Marine Ecosystem Evolution in a Changing Environment

Reporting

Project Information

MEECE

Grant agreement ID: 212085

Status
Closed project

Start date
1 September 2008

End date
28 February 2013

Funded under
FP7-ENVIRONMENT

Overall budget
€ 8 577 985,11

EU contribution
€ 6 499 744,74

Coordinated by
PLYMOUTH MARINE LABORATORY LIMITED
United Kingdom

This project is featured in...

RESEARCH*EU MAGAZINE
Cleaning up space junk
NO. 32, MAY 2014

Final Report Summary - MEECE (Marine Ecosystem Evolution in a Changing Environment)

Executive summary:

Marine ecosystems are increasingly under pressure from the activities of man and are consequently changing. Climate change may lead to large scale changes in climate patterns, ocean circulation and climatic variables such as temperature and light and simultaneously, combinations of direct anthropogenic drivers such as fishing, eutrophication and pollution impact on marine ecosystems. The primary goal of MEECE was to improve the knowledge base on marine ecosystems and input to the development of innovative tools for understanding and assessing good environmental status (GES) in marine waters in European regional seas to inform the implementation of the MSFD. The implementation of the Marine Strategy Framework Directive (MSFD) requires Member States to develop strategies to achieve a healthy marine environment and make ecosystems more resilient to climate change in all European marine waters by 2020 at the latest.

Project context and objectives:

Marine ecosystems are increasingly under pressure from the activities of man and are consequently changing. For example climate change may lead to large scale changes in climate patterns, ocean circulation and climatic variables such as temperature and light. Enhanced atmospheric carbon dioxide (CO_2) levels will lead to acidification of the oceans with significant impacts on ocean biogeochemistry, planktonic ecosystems and potentially the reproductive success of higher trophic levels (e.g. changing survival rates of larval stages of metazoans and fish). These changes will all impact on the overall trophic structure and function of marine ecosystems. Simultaneously, combinations of direct anthropogenic drivers such as fishing, eutrophication and pollution impact at both an organismal and population level thereby influencing the competitive ability and dominance of key species and thus the structure of marine ecosystems. Finally, the introduction of alien invasive species has the potential to restructure marine ecosystems, a mechanism of change which has the potential to be exacerbated when key species are already under stress due to the combined effects of abiotic and biotic stressors. In many regions these activities are acting on the ecosystem simultaneously, potentially leading to additive, synergistic or antagonistic effects. Ultimately, if we do not understand how the ecosystems responds to combinations of these drivers either in the past or in the future we will find it very difficult to manage marine ecosystems in the future.

Project results:

MEECE followed a logical process starting with targeted data synthesis, experimentation, model parameterisation and development. This was followed by model exploration through a range of scenarios addressing the full set of drivers. This innovative approach was aimed at helping scientists and decision makers to respond to the multiple driver impacts with appropriate, knowledge-based, management applications. Outputs from the experiments and model simulations were used to devise decision support tools and develop management strategies.

The report has been split into three sections to reflect this:

-Tools, methods and data: This section summarises the data collection and experiments undertaken along with technical achievements in terms of model coupler development, new parameterisations and methodologies for running climate scenarios and model validation.
- Ecosystem response: This section summarises the responses of marine ecosystems to the full range of MEECE drivers, firstly considering each individual driver then in terms of combinations of drivers. Each subsection combines information from the laboratory and numerical experiments and data synthesis as appropriate to the driver in question.
- Implications for resource management: The final section is a synthesis of the resource management tools that have been developed and applied (e.g. integrated assessments, decision support tools, indicators and management strategy evaluation tools).

Tools, methods and data:

Datasets and meta-analysis:
Recognising the need for structured, coherent databases on observational and experimental results of ecosystem- driver interaction and response, MEECE has collated existing data on key process and drivers into new meta-databases for the ecosystem drivers and model validation datasets. MEECE has also collated a large dataset on discharge of European and non-European rivers integrating information from other European and global projects like GLOBALNEWS and WATERBASE. The database contains field data and model outputs on rivers flow and chemistry (for example nutrients), useful for analysing the impact of past policies on riverine nutrient loads and to force biogeochemical models such as those used in MEECE. The meta- database for ecosystem drivers contains information on climate and ocean acidification, pollution, fishing, invasive species and plankton metabolic rates. Meta-analysis of these databases has generated new parameterisations and scenarios on critical processes pertinent to ecosystem models. Of particular note is the meta analysis of plankton metabolic rates, which demonstrated that, in spite of their primitive life-style, jellyfish exhibit similar instantaneous prey clearance and respiration rates as their fish competitors and similar potential for growth and reproduction; this work was published in Science (Acuña et al., 2011, Science, Vol. 333 No. 6049 pp. 1627-1629). A range of meta- analysis have been completed on invasive alien species (IAS) impacts, ecological traits and the functional traits and environmental tolerance limits for phytoplankton in order to parameterise a climate envelope modelling approach and a bio pollution expert system for the Baltic. Meta-analysis of ocean acidification (OA) experiments on calcifying organisms suggests the current evidence is highly ambiguous even in terms of the sign of the impact of OA on calcification, thus preventing the extrapolation of this work to a consensus model parameterisation.

Regional models and scenarios:

Global and regional model systems:
The following seven regions (six European seas and the Benguela upwelling) and the global ocean have had model systems implemented in them.

Global
- Barents and Nordic Seas
- North East Atlantic (Atlantic Margin, Greater North Sea, Celtic Seas, Bay of Biscay)

- Baltic Sea
- Black Sea
- Adriatic Sea
- North Aegean Sea
- Benguela Upwelling.

Ecosystem response to drivers:

Marine ecosystem responses to drivers

In order to summarise the responses of marine ecosystems to the full range of MEECE drivers, the MEECE scientists provided their expert opinions on how sensitive a regional system is in general to each driver on a scale from 0 (no response) to 3 (highly responsive). The summary table (see attached pdf) combines these expert opinions, with a value judgement as to how confident they are in their views (red = low, yellow = medium, green = high), thus providing a systematic overview of the sensitivity of the marine ecosystem to key drivers in each region. It should be noted that the quantitative and specific nature of the response on an individual scenario basis is generally less certain.

Climate change

Ocean ecosystems are increasingly stressed by human-induced changes of their physical, chemical and biological environment. Among these changes, warming, and changes in circulation and stratification leading to de-oxygenation and changes in primary productivity by marine phytoplankton can be considered as the major stressors of marine ecosystems.

Acidification

Ocean acidification refers to increasing CO_2 dissolved in seawater leading to the lowering of pH in the marine environment and impacts at all spatial scales. This is occurring mostly as a consequence of anthropogenic carbon emissions into the atmosphere. Increasing CO_2 may lead to enhanced phytoplankton growth, at the same time the lowering of pH it induces may have negative impacts on the health and reproduction of a wider range of marine organisms for example plankton and fish larvae. Currently the experimental evidence on impacts is often contradictory making it hard to predict what the future may bring. Many organisms, particularly those in extreme coastal environments are adapted to large pH ranges and are likely only to be affected once the pH range moves away from their natural tolerance. The ocean acidification response of other species may depend on the food supply and the ability to transfer energy costs over to repair and survival. The ability of marine biota to rapidly adapt to pH changes remains largely unknown and should be seen also in the context of other changing stressors (e.g. warming, de-oxygenation, nutrient supply). Similarly to climate, acidification is currently unmanageable in a marine context, but represents an issue that management strategies for other drivers may need to take into account.

Eutrophication

Eutrophication results from the anthropogenic nutrient enrichment of the marine environment leading to a variety of outcomes including enhanced algal blooms, harmful algal blooms, de-oxygenation and mortality of benthic fauna. The standard approach for modelling eutrophication processes and the consequences of changes in anthropogenic nutrient inputs on the eutrophication status of a region is to apply coupled hydrodynamic ecosystem models. This is the approach we have taken in MEECE.

Invasive species

Non-indigenous species (NIS) introduced by humans, both intentionally and un-intentionally, can have both significant ecological and economic impacts and their increasing spread is a major concern for many European seas. NIS can represent very large numbers (e.g. approximately 1000 species in the Mediterranean) of very different taxa ranging from parasites to fish. A subset of NIS is the invasive alien species (IAS) which have spread, can spread or have demonstrated the ability to do so and have the potential to impact biodiversity, communities, habitats and ecosystem functioning. Although the term biopollution has been used in connection to IAS, they do not respond in the same way as classic chemical pollution, which can be tackled at source with appropriate local measures. Arrival, distribution and spread of an IAS can involve a suit of vectors and pathways, although main pathways linked to arrival are shipping (through ballast water and fouling), canals and the mariculture and aquaria trade. Established NIS may expand their distribution and increase their abundance beyond a local starting point through processes, which may not be controllable. Further, vectors and pathways are not static i.e. they can change over time, impacting the spatial extent of the NIS (and further facilitating secondary spread) which depends on both species life history traits and the state of the receiving ecosystem upon arrival. Equally complex and varied is the timescale component of an invasion event, as this will depend on the species life cycles and can vary from days to decades, and have a permanent or seasonal nature. In addition, climate warming has been reported as an additional stressor modifying marine ecosystems and enabling and enhancing biological invasions. While mitigating the spread or eradicating existing IAS is currently very challenging, the risk of new biological invasions can be reduced by controlling vectors and implementing pathway-relevant precautionary measures e.g. aquariology prohibitions or the Ship's Ballast Water Convention. Consequently, the best management strategy regarding invasive alien species is to avoid new invasions as targets for biopollution levels are not possible to set. Therefore, the work on invasive alien species in MEECE has focused on understanding ecosystem responses to this driver and related parameterisations to include alien species in ecosystem models, estimating biopollution levels and their impacts on ecosystems and incorporating these to expert systems.

Pollution

Contaminants enter marine environments from both diffuse (e.g. atmospheric fall-out) and punctual sources (e.g. estuaries, urban areas, industrial plants, aquaculture, oil spills, etc.) affecting marine ecosystem quality. Marine contamination control is crucial in light of the more recent European Directives on water quality assessment. In particular, MSFD GES descriptors clearly require a shift in monitoring activities from classical techniques based on determining chemical concentrations to risk-based methodologies integrating chemical data with biological results thus discriminating contamination and pollution. From a management perspective, persistent contaminants (pollution) may require decades to be removed. Further, chemical data 'per se' can only furnish partial information of the system. Understanding the effects (i.e. ecotoxicological test and ecological surveys) of exposure (i.e. chemical concentrations) is needed to determine risks due to chemicals, supporting the MSFD goals. Further, only a minimal part of toxic compounds in the world (more than 295 000 compounds) is quantified in monitoring programs; while interactions among chemicals in a mixture can give unpredictable effects (i.e. additive, antagonistic, synergistic). Also, different processes can alter pollutants bioavailability in the system. Consequently, the work in MEECE relating to the pollution driver has focused on improving the knowledge base and modelling capabilities regarding these issues and developing expert systems for decision support.

Fishing

Broadly speaking the impact of fishing is to selectively remove certain species which have a commercial value, and to perturb habitats. The consequences of selectively removing species can restructure foodwebs, while demersal trawling in particular can cause extensive damage to benthic habitats. There are a wide range of models of higher trophic levels which include fish and commercial fisheries of varying skills which provide information on fish stocks as well as the wider fish community and their response to changes in fishing pressure at regional scales. A variety of such models are employed in MEECE. All of these models can be driven by the outputs of coupled hydrodynamic plankton models through either one way or two way coupling. In terms of exploring top-down fisheries impact in an integrative way, end to end models are required. Such end-to-end models combine hydrodynamics, nutrient-phytoplankton-zooplankton (NPZ), and higher trophic level (HTL) organisms, into a single modelling framework. Such models are currently in the proof of principle phase to show that they can be developed and implemented to further explore the top-down effects of fishing down to the lowest trophic level organisms.

Multiple drivers: impacts on foodwebs

Amplification from lower to higher trophic levels:
To compare, in a synthetic way, the ecosystem response to combinations of drivers we applied a framework to assess the processes of amplification and attenuation in the ecosystem response from lower to higher trophic levels. In this approach, the response (i.e. fractional change) of a given trophic level to climate change is compared with the response of the immediately lower trophic level to the same driver. Thus, the response can be split into four classes of trophic propagation: amplification, attenuation, proportional response and top down control; all classes having both a corresponding positive or negative case.

Summary of regional responses to multiple drivers

Northeast Atlantic: Climate, eutrophication and demersal trawling

For the northeast Atlantic, the sensitivity of the ecosystem to changes in multiple anthropogenic drivers (river nutrient and benthic trawling) in the near future was also studied, as is the impact of the anthropogenic changes combined with the climate change signal. In the northeast Atlantic, away from the European continental shelf, river nutrient loads and benthic trawling effort have little impact on the pelagic ecosystem. Climate change effects dominate in this area. In the scenarios considered here, these reduce net primary production and the biomass of zooplankton and small phytoplankton in the future. On the continental shelf, the impact of climate change on net primary production and phytoplankton biomass may be mitigated to some extent by environmental policies that reduce river nutrient loads, particularly in near coastal regions. However, such environmental policies amplify the effects of climate change on the biomass of small zooplankton. Policies that allow river nitrogen loads to increase in the absence of any increase in river phosphate loads have little impact on net primary production and phytoplankton and zooplankton biomass. Reducing trawling effort in the North Sea leads to an increase in benthic biomass. However, climate change in the long term is expected to decrease the benthic biomass on the shelf and therefore counteracts the reduction in fishing effort.

North Sea: Climate, eutrophication and fishing

The water temperature is projected to increase along with the potential for ocean acidification (decreasing pH). Additionally, changes in river nutrient supply might exacerbate the climate effect. Here, we compared two scenarios for varying nutrient loads projected for 2030 - 2040 and found that for this period climate impacts were projected to dominate over direct anthropogenic impacts in the North Sea. The wider effect of changes to the North Sea food web is necessarily a complex emergent property of the interactions of the many groups. In general though there are some broad conclusions about some of the trends that might be experienced as a result of changes in production: the highest trophic level species respond positively to less fishing and more nutrients, whereas the effects on demersal and flatfish are smaller. Moving to a maximum sustainable yield (MSY) based fishing approach clearly benefits the fish that are fished less whilst their competitors may be adversely affected. In other words, the fishing quotas of some groups that are being fished sustainably now may have to be revisited as a result of changes in population of competitors and predators. Smaller pelagic fish are the 'closest' trophically speaking to the plankton whose levels may change and are likely to see the most dramatic effects of any deliberate or inadvertent change in plankton composition.

Baltic Sea: Climate, eutrophication and fishing

The dynamics of the Baltic Sea ecosystem are rather complex and impacted by the very limited exchange with the North Sea, the imbalance in the freshwater budget and the upwelling response to the atmospheric forcing. This makes them quite sensitive to climate and hence, climate variability / change can affect the ecosystem in many different ways and on several time scales. Scenarios that account for short-term ecosystem response combined forcing from the interaction of policy related changes in the river nutrient supply and climate indicate that both factors affect the Baltic Sea lower trophic level ecosystem dynamics with the same order of magnitude. Direct anthropogenic impacts accumulate in the Baltic Sea due to a long characteristic time scale and limited exchange with the North Sea and the North Atlantic. The Baltic Sea is therefore especially vulnerable to anthropogenic impacts and the importance of ecosystem relevant policies for the Baltic Sea is emphasized. In terms of higher trophic levels, the projected future environmental conditions clearly hamper successful cod recruitment. However, the contrary is found for sprat. The fishing regime has no major effect on sprat biomass, instead, sprat spawning stock biomass is predicted to increase markedly and almost independently of the fishing regime.

Bay of Biscay: Climate and fishing

In the Bay of Biscay, one of the main anthropogenic drivers for the pelagic ecosystem is fishing. The main conclusion from the simulations performed here is that fish total stock responds differently to the FMSY and Fpa scenarios following the simulated period (near past 1980 - 2000 or future 2010-2099), and thus following the plankton input prey fields.

Black Sea: Climate, eutrophication and fishing

This study projects potential responses of the current Black Sea ecosystem to eutrophication in combination with climate change and therefore provides useful information for those concerned with mitigating and managing eutrophication in the Black Sea. Simulated chlorophyll concentrations are found to be a poor indicator of eutrophication, with zooplankton biomass found to be more responsive to changing nutrient loads. One interesting result of these simulations is that in two of the scenarios considered the opportunistic and non-native heterotrophic dinoflaggelate Noctilua scintillans disappears from the simulations as nitrate concentrations become too low to sustain its food sources (flagellates, diatoms and microzooplankton). The models described in this work may be applied to predict changes in relative phytoplankton biomass, relative fish biomass, nutrient enrichment and frequency distribution of events such as phytoplankton blooms etc. corresponding to thresholds defined by the MSFD.

North Aegean Sea: Climate, eutrophication, fishing and pollution

Under a warming scenario, small phytoplankton cells will become even more dominant in the autotrophic group while the heterotrophs to autotrophs ratio will increase. All scenarios describe decreasing river phosphate loads, resulting in a similar decrease of plankton productivity in coastal areas; which affects phytoplankton composition, showing a relative decrease of dinoflagellates. The reduction in plankton biomass led to a decrease of total fish biomass in the baseline scenario. This decrease was counterbalanced by decreasing fishing mortality in 'global community' and 'local responsibility' scenarios that also affected the overall structure of the food web, showing an increase in the mean trophic level and the small pelagic/large fish ratio. A similar, although weaker, counterbalance in the effect of decreasing plankton with decreasing fishing mortality and copper concentration was also simulated in scenarios with the Anchovy IBM, being more sensitive to changes in phytoplankton productivity than the pollutant.

Adriatic Sea: Climate, eutrophication and pollution

Large differences in the trophic state of the Adriatic Sea were driven by the reduction of the land based phosphate load occurred in the last two decades of the 20th century. The annually averaged chlorophyll profiles suggest how the reduction of phosphate load from rivers determines an overall decrease of the phytoplankton biomass at all depths (not only at the surface). The lower trophic level dynamics of the basin are very sensitive to variation in the land-based nutrient load, decreasing nutrients resulting in a shift towards more oligotrophic conditions. Progressive warming of the Adriatic basin is effectively boosting primary production but at the same time all the respiration losses are concurrently enhanced, therefore providing a compensating effect. Organic pollutants such as the herbicide terbuthylazine seem to have minimal effect when considering the region as a whole but may have an important role in limited areas where the impact may be acute.

Benguela upwelling: Climate and fishing

The impacts of a combination of climate and fishing pressure on the Benguela ecosystem have been explored for the period 2030 - 2040. The 'business as usual' scenario seems to favour an overall increase of fish biomass while all the other fishing scenarios cause fish biomass to decrease.

Implications for resource management

The goal of this aspect of MEECE was to contribute to the development of tools and management strategies to which take account of trends in uncontrolled (e.g. climate) or difficult to control drivers (eutrophication, pollution) and allowing a better management of drivers under human control (i.e. fisheries and introduction of alien species), as an important contribution to the ecosystem approach to management. Decision support tools (DST) are interactive computer-based systems that help decision makers utilise data and models to solve unstructured problems. We distinguish four major categories of DST that are applied in different stages of the process intended to provide relevant scientific advice to policy:

-Problem structuring: integrated assessments involving stakeholders in order to identify the problem, explore options to resolve the problem and agree a set of criteria against which these options can be evaluated.
-Information synthesis: tools which essentially synthesize monitoring data into meaningful metrics summarizing ecosystem state.
-Expert systems: tools that mimic the way decisions are reached by experts.
-Scenario planning: tools involving numerical models which can simulate and predict changes in the state of marine ecosystems in response to different management and climate driven scenarios (management strategy evaluation (MSE)).

Integrated ecosystem assessments (IEA)

The purpose of this IEA was to determine the main human activities, pressure/impacts and ecosystem components from a management / policy perspective. As the integrated management of the human activities should be driven by the European Integrated Maritime Policy of which the MSFD provides the ecological pillar this assessment was aimed at determining the risk that the main MSFD objective (i.e. GES in 2020) is not achieved. As only the pressures caused by human activities can be managed this IEA was based on establishing all relevant links between these activities and the 11 descriptors that determine GES. A risk assessment framework was developed and applied in order to determine for each of these activities their importance in terms of their contribution that GES is compromised. This was done through a qualitative/semi- quantitative assessment based on expert judgement in three regional teams covering some of the main MSFD (sub-) regions: the North Sea, Bay of Biscay, Mediterranean and Baltic Sea. The outcome of this IEA was then used as the basis for an evaluation of the relevance of the outputs of the MEECE simulation models in a policy/management context. When considering this relevance we distinguish between the pressure- and state-type of descriptors as the pressure descriptors are often directly linked to a specific pressure/activity while the descriptors of state essentially integrate the impacts of these different pressures. The IEA shows that fisheries were considered the most important human activity. Others are transportation, dumping, coastal protection, land reclamation and dredging but here their relative importance may differ depending on the region but also the uncertainty in this exercise. For the descriptors, state results show that overall biodiversity is the descriptor most likely to be compromised which follows from the fact that it encompasses most ecosystem components including those that contribute most to the risk of not achieving GES (i.e. several habitats and top predators like cetaceans, seals and seabirds). Most of the main ecosystem components are covered by the MEECE models except for the different habitats.

MSE

MSE tools provide a methodology for assessing the consequences of a range of management strategies or options and presenting the results in a way which helps the decision maker to make a rational decision, in the context of their own objectives, preferences, and attitudes to risk. The approaches developed in MEECE include analyses of empirical data and development and application of advanced quantitative models and methods, with examples of their use in management context of different drivers. The degree to which a given ecosystem is manageable partly depends on which are the most dominant pressures influencing the system. For example, eutrophication is one of the key pressures in the Baltic Sea, which can in principal be regulated by nutrient inputs, although the time scales of ecosystem response may be long. However, compared to, for example, the open waters of the North East Atlantic largely driven by ocean currents, the coastal ecosystems, which are relatively more directly and heavily influenced by human activities, are more susceptible to effective management. Nevertheless, climate impacts also interact with other human pressures in these relatively closed ecosystems and developing a general risk-based framework to support decision making and environmental management in marine ecosystems should allow the incorporation of climate change in order to be effective. For example, the information generated in MEECE suggests introducing temperature-induced effects (as well as effects due to other environmental stressors, such as pH) in the determination of reference values (EQSs) for marine and freshwater ecosystems, thus allowing the incorporation of climate change in the implementation of classical environmental management tools. Climate-driven alterations of environmental parameters (e.g. temperature, salinity, pH, oxidative potential) can, for example, act on contaminant bioavailability as well as on organism sensitivity to chemicals, thereby directly altering environmental risk on marine biota.

Indicators for the Seas (IndiSeas)

IndiSeas uses ecosystem indicators to evaluate the status of the world's exploited marine ecosystems in support of an ecosystem approach to fisheries, and global policy drivers such as the 2020 targets of the Convention on Biological Diversity. Key issues covered relate to the selection and integration of multi-disciplinary indicators, including climate, biodiversity and human dimension indicators, and to the development of data- and model-based methods to test the performance of ecosystem indicators in providing support for fisheries management. A major gap identified in IndiSeas and MEECE was that fishing may not always be the only or even the main driver of some ecosystem indicators of fishing. To determine whether, when, where and how ecosystem indicators can be used to measure effects of fishing in a fluctuating environment, specific aims of IndiSeas are to:

(i) assess the relative importance of fishing and environment for different ecological indicators;

(ii) identify years where the environment was more important than fishing; and
(iii) compare relative effects of fishing and climate across ecosystems.

To enhance the robustness of our cross-system comparison, unprecedented effort was put in to gathering regional experts from MEECE partners but also from other non-European developed and developing countries, working together on multi-institutional survey datasets, and using the most up-to-date ecosystem models.

Potential impact:

Coastal seas provide many beneficial goods and services to humankind, such as fisheries, recreation, climate regulation and coastal defence; however, marine environments are being disrupted by climate change and human activities. MEECE has explored a wide range of climatic and direct human influenced drivers which may affect the marine system. Policies related to marine resources and environments today require the development of management strategies that are robust to changes in the drivers affecting ecosystem productivity, such as climate change. The successful implementation of an ecosystem based approach to management requires evaluation of management strategies which take into account biological processes such as species interactions and their variability over space and time. It is important that the marine environment is observed and monitored to provide high quality environmental information / data, understand its role in our Earth system, track changes and predict the potential response of the ocean to stressors.

The target audience for MEECE research is primarily, decision makers in both the policy and management arenas but also includes SMEs interested in the application of knowledge, the wider marine science research community and the interested public. A particular focus of MEECE is the MSFD which provides a transparent, legislative framework to apply an ecosystem based approach to the management of human activities in the marine environment. The outputs from MEECE will also benefit the Common Fisheries Policy (CFP) aimed at protection of the marine resources from degradation and a sustainable exploitation of these resources needs integrative approaches that consider multiple drivers and biological interactions

in ecosystems.

The MSFD aims to achieve GES across Europe's regional Seas by 2020. The strategies to achieve this must contain a detailed assessment of the state of the environment, a definition of 'good environmental status' at regional level and the establishment of clear environmental targets and monitoring programmes. The MSFD also identifies 11 high level descriptors, 7 of which are considered by MEECE (D1 Biodiversity, D2 Non Indigenous species, D3 Commercial Fish, D4 Foodwebs, D5 Eutrophication, D6 Hydrography and D8 Pollutants). Each descriptor is characterised by a set of indicators which characterise marine ecosystems and requires and understanding of the possible pressures and impacts on them. The diversity in environmental conditions and the issues of scale have implications for the implementation of the descriptors in the assessment of GES. There is no single set of criteria and indicators which can meaningfully be applied to all marine regions/sub-regions, and often not even for a single descriptor within a marine region/sub-region, this requires a regional approach as used in MEECE.

It is important to recognize that only a few of the MEECE drivers (the ones directly related to human pressures) can actually be influenced by direct management actions. The simplest example is fisheries where management decisions have direct impacts on the ecosystem at a relatively small spatial and temporal scale. In contrast, the drivers of eutrophication, pollution and acidification in the marine environment mostly require land based management solutions, with possibly long time lags in environmental response. Whereas climate, as a natural driver, acts at a more global scale over extreme timescales, and is arguably beyond management possibilities but may be a factor to consider when developing management of the direct impacts.

The simulation models developed and applied in MEECE provide tools for addressing complex driver impacts and ecosystem responses. Such numerical models which can simulate and predict changes in the state of marine ecosystem in response to different drivers and management scenarios can support the decision-making process. A schematic view of the ability of the current models to provide policy-relevant information gives a subjective representation of the general skill of the models for each driver in relation to the knowledge base to usefully exploit the model information.

More specifically:

-Warming, circulation and stratification: Hydrodynamic models are able to provide useful information on temperature, circulation and stratification at a regional scale. This provides useful information on habitats and the transport of nutrients from which impacts on phytoplankton can be inferred. As we move up the foodweb, the implications of change become less clear.
- Acidification: Currently models are able to provide useful information on the inorganic carbon cycle (e.g. pH, PCO2) at regional scales; this is hampered in coastal regions by the lack of knowledge of alkalinity sources. The knowledge of the ecological implications of change is currently limited, but improving.
-Habitats: Models can provide useful information to define pelagic habitats (e.g. temperature, salinity, nutrients, stratification) at regional scales. The consequence of changes in habitat on the ability to achieve GES remains an open question.
-Eutrophication: Coupled hydrodynamic ecosystem models can provide useful information of nutrient loads, and chlorophyll concentrations and in some cases summer oxygen levels, but require the land derived sources to be well characterised. The consequences of change are well understood.
-Commercial fishing: There are a wide range of models of commercial fisheries of varying skills which provide information on fish stocks as well as the wider fish community and their response to changes in fishing pressure at regional scales. The capacity for simulating the impact of fishing on the whole ecosystem has been increased through the development of coupled end to end models. However these models are still in the proof of concept phase and should be applied with care.
-Pollution: This includes a wide range of compounds (greater than100 000) whose ecological impacts are often poorly characterised. Additionally there are always unknowns as new compounds are constantly being developed. Finally, the ecological implications of mixtures of compounds remain a topic of on-going research. If the source of a contaminant is well defined then existing models have the ability to trace its distribution at local and regional scales.
-Invasive species: Currently, there are no modelling tools which can usefully predict invasion and colonisation by invasive species. This is partly due to lack of knowledge of the ecology of invasive species and is confounded by the fact that new species periodically appear so there are always unknowns. Bioclimatic envelope modelling can provide useful information on changes in the distribution of species

whose habitat is well characterised.

MEECE and the Marine Strategy Framework Directive:

To meet the goals of EU Marine Strategy Framework Directive to achieve Good Environmental Status for marine ecosystems a holistic view considering all ecosystems is required. To illustrate and provide examples of the kind of information and outputs models can provide the MEECE Descriptor fact sheets were developed. Each one focuses on a descriptor and demonstrates via detailed case studies how models and related tools developed during the project can be applied to help answer some of the difficult questions that need to be addressed in order to meet the objectives of the MSFD. A fact sheet has been written to address each descriptor that was relevant to MEECE's activities; the full suite of fact sheets have been compiled into a distribution pack for broad dissemination and are available to download from http://www.MEECE.eu/kt/fs.html . A brief summary of what MEECE can contribute to each descriptor follows.

D1 Biodiversity:

Marine biodiversity is the range of life forms in the seas and oceans. This biodiversity may be measured by number of species, genetic resources and functional diversity. This makes assessing biodiversity a difficult process, given the variety of species and their functions in an area or region, as well as the genetic variation between individuals of a species, the structure of plant and animal communities, and their physical environment. The state of an ecosystem and therefore biodiversity is highly dynamic; changes in the state or pressures in one part of the ecosystem can lead to unexpected changes in another part, easily affecting overall biodiversity. This descriptor therefore has a strong inter-relationship with other MSFD descriptors. GES for biological diversity is deemed to be maintained when the quality and occurrence of habitats and the distribution and abundance of species are in line with prevailing physiographic, geographic and climatic conditions. MEECE has developed a number of models that can be used to predict indicators of biodiversity. For example, the impact of a range of drivers on functional biodiversity can be examined by looking at changes in phytoplankton and zooplankton populations. Plankton can be classified by size, function (carnivorous versus omnivorous) or taxonomically, providing information on the health and changing state of a defined region.

The OSMOSE model predicts spatial extent and temporal community population trends of fish species in regions including the Bay of Biscay and the Adriatic. Individual based modelling can be used to predict the fate of fish larvae leaving the spawning grounds. The size range of communities have been modelled by linking the APECOSM model (a model of top predator dynamics) to models at the bottom of the food web, and categorizing results in terms of habitat. Using the EwE model changes in abundances of many species can be examined providing an indicator of population dynamics in marine communities. Regions studied include the North Sea, Black Sea and the Benguela uprising off South Africa. This approach allows biodiversity to be evaluated through looking at; the replacement of native species by invasives, the relative number of the least common and higher trophic level groups such as sharks, mammals and seabirds, and the status of commercially important stocks.

D2 Invasive species:

NIS are those that are introduced from their native range through the ballast water of ships, through marine and inland canals, via culture and stocking procedures, or by other unintentional or deliberate human vectors. Some NIS may become invasive, increasing their abundance and spreading over large regions, with adverse impacts on native biodiversity, habitats and ecosystem functioning, and even economy and human health. Such an adverse alteration of ecosystems is called biological pollution (biopollution). GES is achieved if non-indigenous species introduced by human activities are at levels that do not adversely alter the ecosystems. The EC decision on criteria and methodological standards on GES of marine waters (EC 2010/477/EU) calls for scientific and technical development of indicators of impacts of invasive NIS. To classify the level of invasive species impacts an integrative method, the 'biopollution level index' (BPL), was developed. The index is based on the classification of the abundance and distribution range of NIS and the assessment of the magnitude of their impacts on native communities, habitats and ecosystem functioning. BPL ranges from 0 ('no measurable impact') to 4 ('massive impact'). Such a scale for biopollution impacts helps to reduce subjectivism in measurement and reporting impacts, but also makes possible initial and trend assessments to determine the status quo according to MSFD requirements.

The MEECE project supported development of the online Biological invasion impact/biopollution assessment system (BINPAS) based on BPL methodology. BINPAS was created using open source web technologies and relational database management systems. It provides a user-friendly interface to calculate BPL and allows for the sharing of ecological data, providing inter-regional comparisons and meta-analysis of biological invasion effects at different spatial and temporal scales
http://www.corpi.ku.lt/databases/index.php/binpas

BPL may be estimated only for the areas with known history of biological invasions. Data on abundance and distribution of NIS present in the system is a prerequisite for the assessment, and at least, basic knowledge on local native biodiversity and environmental impacts of invasive species is required. Extensive literature searches are required to make the assessment and despite robust rule-sets, still a certain level of subjectivity may be present in the assessments, because the assessor needs to deal with incomplete scientific information. However, all background data is stored in BINPAS may be easily extracted and checked for validity.

D3 Commercial fish:

The descriptor 3 definition for GES is: 'Populations of all commercially exploited fish and shellfish are within safe biological limits, exhibiting a population age and size distribution that is indicative of a healthy stock.' Key criteria for measuring GES include the level of fishing pressure, the reproductive capacity of the stock and the age and size distribution of the assessed population.

Fishing is the only driver explicitly considered as part of this descriptor and the only activity subject to tactical management at the appropriate scales of space and time. Other drivers such as climate, however, could become relevant and should be considered for the longer-term strategic management of fishing activities. At the scale of several decades, considerable and regionally-different changes in productivity can be expected due to climate or eutrophication which should be considered when setting management targets for this descriptor.

A suite of modelling tools has been identified, each targeting the major exploited fish resources in each of the MSFD regions. A diversity of approaches has been used ranging from foodweb and size structured models to individual based models (IBM) and single- or multi-species stock assessment models. Several of these models can be coupled to models of the bottom of the food web, allowing the exploration of the impact of fishing pressures and other drivers. One important exercise within MEECE has been the application of such models to explore the reference levels required for operationalising the objectives/criteria for GES of this descriptor.

D4 Foodwebs:

Climate change will exacerbate the impacts of human activity on the structure and function of marine ecosystems, and the services they provide. The combined effects of climate, fishing, nutrient loading and pollution impacts at both organismal and population levels, influencing the competitive ability and dominance of key marine species, which in turn reorganises the structure of marine food webs. The MSFD states that GES is achieved if the integrity of food webs ensures the long-term abundance and reproduction of its species.

The MEECE project provides climate and ecosystem (from plankton to fish) response scenarios, to support decision making for marine policy and management. In MEECE, coupled physical to ecosystem models are used to evaluate the marine food web responses to climate scenarios in the medium (2030 - 2040) and long-term (2080 - 2100). In these scenarios, oceanographic circulation models are forced by climate drivers, which in turn, are coupled with lower trophic models (phytoplankton and zooplankton) to evaluate changes in oceanic primary production.

D5 Eutrophication:

Eutrophication refers to the processes related to discharge of macronutrients in the marine environment that stimulate the rapid growth of microalgae and lead to disruptive effects on the marine environment. The eutrophication descriptor focuses on both anthropogenic and natural causes (i.e. human induced increased river nutrient loads, and coastal nutrient increases due to climate effects), and their direct (increased phytoplankton blooms or decrease in transparency) and indirect (decrease of benthic plants) effects. Eutrophication has broad reaching impacts and can have negative impacts on other descriptors such as biodiversity, non-indigenous species, food webs and commercial fish.

MEECE has produced a number of tools that can be used in decision making and management around eutrophication in European regional seas. The MEECE suite of regional biogeochemical models provide state of the art tools to understand the impacts of eutrophication, and how climate change and policy management could affect this descriptor. Current models are able to provide estimates for recent trends and future forecasts for several of the indicators for eutrophication. Although each model has different structures and characteristics, indicators relevant to this descriptor that can be addressed by MEECE biogeochemical models include: nutrient concentration in the water column, chlorophyll concentration, phytoplankton biomass, dissolved oxygen. Additionally, some models can provide more detailed information on nutrient ratio and phytoplankton community composition. It should be born in mind that uncertainties related to the coarse resolution of models and process formulations of growth, respiration, mortality and regenerative production in state of the art biogeochemical models are responsible for large model spread in eutrophication risk assessments. Such uncertainties currently limit the applicability of single model approaches to eutrophication management problems, looking at the outputs from a number of biogeochemical models could provide a more robust assessment.

D7 Hydrography:

Hydrographical conditions are the physical properties of seawater (temperature, salinity, depth, currents, waves, turbulence, turbidity). They play a crucial role in the dynamics of marine ecosystems. In the near shore regions many of these are directly influenced by human activity so can be targeted by policy and management actions.

At the scale of the continental shelf these properties are however largely determined by natural phenomena and so less responsive to management action on human activities. However, they are subject to large-scale changes driven both by climate change (including warming and ocean acidification) and natural variability. These can have important and long lasting consequences for marine ecosystems, both beneficial and adverse. GES assessment and targets are based on quantifying the extent, distribution and severity of permanent alterations in hydrographical properties as a result of human activities.

MEECE has made a substantial contribution to the international capability to simulate these effects and explore possibilities resulting from particular climate scenarios, which can include both natural and human induced changes. A particularly relevant aspect of hydrographical change that these models can explore is global warming, including changes in sea temperature and density stratification, as the surface layers of the open ocean warm much faster than the water at depth. Stratification reduces the vertical mixing of nutrients needed to support the growth of the microscopic plants (phytoplankton) that form the base of the marine food chain. Other effects include changes in nutrient transportation from the open ocean to the shelf seas, the timing of spring blooms and the speed at which organic material is 'recycled' back to the inorganic nutrients that support the growth.

While we are not yet in a position to make accurate forecasts for these properties, simulations provide important evidence that can be used alongside expert judgement to inform adaptation policies on issues such as the definition of marine protected areas, the level of exploitation of marine living resources and marine renewable energy resources. There is still a high degree of uncertainty in projecting future change in marine ecosystems resulting from changes in hydrographical conditions. However, many of the principles are well established and by relating the output of models such as these to well-founded scientific concepts, such as the increase in growth rates with temperature or reduction of mixing with density stratification, these simulations can build a body of increasingly reliable evidence.

D8 Pollution:

GES for contaminants under the MSFD states that 'concentrations of contaminants are at levels not giving rise to pollution effects'. Pollution effects are defined as 'direct and/or indirect adverse impacts of contaminants on the marine environment, such as harm to living resources and marine ecosystems, the hindering of marine activities, impairment of the quality for use of sea water and reduction of amenities or, in general, impairment of the sustainable use of marine goods and services'. Consequently, chemical pollution is closely linked to other GES descriptors, such as biodiversity, integrity of food webs and sea-floor ecosystems.

Impacts of contamination have been considered in several tasks of the MEECE project. In particular, project activities were focused on target contaminants such as heavy metals, alkylphenols, antibiotics and herbicides. Available scientific information about the fate of key-pollutants and the biological effects on marine organisms were collected and collated into structured databases. A set of multi-driver experiments was then carried out in order to parameterise biological responses induced by key-pollutants and other climate change relevant drivers.

MEECE has developed an expert DSS, focused on managing contamination in marine coastal areas which calculates the pollution-related environmental risk on a scale from 0 (no risk) to 1 (maximum risk) integrating a complex set of chemical (concentration of target contaminants) and biological data (ecotoxicological effects on model organisms), thus supporting environmental managers in the estimation of environmental quality. The framework of the expert DSS is mainly based on the integration of heterogeneous (chemical and biological) data, through a weight of evidence approach, into risk indexes useful in improving the decision-making process. With this objective, the quality and quantity of input data are key factors in determining the reliability of results obtained.

Managing marine ecosystems in a changing environment

MSE in a broad sense involves addressing the consequences of a range of management strategies or options and presents trade-offs in performance across a range of management objectives. An MSE framework generally includes a model of a virtual ecosystem where parts are affected by human activates. Feedback loops ensure the system is dynamic and responsive to changes in human and ecosystem response. MEECE has developed a number of bespoke MSE frameworks and models to address management questions, including:

- forecasting changes in productivity,
-assessing potential spatial expansion of the habitat of NIS,
- assessing the extent of spawning habitat of key fish species and distribution of fish in relation to climate change,
- quantifying spatio-temporal overlap between ecosystem components and pressures,
- evaluate management strategies for fisheries (Bay of Biscay, Baltic and North Seas), taking into account species.

Web-based dissemination tools:

MEECE has developed a number of online tools to help disseminate its outputs. The model Atlas provides interested users and site visitor's access to model derived outputs and simulations produced as a result of the efforts of the MEECE scientific community. The model library gives users an overview of the available modelling tools and indiSeas provides online indicators of the status of 34 marine ecosystems worldwide, both are described in more detail below. The online decision support tool for NIS, BINPAS is described in section D2 NIS.

The MEECE model Atlas (see http://www.meeceatlas.eu online) covers the main European regional seas and provides simulations and projections for how ecosystems will respond to different scenarios for environmental change, in a form that's readily accessible to policy-makers, fisheries officials and other users of marine science. Using ecosystem end-to-end models, the Atlas provides a holistic view of the continent's marine resources. Marine ecosystems are represented at all levels, from the physics and chemistry that underlie it to plankton, fish and human activities. During the MEECE project, predictive regional models and have been developed and refined to explore the combined impacts of ecosystem drivers of change. The results of these efforts are presented through a publically available web Atlas. Aimed at environmental managers and marine policymakers to help make scientifically informed decisions about resource management and usage strategies, the Atlas incorporates a range of potential future scenarios based on climate trends and socio-economic development over the coming decades. These scenarios include the Intergovernmental Panel on Climate Change (IPCC) climate projections for near future (up to 2040) and the far future (up to 2100) alongside the human development scenarios of 'local responsibility', a community-based approach with slow economic growth but increases in small scale production; 'world markets', rapid growth and favouring consumerism over environmental objectives; and 'global community', growth that balances economic, environmental and social needs.

Web-based model library tool with mapping to GES indicators:

MEECE consortium created the MEECE model library, available from http://www.meece.eu/Library.aspx online. To increase its functionality and policy relevance, the capabilities of the modelling tools in the model library have been mapped onto the EU's MSFD's descriptors for GES. Users are able to search for a modelling tool addressing specific descriptors in a geographic region of interest, or browse the technical content of the library. The library currently proposes modelling tools that can be applied in European Seas to address questions on 7 of the 11 GES descriptors for the regional sea of interest.

IndiSeas (see http://www.indiseas.org online) was initially launched in September 2009, was developed to disseminate results of analyses of the original eight ecological indicators for assessing the status of exploited marine ecosystems, to marine resource managers, fisheries scientists, policy-makers, interested and affected stakeholders and the general public, i.e. beyond a scientific audience. This complemented the suite of scientific papers published in the ICES Journal of Marine Science.

Exploitation of MEECE outputs: Towards operational applications:

MEECE has achieved its two major goals. Firstly, through the development and application of regional ecosystem modelling tools combined with meta-analysis and experimental work the knowledge base on response to climate and anthropogenic driving forces of marine ecosystems has been expanded. In particular, models provide information of the state of the system (historic, present and future), the pressure state interactions, and how the probability of a negative indicator event may change. Secondly by developing innovative decision support and management strategy evaluation tools and strategies to resolve the dynamic interactions of the drivers, in support of marine management and policy. This is augmented by the MEECE Atlas and indiSeas websites. The challenge for the future is to ensure this work is taken forward and used both in a research and a policy/management context.

The schematic diagram shows the relationships between research and operational applications, illustrating how starting with experiments and observational data, models are developed and applied and then used in an operational context.

MEECE has been proactive in engaging with the development of the MSFD; MEECE scientists led the working groups which developed the D2 NIS and D3 Commercial fish descriptors. Other scientists have been involved in working MSFD, Arctic acidification and ICES working groups. This type of activity is ongoing and will ensure that the MEECE knowledge base is disseminated widely amongst users. These activities are backed up by the MEECE Atlas and the accompanying factsheets.

The MEECE regional modelling tools along with the associated methodologies for downscaling and simulation assessment will be exploited both in new national and European research programs and through the GMES marine core service through the development of operational ecology. Operational ecology refers to the provision of operational services for biogeochemical and ecological parameters through a forecast system to project the future status of marine ecosystems by delivering a suite of error quantified indicators which describe changes in ecosystem function. The system should include an observational network along with models of the hydrodynamics, lower and higher trophic levels (plankton to fish) and biological data assimilation. Such systems are required to help assess and manage the risks posed by human activities on the marine environment. For example, a number of MEECE models and regional model systems (Norteasr Atlantic, North Aegean, Black Sea, SMS-Baltic) are being further evaluated as to their suitability for making operational rapid environment assessment of the state of the ecosystem in the recent past terms of key indicators. In addition, the indiSeas and BINPAS activities provide valuable information on the state of regional ecosystems. BINPAS is being used to make assessments for D2. Both activities will carry on after MEECE.

The DSS and MSE tools sit on the boundary between the research and operational domain. MEECE has developed a number of frameworks and models which address management questions in the context of the interactions between climate, fishing, pollution, NIS and eutrophication. The next step is the practical application of such systems to develop management strategies which are robust to changes in environmental drivers. Many of these tools were developed by MEECE and will be further exploited by organisations directly involved in the implementation of the MSFD at a national level.

Finally, MEECE was a genuinely European project. It brought together expertise and intellectual resources from across Europe. The progress made by MEECE in understanding the response of marine ecosystem to external perturbations and developing tools and strategies to manage them was only possible through Europe wide interdisciplinary cooperation.

List of websites:

- http://www.MEECE.uk
- http://www.MEECEatlas.eu

Related documents

143671991-8_en.zip

Last update: 1 September 2013
Record number: 58535