and presumably higher winter turbulence values. This leads to a stronger and more abrupt spring bloom. In itself this does not greatly affect total annual primary or secondary production. Perhaps more significantly, the NNA shows a more accurate circulation patterns, particularly the Gulf Stream separation and Northwards extension are more accurately simulated compared with the broader and more directly eastwards flow in BASIN.

This leads to less production in the western sub-tropical gyre, which is in general agreement with observations. Both models exhibit export production values in reasonable agreement with observations at BATS, but the lower values in NNA are in better agreement. On-shelf, the presence of tides in NNA has a clear benefit in its ability to reproduce tidal mixing fronts, and hence the spatial distribution of seasonal stratification. This leads to some significant differences in the on-shelf ecosystem properties (e.g. summer surface chlorophyll in the North Sea), but these require further investigation and a detailed comparison with contemporary observations.

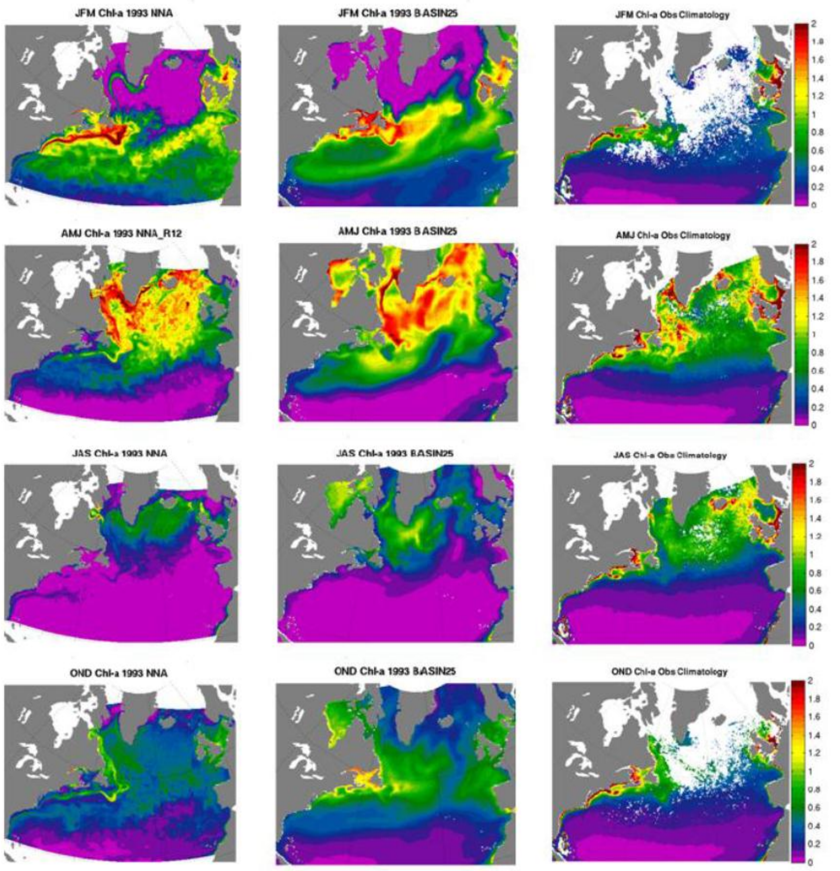


Figure 26 Comparison between BASIN 1/4o model and the NNA 1/12o model.

Deep convection has been suggested to play an important role in winter phytoplankton dynamics in the North Atlantic. In order to account for this effect in coupled ecosystem models, a simple parameterisation, named 'phytoparameterisation', has been tested. The effect on phytoplankton biomass was strongest during winter with an increasing effect from December to March leading to the largest increase (~150%) during early spring when light conditions became less limiting, but prior to the onset of stratification (Figure 27). These results can be explained by the retreat of the MLD, leaving a large proportion of the cells below the mixed layer and thus to sink to the deep ocean. These results indicated an underestimated importance of the simulated winter phytoplankton stock on the annual carbon budget and highlight the need to further improve our knowledge about winter phytoplankton

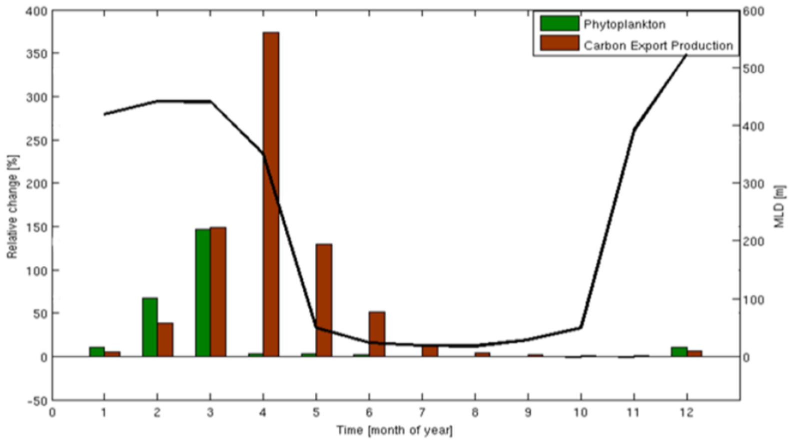


Figure 27 Simulated influence, expressed as relative change [%] of the integrated phytoplankton biomass (green, left axes) and carbon export production at 500 m (red, left axes). Also shown is the annual maximum mixed layer depth (black line, right axes) in the open ocean.

4.0 Potential Impact: Valuing the ecosystem based resources of the Atlantic

- The estimates of the economic cost of sub-optimal fisheries management are of significant interest in non-academic sectors when discussing future options for management strategies. EURO-BASIN concluded that the economic loss of North Atlantic fisheries in 2010 was € 12.2 billion, that the North Atlantic fisheries are under-performing economically and thus that maintaining stocks above MSY is not just ecologically but economically justified.

- A bio economic model of the North Atlantic fisheries has been developed and made available to users outside the EURO-BASIN project. It is based on network economics principles, connecting fish stocks in the ICES areas, the most important European fleets, international trade and European consumption markets. The model is of intermediate complexity (several hundreds of nodes) and has been calibrated using ICES, FAO and UN trade data sets. The simulation model is available through the EURO-BASIN webpage. The front page is showed in Fig. 4. The user can determine its own scenario by setting the rate of change of chosen parameters for the next 30 years. The main use of this implementation is to allow stakeholders to check the sensitivity of the system to these parameters and to support public discussions about the future of North Atlantic resources and associated industries.

As achievements beyond academic interest we note:

- We have solved the question of integration of climate modeling and economic modeling at the scales and resolution implied by the governance of a large system such as the North Atlantic. Even if the actual model is restricted to fisheries, it appears that the results of simulations, their sensitivity to a selected set of parameters allow a better exchange between scientists and other stakeholders.

- We have identified and simulated contrasted scenarios that can constitute the background of the discussions between stakeholders.

- We have identified several major issues involved by the governance of the North Atlantic system: the substitution between wild fisheries and aquaculture, the variability of fishermen income, the importance of controlling catches, the effects of changes of international trade;

- Specific computer tools that have been developed for the implementation on Internet of a large network economics model and the whole approach represent noteworthy progresses in the methodology of integrated modeling of exploited ecosystems.

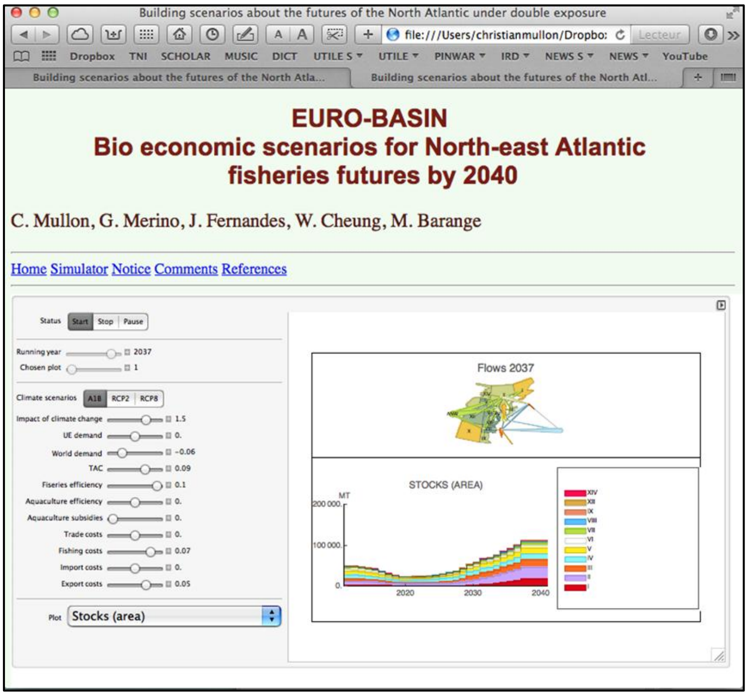


Figure 28 Web interface of the Simulation linked to the EuroBASIN Bio-economic model. Modifications of the parameters on the left allows for projections in a number of biological variables, industry processes, trade patterns, and interactions with aquaculture developments.

4.1 Evolution of North Atlantic Ecosystems, Implications for understanding food web dynamics:

Aspects related to trophic roles of the species increase our understanding of the effects of fish populations and fishing on biogeochemical fluxes in north Atlantic ecosystems, as well as how the fish species and their prey affect each other's ecology (e. g., prey mortalilty rates, predator growth rates and condition). New dietary information developed within the project, much of it summarized in an open-access PANGEA database publication, will help improve the understanding of the dynamics of predation (spatially, seaonally, interannually) and the impacts of such predation on prey species and food webs. This knowledge can potentially be used in new multi-species fishery management models, and reference point estimation, and in new models of how fish populations affect biogeochemical processes, including those related to the carbon pump

4.2 Climate change impacts on the biogeography, habitats of key species in the N Atlantic: consequences for Good Environmental Status, fisheries and conservation.

Changes in ecosystem state and primary and secondary production result in alterations of growth conditions and loss of critical habitat for the higher trophic levels and changes in food web structure. Our simulations provide model estimates of the a range of habitat indicators including temperature, oxygen, pH, food / prey availability in terms of primary production, phytoplankton biomass, and chlorophyll as a proxy, salinity, nutrients, hydrodynamic transport and mixed layer depth. Our results indicate dramatic changes to ecosystem function and significant habitat shifts (including the almost total loss of some northern biomes by 2100) of the North Atlantic ecosystem. These results suggest that we can expect significant changes in the biogeography of the N Atlantic Ocean over the next century when compared with today. On top of this we are also predict changes in the seasonal cycles of primary production and well as its magnitude, an effect which will propagate through the whole ecosystems. This implies that we will expect to see significant changes in the species distribution of both plankton and fish, with the associated consequences for commercial fishing, carbon sequestration and good environmental status.

Our work highlights the potential sensitivity of North Atlantic Ecosystems to climate change. It is likely that warming will lead to reductions in primary production over most of the domain with consequent reductions in secondary production and carbon export. It is important to note that the responses are non-linear as we move from signal to response. By 2030 to 2050 only the temperature primary production response is larger than the variability of the present day. However there are some regions, most notably the open ocean areas to the west of Europe where the trophic amplification and carbon export responses exceed the variability. This is relevant to policy and management, because it suggests that within the next 30 years we will start to see significant impacts of climate change on fish biomass and export flux, with implications for the CFP, MSFD and the global C budget. By 2080-2100 we are seeing highly significant changes in all areas. This illustrates the significant challenges for the future definition of policy and management targets for the North Atlantic ecosystems and fisheries. It highlights the need for better monitoring so we can assess the current state of the system (both baselines and variability) and monitor trends. It also highlights a need for ensemble ecosystem modelling following the methodologies of CMIP. Finally it indicates the need for a more robust dialogue between policy makers and marines scientists if we are to sustainably manage the ecosystems of the N Atlantic and at the same time achieve blue growth.

4.3 Modelling tools

The lower trophic level model tools (ERSEM, MEDUSA and PICSES) developed and applied in Euro BASIN will be used future operational oceanography activities, for example the Copernicus Marine Core Service and future IPCC (AR7) activities. All of these models have benefited from incremental developments, advances in parameterisation, testing and validation undertaken in Euro-Basin and the lessons learnt have been fed into the model versions provided to operational users. For example the MEDUSA model has been selected as the ocean biogeochemistry model for UKESM, the earth system model being developed for the UK contribution to AR7. Similarly the PICSES model has the same role in the French national ESM run by IPSL and is anticipated to fulfil the same role in AR7.

Both the ERSEM and PICSES models are used to provide operational forecasts for marine biogeochemistry in the pre operational Copernicus Marine Core Service. ERSEM coupled to NEMO-Shelf (partly developed in euro-basin) provides the operational model for the NW European Shelf forecast system run by the UKMO, while PICSES NEMO provides the framework for the operational global ocean biogeochemistry forecast run by MERCATOR. It is anticipated that both models systems will be included in the operational marine core service which starts 1st May 2015.

4.4 Habitat evolution under climate change

We have coupled habitat models with hydrographic-biogeochemical models in order to simulate species distribution under future climate change scenarios. Advances in habitat and climate modelling allow us to reduce uncertainties of climate change impacts on species distribution. Thus, using these models we have assessed the potential reduction or increase in the habitat of zooplankton species, which can affect fish populations as well as assessing the potential distributions of key fish stocks. A solid base of work indicates that warming can modify the distribution of marine organisms, which in turn, can be propagated to upper trophic levels. In a context of rapid alteration of marine ecosystems throughout the world, future projections of ocean productivity, based on habitat species distribution, are needed for a detailed assessment of ocean health and benefits and for achieving or maintaining the good environmental status of the North Atlantic (see for instance the environmental status defined by the Marine Strategy Framework Directive, MSFD, European Commission, 2008).

We have addressed factors affecting the large-scale spatial distribution and trophic roles of several of the ecologically and commercially most important pelagic fish species in the north Atlantic. Our results include many findings that will have implications for the sustainable management of these stocks, including issues related to stock structure (e. g., blue whiting, mackerel), the movement and migration of stocks to new jurisdictions (e. g., mackerel, bluefin and possibly albacore tunas), and sustainable fishing levels under altered productivity conditions due to climate change. We have furthermore identified several specific recommendations related to fishery management and assessment and existing knowledge gaps/future research needs for each of the stocks. Details of these recommendations are available in Euro-Basin Deliverable 8.13 *Recommendations for monitoring & assessment procedures to provide fisheries advice.*

We also see potential benefits to incorporate the decadal predictability of the North Atlantic in some fishery management decisions. Recent studies have shown that the physical oceanography and other physical properties of this region is one of the most predictable in the global ocean. This predictability so far remains underutilized in fisheries management and for understanding and predicting dynamics of fish populations and marine ecosystem dynamics in the North Atlantic. Given our many findings of how oceanographic conditions affect the pelagic species in the North Atlantic, it is likely possible that the predictability of the physical environment can be linked more directly to that of its biota, including fish populations. We believe that developing new management frameworks which accommodate predictive properties of the North Atlantic Ocean could be a fruitful avenue for research, implementing operational fisheries oceanography and management, and creating new employment opportunities in the environmental data knowledge and processing sectors of European business communities.

4.5 Good Environmental Status ES indicators of and biological reference points used in fisheries management under climate change.

We developed a list of intermediate level ecological, economic and social management objectives for Northeast Atlantic pelagic ecosystems and then carried out evidence-based selection of corresponding GES indicators and reference points. Based on published evidence for pressure-state links, we selected examples of operational stock or region specific objectives and suitable GES indicators. Given the strong species-specific links of pelagic species with the environment and the large geographic scale of their life cycles, which contrast to demersal systems, pelagic GES indicators are needed at the level of species (or stocks) independent of legislative region. Pelagic community GES indicators may be set at regional scale in some cases. In our evidence-based approach, the selection of species or region specific operational objectives and indicators was based on demonstrated pressure–state links. Hence changes in indicators can reliably inform on appropriate management measures. Finally, climate change is expected to affect both the relevance of many operational objectives as well as suitable reference levels. In contrast the indicators themselves will not be affected

Tabel 3 Example operational objectives, indicators, reference levels and management actions for pelagic ecological, economic and social objectives identified by stakeholders including scientists. Categories as in figure 1. Ecological level: C community, *P population/stock, I individual. Grey cells are expected to be impacted by climate change.*

No	Cat.	Ecological objective	Level	Example operational objectives	Indicators	Reference levels	Management
O1	C1	Limit slippage, discarding	C	Limit discarding of pelagic trawlers in Bay of Biscay and North Sea	Discards/ catch	x% of total catch	Spatio-temporal closures, gear rules, TAC distribution across vessels
O2	C1	Limit marine mammal, birds, pelagic sharks, elasmobranchs bycatch	C	See O8			
O3	C1	Achieve low level of contaminants from land	C	Limit contamination by dioxins and dioxin-like PCBs in Baltic Sea herring	Dioxins and dioxin-like PCB concentration in herring	Sum of dioxins and dioxin-like PCBs < 8 pg/g wet weight (EC, 2006)	Regulate polluting terrestrial activities
O4	C2	Maintain exploited stocks	P	Maintain stock biomass and exploitation rate within safe biological limits	-Stock biomass -Exploitation rate relative to biological reference point	Biological reference points ensuring no impairment of recruitment, e.g. SSB_{lim}, F_{PA}	TAC
O5	C2	Maintain food supply for higher trophic levels	C	Maintain herring and sprat biomass in the Baltic for cod; Maintain sandeel biomass in the North Sea for seabird predators	Prey biomass or F; Predator condition/growth/ productivity	>X tons of prey species	TAC
O6	C2	Maintain functional diversity in the pelagic system	C	Manage all exploited pelagic fish stocks sustainably; Improve red listed marine mammals and turtles	-Biomass/ abundance - Fishing mortality	Bmsy; Fmsy; IUCN criteria	TAC, Reduce bycatch using gear devices
O7	C2	Maintain structural biodiversity	C	See objective 6			
O8	C2	Limit marine mammal, birds, pelagic sharks, elasmobranchs	P	Reduce marine mammal and bird bycatch in bluefin tuna fisheries	- Bycatch rate	x individuals	Spatio-temporal closures, escape devices/pingers

		bycatch					
O9	C2	Maintain prey diversity in the diet of predator *x*	P	None			
O10	C2	Maintain functional plankton community	C	None			
O11	C2	Predator of pelagic resource condition and growth rate	P	Maintain reproductive success of great skua, European shag and common guillemot in North Sea	Number of chicks fledged per nest	x chicks fledged per nest	Adjust local sandeel catches
O12	C3	Maintain the stock component diversity	P	Maintain all herring spawning stock components	- SSB for each herring spawning component	SSBlim	Area & season based quotas
O13	C3	Maintain a healthy age distribution of the pelagic fish community	P	Maintain age structure in sardine stocks in European waters	-Abundance/ proportion of fish that are older than age-at-maturity -$F_{immature}/F_{mature}$	Long-term mean	TAC and fishery size selection pattern
O14	C3	Maintain a spatial distribution of pelagic fish	P	None as factors not understood			
O15	C3	Maintain body condition / growth rate / age at maturity	I	See objectives 5 & 11			
O16	C3	Maintain genetic diversity	P	Avoid overly selective fishing of any species	?		
O17	C3	Maintain phenotypic width / breadth	P	None			
O18	C4	Maintain spawning habitat	P	Maintain herring spawning habitat; Maintain capelin spawning habitat	Size of suitable spawning habitat	x km^2 of suitable habitat	Limit gravel extraction/habit at destruction
O19	C4	Maintain juvenile habitat	P	None			
O20	C4	Maintain feeding habitat	P	None			
O21	C4	Limit contaminants that effect recruitment success	P	None			
O22	C4	Maintain migration ways	P	Ensure potential migration ways are not increasingly impacted by bridges, dams, etc.	Proportion of migration ways impacted by physical constructs	x% migration ways impacted	Spatial planning
O23	C5	Optimize yield	P	Interannual stability of	Interannual variance of	X landings,	constant TAC, capped TAC

				landings	landings	X% change in landings	change
O24	C5	Maximise sustainable yield	P	Stock management compatible with MSY	Fishing mortality	F_{MSY}	TAC, etc.
O25	C5	Limit slippage, discarding	P	Limit slippage and discarding of herring, blue whiting and mackerel in North Sea; Limit discarding of anchovy in Bay of Biscay	Discards/catch per species; Slippage/catch	x% of species catch	Spatio-temporal closures, gear rules, TAC distribution across vessels
O26	C5	Maintain physical space to fish	C	-Maintain space to fish for pelagic fisheries in North Sea	-Size of suitable fishing areas	x km^2 of suitable fishing area	Spatial planning

4.6 Open Data

Understanding the future requires identifying the key processes acting in the past and extrapolating into the future. Over 350 data sets (>3 million data values) were published during the course of project EURO-BASIN. The vast majority of these data (75%; Figure 1; non-cruise historic data in blue) are published in Open Access and freely available to the wider scientific, commercial and public communities. The remaining 25% originates from EURO-BASIN cruises and is still under the moratorium period described in the project data policy. These data will be released in Open Access no later than two years after the end of the project. Open Access data are about living resources (key commercial fish stocks; 62%), key plankton species (27%), key commercial fish catches (socio-economic), and the biological carbon pump (Fig. 2.2.2).

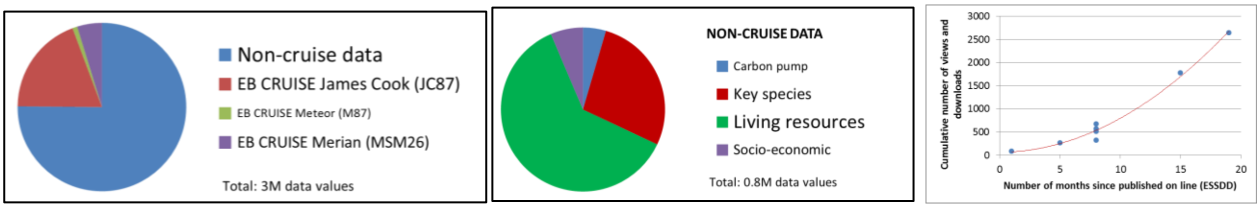


Figure 29 EURO-BASIN data that are in Open Access (Non-cruise data in blue) , stocks of living resources (green), key plankton species (red), socio-economic activities (purple) and the biological carbon pump (blue), and downloading frequency since publication.

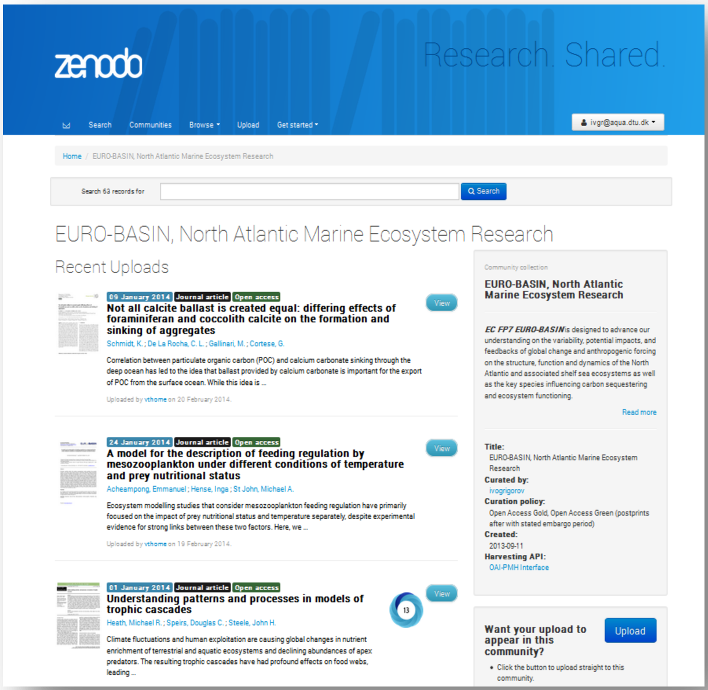
The EURO-BASIN special issue published in Earth System Science Data (ESSD) shows a growing impact with a steady increase in views and downloads across all data papers describing data compilations undertaken by EURO-BASIN (Fig. 29). Each paper has corresponding data sets published in Open Access at PANGAEA, Data Publisher for Earth and Environmental Science. No metric is available yet regarding access to data.

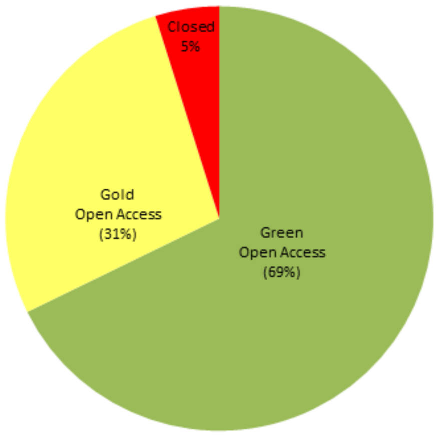
4.7 Open Access:

Passively, the EURO-BASIN Consortium delivered to the EC Digital Agenda and Access to Research by fully complying with the Horizon 2020 Mandate on Open Access (GA Article 29.2-3)[1], for the duration of the program, and 3 years before the Horizon mandate was announced.

[1] EC Model Grant Agreement http://ec.europa.eu/research/participants/data/ref/h2020/mga/gga/h2020-mga-gga-multi_en.pdf

Jointly with partners from University of Bremen, and [Pangaea.de](), the consoritum ensured that all primary data is perennised and archived long-term in the form of 58 datasets (cf www.pangaea.de search term"euro-basin"), some of which have been published in the Earth System Science Data (ESSD) Journal Special Issue, and have since attracted over 2.500 downloads by the community. The EURO-BASIN Project also published 89 peer-reviewed publications, all of which are archived in Open Access in the EC-developed e-infrastructure via FP7 OpenAIRE and OpenAIRE+ projects.





The impact for society is not just an Ethical one, although that too is a priority for EC Responsible Research and Innovation. The combination of Open Data and Open Access directly contributes to EC Digital Agenda and the Innovation Union objectives on economic growth and innovation. Open Data and Open Access not only are paramount for the reproducibility of research[2], but also have proven and measurable economic benefits for the knowledge-based SME sector[3].

4.8 Media Footprint:

The higher project objectives of better resource management at basin scale, better stewardship of the ocean, and lessening human impact on the marine realm, captured media and public attention.

Project partners had direct and measurable impact on media outlets. A significant proportion of the peer-reviewed publications in the EURO-BASIN Open Access Collection (www.zenodo.org search term "euro-basin") have at least one media outlet referring to the published findings.

Michael Heath`s (Un. Strathclyde) publications on fish discards, and Brian MacKenzies` (DTU) research on Atlantic tuna profile societal attention from peer citations to blogs, tweets and news media coverage.

[2] *Peng 2011 DOI: 10.1126/science.1213847*
[3] Houghton, J., Swan, A., Brown, S., 2011. Access to research and technical information in Denmark [WWW Document]. URL http://www.deff.dk/uploads/media/Access_to_Research_and_Technical_Information_in_Denmark.pdf

As a direct result of the published findings, Mike Heath (Un. Strathclyde) is solicited by Dutch MEP Ms. Anja Hazekamp to a hearing of the Fisheries Committee of the European Parliament (13 April 2015), to advise on means and methods to minimize impact of fish discards on the marine environment.


BBC NEWS SCOTLAND

Worry over fish discards ban on wildlife and fish stock

13 May 2014 Last updated at 14:48 BST

Researchers at Strathclyde University have said a ban on fishermen throwing away healthy fish could harm wildlife and fail to improve fish stocks.


THE SUNDAY TIMES

NEWS

Tuna follow global warming to Arctic

Jonathan Leake, Science Editor

BLUEFIN tuna have been caught as far north as the east coast of Greenland for the first time in more than 300 years in what scientists say is one of the clearest signs of rising ocean temperatures.

Three were caught within 100 miles of the Arctic Circle in a trawl carried out by five chartered vessels with Danish researchers onboard. The scientists were investigating the impact of global warming on the distribution of key commercial fish species.

They had been following schools of mackerel and set their nets to bring some of them in. When they did so they found three tuna among them, each weighing more than 220lb and apparently part of a school.

There are two populations of Atlantic bluefin tuna, one based in the Mediterranean and the other in the Gulf of Mexico. Both range across the Atlantic, venturing north in winter and returning south in summer.

Research activities and publications also regularly captured the print media attention on topics as varied as life at sea on an ocean expedition, to migrating species pushing the ranges of their usual habitats under climate pressure.

4.9 EU-US-Canada Network:

The political ambitions of the EC, USA and Canada to work together on common Societal Challenges was formulated in the Galway Declaration on the Atlantic Ocean Research Alliance.

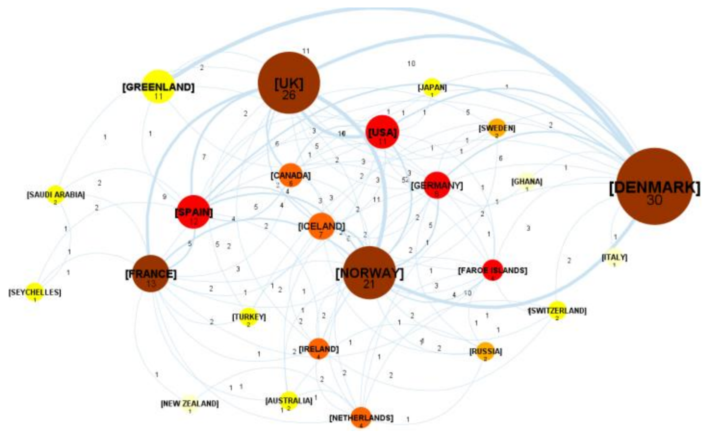
Michael St John presenting challenges for basin-scale ecosystem-based management at the Lisbon Atlantic Conference, 2011 http://www.fem.pt/lac2013/Ingles/princ_ing.htm

EURO-BASIN Project was one of the flagship project implementing stronger cooperation by setting the research agenda within the Atlantic Action Plan & Forum.

The Scientific Coordinator contributed significantly to the EC Atlantic Action Plan, and the resulting Galway Declaration between the EU-USA-Canada that lays the political ground for stronger transatlantic collaboration on Societal Challenges.

Some of this effort is directly reflected in the cooperative nature of the project results, even in the early stages of the publication history of the project. Much of the body of peer-reviewed published findings are to yet to be published.

Network of collaboration between countries, based on cooperation on publications, and breadth of topics covered by the publications so far.



The resulting interaction between the US, EU and Canada, both at Research Funding Agency level, and at Principle Investigator level resulted in the North Atlantic-Arctic International Science Plan, drafted with the participation of EC, National Science Foundation (US) and Department of Fisheries and Oceans (Canada)[4].

[4] Benway, Heather M., Eileen Hofmann, and Michael St. John. "Building International Research Partnerships in the North Atlantic–Arctic Region." *Eos, Transactions American Geophysical Union* 95, no. 35 (September 2, 2014): 317–317. doi:10.1002/2014EO350007.