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EUROMARINE

INTEGRATION OF EUROPEAN MARINE RESEARCH NETWORKS OF EXCELLENCE

EUROMARINE RESEARCH STRATEGY REPORT

EuroMarine Deliverable 3.2.

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SEVENTH FRAMEWORK PROGRAMME

EUROMARINE RESEARCH STRATEGY REPORT

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Suggested citation

Boyen C., Heip C., Cury P., Baisnée P.-F., Brownlee C., Tessmar-Raible K., *et al.* (2012) EuroMarine Research Strategy Report - Deliverable 3.2. Seventh Framework Programme Project EuroMarine – Integration of European Marine Research Networks of Excellence. FP7-ENV-2010.2.2.1-3. Contract Number 265099.

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SEVENTH FRAMEWORK PROGRAMME

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Executive Summary

EuroMarine is a Coordination and Support Action funded by the European Commission for two years (FP7, 2011-2013). Its aim is the integration of three major European marine FP6 Networks of Excellence (NoE) (**EUR-OCEANS, MarBEF** and **Marine Genomics Europe**) into one durable organization EuroMarine+, bringing together leading European marine scientists and organizations to create a major internationally competitive network that will facilitate collaboration and promote interdisciplinary approaches in the marine sciences. EuroMarine's main responsibilities therefore lie, firstly, in the definition of the vision, the specific role and the organizational and operational modes of EuroMarine+, and secondly, in a timely launch of EuroMarine+.

One key objective of EuroMarine is, founded on the achievements, conclusions and prospective from each of the three NoEs, to develop a common vision on **research priorities** and a common **research strategy** based on a shared vision for the oceans, regional seas and coasts of tomorrow, in order to create a strong marine R&D leadership for Europe based on scientific excellence.

Three main areas were identified as key priorities and challenges for the future of marine sciences in Europe, based on the combined and comprehensive expertise of the large EuroMarine community. Among these areas both scientific and societal priorities were defined. In addition key emerging fields were identified exemplifying strategic issues common to the three NoE communities and clearly requiring combined expertise to be addressed. These emerging fields are fully in line with the trading zone notion which describes how exchanges across disciplinary boundaries and interdisciplinary collaborations can lead to new concepts and new discoveries. These emerging fields, illustrating the added value of integrating the three former NoE scientific communities into EuroMarine+, inform and provide targeted priority actions, for example, the organization of specific exploratory workshops.

Priorities and Challenges

Area 1- Understanding Marine Ecosystems for Healthy Oceans

Priorities

- Determine the combined impact of many stressors - which act differently according to locality and ecosystem, and with species- and life cycle/stage-dependent effects - in order to predict future changes and to design and prioritize mitigation policies;
- Understand the resilience of marine ecosystems in general and food webs in particular, including the role of top down food web regulation and its vulnerability through global change including acidification and overfishing. This includes how adaptive processes will change species characteristics and therefore ecosystem functioning under increasing selective pressures.

Challenges

- Understand the impacts of environmental change on marine ecosystem functioning and health;
- Sustain and restore marine ecosystem functioning and health.

Area 2- Building Scenarios for Changing Oceans

Priorities

- Develop and improve the predictive capabilities of a hierarchy of ecological models to their full potential together with the use of a suite of integrated environmental, biogeochemical, and ecosystem end-to-end models to explore the range and extent of possible future ecosystem states under different scenarios;
- In order to meet the societal needs of preserving ecosystem services, a wide range of scenarios over long (50 - 100 year) time horizons for the future state of marine ecosystems need to be taken into account.

Policy makers and stakeholders need to understand the fundamental uncertainties associated with predictive models and complex systems, the services associated with ecosystems and biodiversity, and the risks associated with degradation or loss of the latter. They will engage with scientists in iterative exercises for the construction of scenarios for regulatory or target state options or the evolution of drivers of environmental change and ecosystem dynamics.

Challenges

- Combine disciplines to address complex questions and include key processes in models (scaling up from organismal processes to ecosystem functions and services);
- Define and implement a common strategy for next generation ocean and end-to-end ecosystem models;
- Develop and promote interoperability and free access to the great variety of structured observation/data/information systems presently available in marine sciences;
- Use narrative scenarios to link socio-ecological scientific issues and to inform stakeholders;
- Promote scenario laboratories in order to facilitate communication, comprehension and discussion of available information and possible scenarios between stakeholders and the scientific community;
- Provide a European marine focal point and resource centre for the Intergovermental Platform on Biodiversity and Ecosystem Services (IPBES).

Area 3- Marine Science as a Provider of New Concepts and Driver for Innovation and Technology

Priorities

- Unlock the potential of the marine realm through the development of marine research to discover and develop new biological models/concepts and to incorporate new discoveries into biomedicine, biotechnological applications as well as ecosystem models;
- Better understand fundamental life processes and special adaptations, from molecular to whole organism levels;
- Improve understanding of the importance and impact of marine discovery to the benefit of society;
- Satisfy the increasing need for marine-derived products, including food, biomedical and biotechnology products, energy and ores;
- Provide new services, including recycling and bioremediation.

Challenges

- Facilitate cross-disciplinary interaction to underpin the exploration/discovery of marine organisms, systems and processes;
- Create innovative fundamental and strategic research through cross-disciplinary teams to address the key scientific and societal needs;
- Promote integration and synthesis in the trading zone.

A common overarching challenge is to empower society through training, education and outreach; reinforce quantitative techniques for students and maximise the impact of research through a strong knowledge exchange programme.

Emerging Fields in the Trading Zone

1-Intra-generational (plasticity) and intergenerational (adaptation) evolution and forecasting of living marine resources. Contribution of genetic adaptation, including epigenetics, in ecological decadal time frames;
2-Complex interactions including tipping points, regime shifts and shifting assemblages;
3-Effects of global warming, acidification, sea level rise, hypoxia and biodiversity change on ecosystems;
4-Marine rhythms of life and their alterations. Chronobiology at tidal, diurnal, seasonal, annual and decadal scales: from molecule to ecosystem function;
5-Valuation of goods and services delivered by marine ecosystems;
6-Restoration and conservation of sustainable marine ecosystems.

Fig. 1. A common overarching challenge is to empower society through training, education and outreach; reinforce quantitative techniques for students and maximise the impact of research through a strong knowledge exchange programme.

1. Introduction

EuroMarine is a Coordination and Support Action funded by the European Commission for two years (FP7, 2011-2013). Its aim is the integration of three major European marine FP6 Networks of Excellence (NoE) (EUR-OCEANS, MarBEF and Marine Genomics Europe) into one durable organization (hereafter referred to as EuroMarine+) bringing together leading European marine scientists and organizations to create a major internationally competitive network that will facilitate collaboration and promote interdisciplinary approaches in the marine sciences. EuroMarine's main responsibilities therefore lie, firstly, in the definition of the vision, the specific role and the organizational and operational modes of EuroMarine+, and secondly, in a timely launch of EuroMarine+.

One key objective of EuroMarine is, founded on the achievements, conclusions and prospective from each of the three NoEs, to develop a common vision on research priorities and a common research strategy based on a shared vision for the oceans, regional seas and coasts of tomorrow, in order to create a strong marine R&D leadership for Europe based on scientific excellence.

In order to achieve this objective and with the final goal to produce a report describing the future research strategy of EuroMarine+ for the next 10 years, two 2-day workshops were organized, one in June 2011 and the other in February 2012 with about 30 participants from the three NoE communities. Each of these workshops combined scientific presentations, general discussions and parallel working group meetings. The first workshop was devoted to analysing and synthesizing the legacy of the three FP6 NoEs, which were built and operated quite independently. The major goal of Marine Genomics Europe was to integrate genomics with marine biology in order to implement high-throughput approaches in genomics and post-genomics in the biology and ecology of marine organisms and ecosystems. MarBEF's overall objective was to investigate the relationships between marine biodiversity and ecosystem function and to understand the economic, social and cultural value of marine biodiversity. EUR-OCEANS focused on the development of models for assessing and forecasting the impacts of climate and anthropogenic forcing on food-web dynamics of ecosystems in the open ocean.

Three main areas were identified as priorities and challenges for the future of marine sciences in Europe, based on the combined and comprehensive expertise of the large EuroMarine community:

Area 1- Understanding marine ecosystems for healthy oceans
Area 2- Building scenarios for changing oceans
Area 3- Marine science as a provider of new concepts and driver for innovation and technology

The first workshop also analysed the FP6 NoE's background and identified scientific and societal needs, major challenges and research priorities for each of the three main areas.

During the second workshop, parallel working sessions and general meetings allowed the participants to define leading priorities and common objectives. One aim of the second workshop was to identify key emerging fields, exemplifying strategic issues common to the three NoE communities for which combined expertise was essential in order to be addressed. These emerging fields are fully in line with the trading zone concept where exchanges across disciplinary boundaries and interdisciplinary collaborations can lead to new concepts and new discoveries.

1-Adaptation, plasticity, evolution and forecasting the future of living marine resources. Contribution of genetic adaptation, including epigenetics, in ecological decadal time frames;
2-Dealing with complex interactions including tipping points, regime shifts and shifting assemblages.
3-Effects of global warming, acidification, sea level rise, hypoxia, biodiversity change (e.g. invasive species) on ecosystems;
4-Marine rhythms of life and their alterations. Chronobiology at tidal, diurnal, seasonal, annual and decadal scales (with marine organisms showing unique features): from molecule to ecosystem function;
5-Valuation of goods and services delivered by marine ecosystems;
6-Restoration and conservation of sustainable marine ecosystems.

These emerging fields illustrate the added value of integrating the three former NoE scientific communities into a single consortium, namely EuroMarine that can inform and provide the priority actions for EuroMarine+. Priority should be given to, for instance, the organization of specific exploratory workshops in these emerging fields for research, training and education strategies.

Fig.2. Emerging fields in the trading zone; where exchanges across disciplinary boundaries and interdisciplinary collaborations can lead to new concepts and new discoveries.

Fig.3. © Y. Fontana - Station Biologique de Roscoff

2. Priorities and Challenges

2.1. Area I- Understanding Marine Ecosystems for Healthy Oceans

The Marine Strategy Framework Directive will be the legal framework for the future management of Europe's marine environment. It provides inter alia the requirement that the EU will achieve a Good Environmental Status (GES) of its marine waters by 2020. The European Commission's decision from 2010 provides a list of 11 descriptors and related criteria and indicators. One of the criteria to judge GES is biodiversity, another is the integrity of the sea floor. The Common Fisheries Policy (CFP) of the EU is another legislative document built on the ecosystem approach. Do we really understand marine ecosystems sufficiently well to use that knowledge in such a context? What have been advances in (fundamental) knowledge that are relevant and where are the gaps? What are the new technologies that are required to observe and understand marine ecosystems? How should ecosystem health be characterized and how should we integrate natural sciences with socio-economics in order to better understand changes and their potential impact on citizen well-being and quality of life? One aim of EuroMarine+ is to improve the knowledge on processes to better understand marine ecosystem dynamics in order to contribute to the GES.

2.1.1. Background

Despite their vastness, the oceans are increasingly impacted by human activities at all levels. There is overwhelming scientific evidence showing that the oceans are vulnerable and overexploited and that ever-rising emissions of greenhouse gases are causing climate change with profound impacts on the marine environment. As a consequence of overfishing top predators are disappearing and food webs are changing (fishing through the food chain). Further, due to increasing anthropogenic CO_2 emissions, sea level is rising, oceans are becoming warmer (global warming), more acidic (ocean acidification) and losing oxygen (becoming anoxic). These processes are clearly changing ecosystems and marine biodiversity, but it remains unclear how they currently impact marine ecosystem functioning and delivery of marine ecosystem goods and services and how they will do so in the future.

Defining ocean health or healthy ecosystems is a difficult task. The use of the term health may in fact be misleading as there is no real analogy between state and function of an ecosystem and human health. Ecosystems exist and function regardless of our human perception of what their health should mean. But conversely, we can define criteria which translate this perception and which relate to the pressures resulting from human use of the oceans and the planet in general. These pressures are multiple and act together on marine species and ecosystems. Understanding both the pressures and the changes they trigger either alone or collectively, is necessary for defining ecosystem health as an adequate tool for proper management for sustainable use, conservation and restoration, of marine species and ecosystems. Ocean health must also relate to ecosystem functioning, which includes processes such as primary and secondary production, nutrient cycling and mineralization, bioturbation and sediment stabilization, as well as species interactions such as predation and competition which shape food webs. Again it is unclear when and why ecosystem functioning is healthy, this again requires a value judgment based on human use and perception of the oceans. For example: Do we value productive systems over species-rich systems? Do we prefer sandy beaches over sulfide rich muds?

In order to optimize sustainable human use of the oceans we need to better understand ecosystem functioning at all scales, from the gene to the whole ecosystem. Important components of ecosystems are poorly understood, especially the roles of microbes and parasites. Adaptation under selective pressures arising from global change is another area that requires more detailed understanding. Fisheries currently exposed to ecosystem and climate change are an important driver, however economic and social data on impacts of ecosystem change on significant markets such as fisheries, aquaculture and tourism is very limited. The oceans are mentioned over twenty times in the Rio+20 declaration but it remains to be seen whether the future will allow further study and mitigation of the multiple and increasing problems that oceans face.

2.1.2. Identification of key needs/ priorities

Overarching scientific needs

An exponentially growing body of evidence demonstrates the negative impacts of rising temperature, pH/pCO_2 and other consequences of human activity (e.g. overfishing, habitat destruction and hypoxia) on the resilience of marine ecosystems. Over the last ten years, these questions have attracted considerable attention from the scientific community, generating collaborative and multidisciplinary efforts (e.g. EPOCA, the first European Project on Ocean Acidification) and creation of state-of-the-art experimental facilities accessible through infrastructure access programs (e.g. ASSEMBLE, EMBRC) and best practices (e.g. EPOCA best practice guide for ocean acidification research by Riebesell *et al.*, 2010). These efforts, while they are to be welcomed are not sufficient in the face of the rapid changes expected in our marine ecosystems. Experimental work in the laboratory and mesocosms, modelling, as well as paleoceanographic reconstructions of past analogous perturbations are now required to generate scenarios for future change. The combined impact of the many stressors - which act differently according to locality and ecosystem, and with species- and life cycle/stage-dependent effects - has to be better understood in order to predict future changes and to design and prioritize mitigation policies.

Societal needs

Defining and measuring ecosystem health is still a basic requirement for the implementation of management strategies and environmental legislation. To better understand ecosystem functioning, we need research on biogeochemical cycles and on ecological processes. An important problem is understanding the resilience of ecosystems in general and food webs in particular, the role of top down food web regulation and its break down through overfishing, and the adaptation processes that will change species characteristics and therefore ecosystem functioning under increasing selective pressure from anthropogenic stressors. The diversity of organisms in marine habitats provides a range of ecosystem services and benefits of significant value to the European society. These benefits include food (fish and shellfish), reduction of climate stress (carbon and greenhouse gas regulation), genetic resources (for aquaculture), blue biotechnology (e.g. biocatalysts, natural medicines), fertilizer (e.g. seaweed), and also less obvious ones such as coastal protection, waste detoxification and removal, disease and pest control, tourism, leisure and recreation as well as educational and cultural opportunities. Biofuels from macro- and microalgae are likely to become reality in the near future. Many of the benefits are accrued directly by coastal dwellers and visitors, but also indirectly by the whole European society.

2.1.3. Challenges and objectives

The pressures on marine ecosystems are multiple and, although often unrelated, act together on marine species and ecosystems. Both the pressures themselves and their consequences are summarized as environmental or global change. Understanding of both aspects, separately or collectively, is necessary for proper management, including sustainable use, conservation and restoration, of marine species and ecosystems.

CHALLENGE 1: Understand the Impacts of Environmental Change on Marine Ecosystem Functioning and Health

The FP6 marine NoEs, and particularly MarBEF, offered a new framework under which ecosystem health should be re-defined in order to be more efficient in its application to both scientific and managerial fields: biodiversity and ecosystem functioning (BEF). This framework should take into account explicitly the intra-specific components of biodiversity which are modifying species interactions, population dynamics and community trajectories. The development of new methodologies and metrics (bio-indicators) for the efficient and accurate measurement of ecosystem health (including its bench marking) emerges as an urgent need for the effective implementation of the EU Directives and policies (e.g. Marine Strategy Framework Directive, Marine and Maritime Policy). Even as we gain understanding of the conceptual links between marine biodiversity, ecosystem function and provision and value of ecosystem goods and services we will still need to seek better ways of gathering data to further develop and support this understanding. Although there is substantial data concerning the state of European seas, extensive data gaps remain on the characteristics of some of its biodiversity, and some of its functioning. A predictive capacity to anticipate the impacts of human activity on the provision of marine ecosystem services and benefits is urgently required to support policy and management.

A diversity of ecological functions and processes underpin the provision of marine ecosystem services, but the relationships between them need to be elaborated and quantified with the key processes and elements of biodiversity determined. There may be a uniform relationship between biodiversity and the provision of marine ecosystem services or there may be crucial non-linearities ('tipping points') at which delivery is no longer possible. These relationships too need to be defined.

In addition, marine ecology traditionally focuses on the classical food web and since the 80's of the previous century, increasingly on the microbial food web which had previously been only poorly understood. Our knowledge has increased tremendously but still a large number of questions on the role of micro-organisms remain. One of the most important gaps in knowledge is the role of pathogens. The impact of viral and prokaryotic pathogens on ecosystem health is a crucial research area that is largely in its infancy. The world's oceans also harbor a plethora of parasites from various phyla and probably all free-living marine eukaryotes are infected by at least one parasite species. There are indications that marine viruses, bacteria and parasites represent important structuring forces in marine ecosystems and are intricately embedded in marine food webs. Although we have a very basic idea of their role in marine ecosystems, large gaps remain in our understanding of their effects on ecosystem functioning and health. First of all, a combination of molecular and ecological studies is needed to identify the actual richness of pathogens and parasites and experimental studies are urgently needed to link their effects to ecosystem functioning and health. Secondly, it will be crucial to understand the effects of multiple biotic and abiotic stressors, on hosts, food webs and ecosystem functioning. Ecological studies will need to be coupled with metagenomics, gene expression and immunological studies to understand the full chain of mechanisms of parasite, pathogen and virus effects from genes to ecosystems. For more details see Marine Board Position Paper 17 'Marine microbial diversity and its role in ecosystem functioning and environmental change' by Glöckner *et al.*

Understanding how marine organisms adapt to environmental changes over spatial and temporal scales relevant to current processes of global change is of primary importance. In the face of environmental changes, organisms can escape, acclimate through phenotypic changes or adapt. Experiments on short-generation organisms (e.g. micro-organisms) and empirical studies using genomic approaches show that evolutionary changes may be occurring on time-scales that are much shorter than previously thought, a phenomenon called 'contemporary evolution' which plays over ecological timescales. Documenting evolutionary processes is challenging because of the interplay between environment and genetic variations in shaping the evolutionary trajectories. Genomics can help to address these issues on ecologically-relevant models (e.g. indicator species; keystone organisms; endangered, exploited, engineered or introduced species). Experimental studies combining selection experiments, crossing designs, omics toolkits and theoretical models implementing particular traits and characteristics (e.g. complex life cycles, role of oceanic currents) are expected to provide important insights on adaptation processes in the wild.

Finally, we need to develop function-value relationships between marine ecosystem services and the benefits they generate so that we can understand how changes in marine ecosystem processes and functions will affect their social and economic values. In order to determine the socio-economic impacts, it is thus necessary to integrate efforts of economists, natural scientists and social scientists in a joint research area.

CHALLENGE 2: Sustain and Restore Marine Ecosystem Functioning and Health

To keep marine ecosystems healthy in the face of change, it is necessary to manage adequately the ocean and coastal areas as well as continental watersheds and the atmosphere. This requires an integrated or holistic approach to ecosystem management, recognizing the need to manage the impacts of human activities on ecosystems in order to achieve sustainable use of ecosystem goods and services and maintenance of ecosystem integrity (ICES 2000). To be able to do this, data and models are necessary. Monitoring and observing the global oceans requires an international vision and broad cooperation. The IOC manages the Global Ocean Observing System to provide a coordinated approach to deployment of observation technologies, rapid and universal dissemination of data flows and delivery of marine information. This is necessary to inform and support marine management and decision making and to increase the appreciation of the general public of our changeable oceans.

The conditions on which perturbations are superimposed partly define the biological response to the perturbation. Moreover, most of the forcing of modern ecosystem change is abiotic (e.g. CO_2, currents and sediment transport). It is therefore of primary importance to quantify the nature and time scales of this inorganic forcing. Fundamental research to quantify such essential components of the system response is required and includes biogeochemical work and modelling of modern and past systems.
Ecological engineering in the marine environment is an

important challenge considering the extraordinary diversity of marine ecosystems and the vast number of scales at which ecological and evolutionary processes are operating. With increasing utilization of coastal areas by human activities and the increased on-going use of marine environments for producing new resources (biotic or abiotic) and renewable energy, ecological engineering applied to marine systems has a broad set of applications. But before its implementation, it will require basic research to be carried out in parallel with surveys and monitoring and an integrative approach among marine scientists, human science researchers and engineers.

Building on our growing understanding of the spatial and temporal scales of marine biodiversity variability, information is needed on the spatial and temporal scales at which marine ecosystem processes that underlie ecosystem services currently occur, how these relate to the scales at which services are delivered, and what the linkages are between them. Marine landscape (seascape) ecology still needs considerable research effort if it is to reach the level of understanding we have for terrestrial ecosystems. Such understanding is vital to underpin policy requirements of marine spatial planning within the MSFD and the conservation objectives of the Habitats and Birds Directives.
Methods such as integrated multitrophic aquaculture (IMTA), that co-cultivates fish, filter and bottom feeders and algae can be considered as simplified ecosystems that aim at a more optimal use of resources and a decrease of impact on the environment. A properly designed IMTA system can be integrated in a healthy natural ecosystem enhancing the production of several commercial species without depleting natural populations or impacting with waste.

Detailed knowledge of marine ecosystems is necessary not only to manage them but especially to restore them. For example, some experience already exists in restoration of kelp beds in California, where 18,500 m^2 of kelp were restored. No similar experiences exist in Europe, even though kelp beds are disappearing from some locations. Knowledge on the drivers of this loss and on the ecology and ecosystem functioning of these ecosystems is necessary to be successful in restoring them.

Fig.4. Europe aims to achieve a Good Environmental Status of its marine waters by 2020. In order to optimize sustainable use of the oceans we need to better understand ecosystem functioning at all scales, from the gene to the whole ecosystem.

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2.2. Area II- Building Scenarios for Changing Oceans

Quantifying the impacts of climate and global change on marine ecosystems in the coming decades will require the development of an integrated strategy between a wide range of disciplines (including physics, biogeochemistry, biology, marine genomics, marine macro-ecology, engineering, modelling and socio-economics). This combines novel field observations, new experimental studies, new technology, improved scientific knowledge on processes and state-of-the-art modelling all with world leading expertise and new frontier scientific techniques and approaches to build scenarios for marine ecosystems under anthropogenic change for the 21st century. An aim of EuroMarine+ is to define the framework of such a strategy at the European level with a strong link with the emerging IPBES.

2.2.1. Background

Climate change is not only modifying the physics (temperature, stratification and circulation), but also the chemistry and biology of the ocean from global to very localised scales. The former relates to dissolved gas concentrations, pH decrease due to increased CO_2 transfer from the atmosphere and the consequent impact on the carbonate system, transfer of nutrients and contaminants from the geosphere, terrestrial biosphere and anthropoSphere. The latter relates to impacts on primary production and life history traits, shifts in trophic structures and sensitivity of anthropogenic stressors. This results in significant changes in the structure and functioning of marine ecosystems, and potentially drastic impacts on human populations.

In this context, and as increased anthropogenic pressure is exerted on marine biotic and abiotic resources, there is an urgent need to develop methodologies to manage efficiently human impacts on marine biodiversity and the services that marine ecosystems provide, notably if we are to progress at all towards the, as yet, unattained targets set during the 2002 Johannesburg World Summit of restoring fish stocks to maximum sustainable yield by 2015 and of significantly reducing the rate of biodiversity loss.

The Reykjavik Declaration of 2001, reinforced at the World Summit on Sustainable Development in Johannesburg in 2002, requires nations to base their policy related to marine resource exploitation on an ecosystem approach. The ecosystem based management (EBM), or ecosystem based approach (EBA), aims at reconciling conservation and exploitation of resources by considering the effects of exploitation or other pressures in an ecosystem context, i.e. taking into account all components of an ecosystem rather than the exploited components in isolation. At the European level, the June 2008 Marine Strategy Framework Directive, in addition to recognizing the precautionary principle, requests the application of an ecosystem-based approach to the management of human activities in order to minimize their impacts on marine ecosystems. At the international level, and analogous to the IPCC, the newly launched Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) aims to stimulate the scientific community to build scenarios of biodiversity change, thus providing the basis for decision-making as well as advice to policy makers or managers.

In this international context and in the face of an increasing demand, the scientific community must strive to explore possible future states of marine ecosystems, as well as possible trajectories preserving or leading to desirable target states, under different environmental, economic and social scenarios. This requires: (a) a greater convergence of scientific disciplines to understand processes (by modelling and experiments based on predicted changes) that might modify the dynamics of ecosystems within and beyond the envelope of their known, historical states (e.g. processes relating to regime shifts or to adaptation and evolution in ecological time) at multiple spatial and temporal scales; (b) the integration of ecological analyses to understand impacts on whole ecosystems, biodiversity and ecosystem services; and (c) an integrated ecological, economic and social approach to provide the basis for mitigating these impacts and managing human activities. Because this vital question unites different scientific communities (ocean ecosystems under global change, marine biodiversity and marine genomics) at the European level, it presents EuroMarine+ both with an opportunity and a duty to develop a comprehensive community framework within which knowledge can be assembled, models can be developed, hypotheses can be tested experimentally and predicted scenarios for changing oceans can be built.

2.2.2. Identification of key needs/ priorities

Overarching scientific needs

To explore the range and extent of possible future ecosystem states under different scenarios, first there is a fundamental need to develop and improve the predictive capabilities of a hierarchy of ecological models to their full potential together with the use of a suite of integrated environmental, biogeochemical, and ecosystem end-to-end models. Efforts to assess and possibly reduce model uncertainties will also be required. In order to use these predictive capabilities to explore possible trajectories towards assigned goals or for management purposes, we also need: (1) models that integrate across social, economic, environmental and ecosystem dimensions using scenarios and which quantify interactions and trade-offs among ecosystem services; (2) to include and value a broader range of ecosystem services, especially cultural services, and social and economic adaptation; (3) desegregation across multiple scales, from global patterns down to regional scale; (4) and consideration of long time horizons (50 - 100 years) and global perspectives that aim to understand complex interactions between human and ecological systems. In addition to modelling, scenario exercises also require a combination of field observations and experimental studies, all undertaken with world-leading expertise and new frontier scientific techniques and approaches.

Societal needs

In order to meet the societal need of preserving ecosystem services while dealing with trade-offs between these services, policy makers; management and stakeholders need to: (a) take into account a wide range of scenarios over longer (50 - 100 year) time horizons for the future state of marine ecosystems, based on sound knowledge, observation-based and experiment-based evidence, as well as on reliable predictive models of these complex and dynamic systems; (b) understand: the fundamental uncertainties associated with predictive models and complex systems, the services associated with ecosystems and biodiversity, and the risks associated with degradation or loss of the latter; and (c) engage with scientists in iterative exercises for the construction of scenarios for regulatory or target states options or the evolution of drivers of environmental change and ecosystem dynamics.

Societal and scientific challenges are intimately connected: addressing the former generates more of the latter by raising new scientific questions or requiring better description and quantification of ecosystem services. Conversely, if any reliable responses exist to meet societal needs, they have to be formulated in terms of options to be defined by stakeholders, and they can only serve as pieces of information to support a decision process. Good communication of science as well as of scenarios relating to driving factors and corresponding ecosystem dynamics is thus essential.

2.2.3. Challenges and objectives

All six emerging fields that EuroMarine identified in the trading zones [see section 3], and the underlying scientific challenges, are essential to progress in scenario building exercises. Among the many key challenges relevant to these emerging fields, we may cite the following:

- understanding the dynamics of regime shifts (e.g. in the Black Sea, Baltic Sea and Mediterranean Sea), the underlying mechanisms, and potential remediation measures;
- risk assessment and quantification of ecosystem services;
- linking marine paleo-ecology and paleo-oceanography to the present and future of marine ecosystems through retrospective studies;
- relating species diversity and eco-physiology to biogeochemistry and ecosystem function, via the cascade of environment-genes-physiology-population-community-ecosystem, paying special attention to the different time scales of the different processes;
- developing socio-ecological coupled models to evaluate ecosystem services.

There are however more specific challenges that correspond to the proposed development, at the European level, of a common framework and strategy to build scenarios for marine ecosystems under anthropogenic change for the 21st century. This framework, as defined by a EuroMarine working group, includes six elements:

CHALLENGE 1: Combine Disciplines to Address Complex Questions and Include Key Processes in Models (scaling up from organismal processes to ecosystem functions and services)

Further emphasis on model development is notably required to: include physiological process description informed by omics; couple plankton to higher trophic level models (including fish and benthic ecosystems); better represent and quantify trophic interactions (plasticity, behaviour, mixotrophy, etc.); improve land-ocean interface understanding (resolving, including or linking to coastal physics, benthic ecology and biogeochemistry, river catchments with their nutrients and the resulting biogeochemical impacts). It is proposed to evaluate processes within the continuum from genes to ecosystems (requiring the exploration of different disciplines and technologies, e.g. physiology, biogeochemistry, transcriptomics, proteomics, metabolomics, etc.). It will facilitate their integration into models and their subsequent parameterization (which could benefit from / integrate systems biology approaches).

CHALLENGE 2: Define and Implement a Common Strategy for Next Generation Ocean and End-to-End Ecosystem Models

It is also proposed, taking advantage of the inclusion of new processes and building on the variety of approaches currently in use, that a common modelling strategy should be developed throughout Europe to improve and enhance current capability.

In addition to model development through the inclusion of new key processes (see previous point), this strategy should cover technical and quality control issues (such as: version control, model complexity and parameterisation, quality of the physics, the ability to produce an ensemble of ecosystem states, and model benchmarking and validation), as well as the evolution towards a next generation community biogeochemical/ecosystem model framework. If we are to project ecosystem states and hence biogeochemical cycling beyond the current climate envelopes, we need to develop new tested and generic models which can adapt (and possibly evolve) in response to environmental change. This may require new concepts, and new model strategies which take better account of physiology, food web plasticity, links to higher trophic levels and which exploit the increasingly large amounts of 'omics' information. The long-term goal will be to develop a unified marine biogeochemi¬cal/ecosystem model framework to facilitate the use of a range of ecosystem models of appropriate complexity suitable for explaining observed patterns and for addressing key issues for management.

CHALLENGE 3: Develop and Promote Interoperability and Free Access to the Great Variety of Structured Observation/ Data/Information Systems in Marine Sciences

Interoperability and free access to data are essential in many aspects, and notably within the present framework it is essential to explore processes across disciplines and to parameterize and validate models. EuroMarine should then engage in, or at least actively promote, initiatives in this direction. Integration with data standards consortia (e.g. the Genomics Standards Consortium) could be for instance a key implementation strategy.

CHALLENGE 4: Use Narrative Scenarios to Link Socio-Ecological Scientific Issues and to Inform Stakeholders

Dialogue with stakeholders is essential to define a set of plausible storylines for the evolution of the various (socio-economic) drivers of change and to adapt models accordingly when necessary; to then iteratively refine or explore new storylines based on the qualitative analyses or quantitative simulations of possible corresponding scenarios for the evolution of marine ecosystems and the services they deliver; and to then assemble assumptions and results in easily understandable 'narrative scenarios'. The EuroMarine scientific community should therefore engage in, and EuroMarine+ could initiate, support and join such exercises.

CHALLENGE 5: Promote Scenario Laboratories (notably using 3D visualization, games and virtual reality techniques) in Order to Facilitate Communication, Comprehension and Discussion of Available Information and Possible Scenarios between Stakeholders and the Scientific Community

If stakeholders are correctly to grasp consequences of decision-making options, it is essential to effectively synthesize and communicate model simulations and to vividly depict scenarios of marine ecosystem change, under the various assumptions or storylines that are considered with regard to the drivers of change (including regulation and management). EuroMarine should then promote the development and use of dedicated laboratories equipped with specific interactive simulation and visualization tools and devices.

CHALLENGE 6: Provide a European Marine Focal Point and Resource Centre for IPBES

The above five framework elements will contribute to help individual scientists in the EuroMarine community to meet future IPBES requests for assessments and scenarios of change in marine ecosystems. As a final element of the present framework, however EuroMarine should also explore how it could become a marine focal point (e.g. in relaying IPBES requests or in fostering or coordinating collective scenario building exercises) and a resource centre (e.g. in consolidating knowledge on 'scenarios' or in providing standardized protocols and repositories for archiving ecosystem state projections).

EuroMarine covers an extensive range of key disciplines and expertise sufficient to address the many and various challenges that fall under each of the areas outlined in the framework above. Weaknesses or threats that have been identified however include: the poor interactions with social sciences (economics, policy, governance, law, sociology, demography and education); the difficulty to correctly describe, quantify and evaluate marine ecosystem services (which yet will ultimately determine regulatory and management decisions); the lack of uniform synthesis of large data flows (observation and model outputs) and the limited field and experimental data available to validate models; uncertainties relating to a sustained societal and political support for marine sciences and long term financial support; and access to qualified personnel in some domains (e.g. economic modellers, taxonomists).

Fig.5. An increased anthropogenic pressure is exerted on marine biotic and abiotic resources. There is an urgent need to develop methodologies to manage efficiently human impacts on marine biodiversity and the services that marine ecosystems provide.

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2.3. Area III- Marine Science as a Provider of New Concepts and as a Driver for Innovation and Technology

The oceans are the cradle of life and the origin of the three domains of the tree of life. Bacteria, Archaea and Eukaryotes all evolved in the marine environment from a common ancestor. The very long evolutionary period of marine life compared to terrestrial life, coupled with an exceptionally diverse range of marine habitats, have generated a massive biodiversity at the gene, genome, species, population and ecosystem level. This evolutionary richness combined with an adaptation to a wide range of environmental conditions and to a variety of specific aquatic habitats, makes marine organisms and marine ecosystems a huge reservoir for new developments in both basic knowledge and innovations with both aspects intimately connected. One aim of EuroMarine+ is to promote new research and innovative applications and biotechnologies, to contribute to the blue economy.

2.3.1. Background

The great diversity of life in the seas has for many years provided a resource that has underpin-ned some of the greatest discoveries in science. The oceans contain representatives of most phyla, and many show highly specialised adaptations to their environment that makes them ideally suited for the study of biological as well as chemosynthetic processes. Indeed the study of marine life has given rise to many modern basic biological concepts - practically every branch of modern biology including evolutionary biology, environmental biology, developmental biology, neurobiology and cell biology has foundations in the study of marine organisms. Some outstanding examples include the following:

- Darwin's studies of barnacles contributed significantly to the development of the theory of evolution;
- Modern evolutionary biology is driven by a rich molecular phylogenetic resource represented by the marine biota, underpinned by centuries of classical taxonomic studies;
- The ease of access to marine vertebrate and invertebrate eggs and embryos has made them particularly valuable as models for cell and developmental biology. Indeed the roles of marine models in laying the foundations of modern cell biology cannot be underestimated. Biochemical and molecular studies of cell division in sea urchin embryos led to Nobel Prize winning discoveries (T. Hunt, Nobel Prize in Physiology or Medicine 2001) about how the cell cycle is regulated - with clear relevance to understanding cell division in normal and cancerous cells. More generally, marine models provide comparative anchors in genome studies for human disorders;
- Nobel Prize winning work (A.L. Hodgkin, A.F Huxley Nobel Prize in Physiology or Medicine 1963) on the nerve impulse by using the giant nerve fibre of the squid laid the foundations for modern neurobiology and membrane biology more generally with wide-ranging biomedical relevance;
- Many biological, biomedical and biotechnological advances have been underpinned by technological advances arising from marine biological research. Work on fluorescent jellyfish proteins led to Nobel Prize winning applications (O. Shimomura, M. Chalfie and R.Y. Tsien Nobel Prize in Chemistry 2008) of green fluorescent protein (GFP) and its derivatives

the most widely used reporter molecules in cell biology and genomics;
- In recent decades, research on physical and biological factors that regulate ocean productivity has revolutionised our understanding of marine biodiversity and how this is likely to be impacted by climate change drivers. The need to understand the biology of phytoplankton as the basis of the marine food chain has never been clearer in allowing predictions of responses of coastal and oceanic ecosystems to anthropogenically induced changes in ocean temperature and chemistry.

While there are many examples of the underpinning role of marine biology in modern biological and biomedical research, it is also clear that only a fraction of the potential of the marine environment and the biota within it has been realised. The potential of marine organisms for biotechnological advances that drive innovation in development of new natural products, biocatalysts, biopolymers and biofuels is enormous. However, research in this area is severely hampered by the state of knowledge of the basic biology of most marine life. There is a clear and urgent need for greater co-ordination of marine biological research to discover and develop new models.

The expansion of the still emerging marine biotechnology sector cannot be disconnected from knowledge development in marine sciences in a broad understanding as successful exploitation of new ideas from science and technology is a recognized key driver for innovation.

The definition of marine biotechnology according to OECD (Organisation for Economic Co-operation and Development) is as follows:

'Marine biotechnology can be thought of as the use of marine bioresources as the target or source of biotechnological applications. This broad understanding of marine biotechnology thus includes both traditional forms of marine biotechnology like aquaculture and modern forms such as bioremediation, production of biofuels and genetic modification of fish. The field has already yielded some notable and wide ranging advances in the fields of medicine, cosmetics, nutraceuticals, food production and environ-industrial applications.'

A very comprehensive overview of marine biotechnology research achievements and future challenges in Europe, based on the outcomes of a working group established by the Marine Board was published in 2010 (Marine Board Position Paper 15 'Marine biotechnology: a new vision and strategy for Europe microbial diversity and its role in ecosystem functioning and environmental change' by Querellou *et al.*). It is clearly stated in this position paper that 'Life science technologies have been and will continue to be in the future, one of the key drivers of marine biotechnology'. Research priorities identified by the working group as drivers for future progress of marine biotechnology are detailed in box A.

TARGET RESEARCH AREA FOR DEVELOPMENT	RESEARCH PRIORITIES AND OBJECTIVES
Genomics and meta-genomics, molecular biology in life sciences	- Implement genomic analyses of marine organisms, including the systematic sampling of different microorganisms (viruses, bacteria, archaea, pico and microplankton), algae and invertebrate taxa; - Implement metagenomic studies of aquatic microbiomes and macrobiomes.
Cultivation of marine organisms	- Develop enabling technologies for culture and isolation of uncultivated microorganisms; - Develop innovative culture methods adapted to vertebrate or invertebrate cell lines for production of active compounds.
Bio-engineering of marine micro-organisms	- Optimise microalgal cultivation systems with respect to energy supply, productivity and cost; - Develop innovative photobioreactors adapted to different species of interest and production sites; - Promote research on the biorefinery approach based on microalgae production to develop a long-term alternative to petrochemistry.
Marine model organisms	- Identify and prioritise new marine model organisms that are still not investigated in the tree of life and which are needed to fill critical knowledge gaps; - Investigate identified marine model organism cultivation and perform genomic and chemical analysis.

Box A: *Modified from Marine Board position paper 15 by Querellou et al. (2010) with permission of the Marine Board*

Fig.6. The potential of marine organisms for biotechnological advances that drive innovation in the development of new natural products, biocatalysts, biopolymers and biofuels is enormous. Genomic analyses of marine organisms is, among others, one of the targeted research areas that need further development.

2.3.2. Identification of key needs/ priorities

Overarching scientific needs

In order to maximise the potential of marine science in the provision of new concepts and in driving technological advances, we need deeper understanding of the diversity of form and function amongst the marine biota. Current biological and ecological concepts do not fully reflect the diversity of life or the dynamics and complexities of interactions within ecosystems. There is a need for further development of marine research to discover and develop new biological models/concepts and to incorporate new discoveries into ecosystem models.

There is an urgent need to unlock the potential of the marine realm to better understand ecosystem structure and function, including the roles of marine biota in driving and regulating key biogeochemical cycles and couplings across the air-sea interface. Improved identification and use of sustainable resources also requires better knowledge of ecosystem structure and function. This knowledge needs to be underpinned by a better understanding of fundamental life processes, from molecular to whole organism and ecosystem levels along with a wider appreciation of the complexities of acclimation and adaptation to environmental perturbation at individual, population and community levels.

Societal needs

Societal needs relating to innovation in marine science are many and varied, spanning a range of timescales and levels of urgency. While marine discovery has had substantial impact on societal development and improvement there is a need to improve understanding of its importance and impact for the benefit of society into the future. This will require that the demand for accessible information about marine life and processes is addressed. There is also a need to satisfy the increasing need for marine-derived products; including food, biomedical and biotechnology products, energy and ores. Technological advances will also be required to realise the potential to provide new services, including recycling and bioremediation and to accommodate the demands for recreation and appreciate the societal health benefits of the coastal and marine environment. Achieving long-term sustainability and conservation will need to be underpinned by improved technologies for ecosystem monitoring, linked with better understanding of the impacts of anthropogenic activities and resource use.

2.3.3. Challenges and objectives

The EuroMarine consortium brings together key features of the former FP6 marine NoEs, with particular attention to those aspects that allow cross-disciplinary fertilization of ideas and development of technologies (trading zones). The key challenges therefore relate primarily to facilitation of the synergistic interactions for maximum benefit.

CHALLENGE 1: Facilitate Cross-Disciplinary Interaction to Underpin the Exploration/ Discovery of Marine Organisms, Systems and Processes

The unexplored potential of marine biota for basic biological, environmental, biomedical and biotechnological research represents both strength and a major bottleneck. There is a wide range of complementary infrastructure and expertise already in place throughout Europe at all levels. Relevant infrastructures include: ships, exploratory platforms, observatories, experimental facilities. This is supported by extensive time series records - European marine laboratories have some of the longest biological time series records in the world coupled with historical expertise in recording methods.

There is a strong taxonomic tradition throughout the European marine laboratories. This sound expertise needs to be maintained (through training and job opportunities) in order to be able to identify and characterize marine biodiversity in the context of marine biodiscovery potential and development. There is indeed a strong threat of loss of expertise and knowledge, particularly in this area, that has to be anticipated. Funding restrictions and lack of investment are resulting in increasingly ageing infrastructures, capacity and increased diverted use of ships for commercial operation. This issue is being addressed through the ESFRI Roadmap project the European Biological Resource Centre (EMBRC). There is an increasing lack of funding opportunities for development of new tools and for training of young and early career researchers that might compromise the optimal use of marine infrastructures and facilities and restrict the innovative capacity of the European scientific community. In order to stay competitive it is essential to build on existing strengths and to facilitate interactions. The objectives of EuroMarine+ will be to co-ordinate integrated surveys of marine diversity (benchmarking), to promote observations on the dynamics in space and time of populations communities and ecosystems as well as observation capacity on major biological and biogeochemical processes in coastal seas and oceans and to develop and adapt new tools and technologies for biological and biogeochemical parameters, including in situ autonomous biological and chemical sensors and remote sensing.

CHALLENGE 2: Create Innovative Fundamental and Strategic Research through Cross-Disciplinary Teams to Address the Key Scientific and Societal Needs

The FP6 marine NoEs have established strong collaborative networks and mechanisms for the transfer of information. National infrastructures are therefore becoming better integrated through European networks. Recognition of the importance of integration at the infrastructure level has gained momentum with the establishment of the EMBRC, which has the primary aim of creating a co-ordinated dispersed infrastructure around the major marine biological facilities throughout the coasts of Europe. These established networks are providing much greater returns than the sum of the individual infrastructures and the basis for combining different components is now well established. However, there is still a strong focus on national and short-term interests at the governmental and higher administration levels that makes long-term maintenance of infrastructures and expertise very challenging. Within this challenge the objectives of EuroMarine+ are to:

- Co-ordinate novel research on existing marine model organisms for biological, environmental, biomedical and biotechnological advances. This will include the application and development of innovative technologies and approaches, building on the opportunities afforded by systems that are amenable to study today;

- Develop new organismal models for understanding basic biological, ecological and evolutionary processes and to underpin discovery in biotechnology and biomedicine. The concept of marine models is changing rapidly with technological advances, opening opportunities for application of omics and systems biology approaches to a broad range of organisms that have not previously been tractable to these approaches, including currently unculturable organisms, but which have high value as models for particular processes;

- Improve understanding of regulatory mechanisms operating from gene and molecular to ecosystem levels: periodicity, feed-back signals and multi-scalar homeostatic windows, host-parasites interactions, stress tolerance and extreme lifespans. Recent studies are revealing that marine organisms, from single celled plankton, to multicellular organisms make enormous investment in the regulation of cellular processes, indicating very robust internal control in the face of fluctuating external conditions. There is a need to understand regulation at a wide range of spatio-temporal scales, including short-term, seasonal, and annual, and how responses to proximate conditions may act as entrainers for internal rhythms. Integration of the classical methods of observational ecology with those of omics and numerical modelling will provide new insights into the co-ordination at different levels of regulation. Notwithstanding inter-annual variability, the emergence of repetitive patterns in community structure can be considered as a further level of regulation. Understanding this will require a strong conceptual approach that considers multiple forms of interactions as well as the ideas behind the emergence of counterintuitive patterns due to the nonlinearity of complex systems;

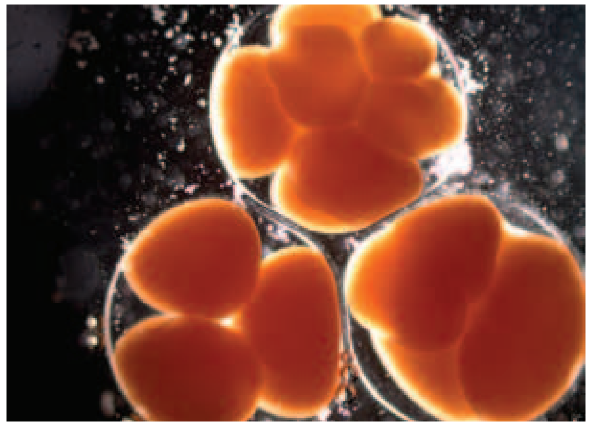
- Improve understanding of the complexities of biological interactions and interfaces in the marine environment. Besides the classical and fundamental predator-prey association, parasitism and symbiosis are key biological processes. There is also growing evidence, derived from genomic data and in situ observations, that the typical division between producers, consumers and recyclers is no longer tenable at least for unicellular plankton. Their trophic potential is multifarious, which leads to much better regulation of the flow of energy and matter in the ocean. Close control of cellular interactions are mandatory for such biological interplay, implying a diversity of undiscovered cellular processes from cell cycle regulation, macromolecule storage, to cellular communication that have high potential for biotechnological and biomedical applications;

- Improve understanding of biogeochemical fluxes (e.g. C, P, N, Si, Fe, O_2, S, Mn, other trace metals) and the processes that drive them in the oceans. Marine microorganisms are particularly relevant for the global equilibrium of major biogeochemical cycles, and ultimately climate on earth.

CHALLENGE 3: Promote Integration and Synthesis in the Trading Zone

The need for integration and synthesis of data is increasing dramatically as a result of unparalleled volumes of data generated through the development of increasingly sophisticated high throughput technology (e.g. NGS technologies). This offers opportunities for integration of biological data at all levels through systems approaches that link analytical, functional and modelling studies. These approaches are becoming applicable to all areas of marine biological research. However, significant bottlenecks, largely centring on the lack of integration of analytical, informatics and modelling expertise need to be addressed. EuroMarine+ will represent the largest integration project in European marine sciences with already strong connections between disciplines at the European scale. The expertise generated by the FP6 marine NoEs is complementary across the NoEs and the grounds are now established for allowing cross-fertilization of scientific fields and communities. In addition, there is already a good critical mass of expertise in some areas combined to strong competitiveness and visibility. This very solid background resulting from many years of work is however potentially vulnerable due to the need for continuing development of the common language and sectoring of research aims in the context of a current focus on short-term gains. Better communication with technological and maritime sectors is needed to improve knowledge transfer between biologists/ecologists and more applied areas. Within this challenge the objectives of EuroMarine+ are to:

- Promote the understanding of levels of organisation, diversity and interconnectivity from genes to ecosystems;
- Develop novel methods of synthesis of existing and new information leading to discovery of emergent properties at each level;
- Develop new approaches, models and simulations for integration (including assessment of confidence and increased interoperability) of information across levels.
- Transfer new discoveries of marine life into medicine and biotechnology as well as into ecosystems and biogeochemical models to improve mitigation / restoration strategies in a warming climate.



One of the objectives of EuroMarine+ is to develop new organismal models for understanding basic biological, ecological and evolutionary processes and to underpin discovery in biotechnology and biomedicine. Some examples of marine organisms currently used as model organisms.

Fig.7. Irish moss *(Chondrus crispus)*
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Fig.8. Oyster eggs *(Crassostrea gigas)*
© Bengt Lundve

Fig.9. Sea squirt *(Ciona intestinalis)*
© Y. Fontana - Station Biologique de Roscoff

Fig.10 Egg of dogfish *(Scyliorhinus canicula)*
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2.4. Conclusions

- An exponentially growing body of evidence demonstrates the negative impacts of temperature, pH/ pCO_2 and other consequences of human activity (e.g. overfishing, habitat destruction, hypoxia, etc.) on marine ecosystem resilience. A solid body of knowledge exists on the effects of single stressors or simple combinations of stressors. This knowledge has been built up in different disciplines, allowing a multi-disciplinary view on the evolving state of marine ecosystems.

- However, there are still fundamental gaps in knowledge. Very little is known on the impact of viruses, pathogenic bacteria and parasites on marine organisms, but it is expected that their importance in population dynamics and the way they contribute to mass mortality events is higher than expected.

- Evaluating the consequences of human activities requires a better understanding of the socio-economic processes at stake. Moreover, the accumulated knowledge must be understood by the public and this requires the development of appropriate science-policy interfaces.

- Understanding the potential consequences of global change and overexploitation for marine species and ecosystems and the identification of strategies to limit or mitigate these impacts are key scientific challenges for the 21st century. The combined impact of the many different stressors which act differently in different localities and on different species has to be better understood in order to predict future changes and design and prioritize mitigation policies.

- Multiple and interacting impacts arise from increasing use of marine space as well as increasing extraction of living and geological resources. These, in addition to global climate change, result in other changes in marine ecosystems including invasions, outbreaks and changes in species distribution and productivity. Increase of noise in the marine environment is another consequence of these increasing human activities and its impacts are poorly understood. Synergistic and antagonistic effects of these pressures and changes on biodiversity, ecosystem functioning, services, benefits and values must be understood to inform effective marine spatial planning of human activity and exploitation and development of future marine policy.

- Building models and scenarios can help in delivering plausible storylines on marine ecosystem responses to global change but also on how humankind may reach objectives that are socially desirable in terms of marine ecosystem states or services, thus answering a societal demand.

Such exercises require the integration of multiple disciplinary perspectives, and scientific progress in the trading zones and emerging fields that EuroMarine+ will focus on. They also require a vision, beyond the EuroMarine perimeter, towards social sciences, as well as improved science-governance interfaces and better communication of scientific results.

In return, the proposed framework for model development and scenario building feeds back into assembly of new knowledge, to foster the formulation of new scientific questions in the trading zones, to communicate scientific results through narratives, and to bring stakeholders together around the construction of scenarios and the exploration of possible future states or trajectories, thus raising awareness of fundamental scientific issues that need to be tackled. Thus, making the development and promotion of a framework to 'build scenarios for changing oceans' as a central objective would help EuroMarine position itself on the European scene while favouring the generation of knew knowledge in the trading zones.

A common challenge to the three main areas is to empower society through training, education and outreach; reinforce quantitative techniques for students and; maximise impact of research through a strong knowledge exchange programme.
Knowledge transfer is facilitated when its components have been organised into information clusters such as narrative scenarios, which in itself contributes to empower society. However, the complexity and diversity of processes underlying marine ecosystem dynamics is such that EuroMarine could coordinate or encourage all kinds of outreach efforts, as well as assemble and make available outreach products from projects or other sources. EuroMarine along with other projects such as EMBRC could also contribute to identify and meet training and education needs (such as the reinforcement of quantitative techniques required for scenario building). The objectives will be to realise the potential for cross-disciplinary training across the EuroMarine partners and promote advanced training in the areas of scientific and societal needs. This involves, for example, fostering degree programmes in relevant areas, to promote technology transfer to stakeholders through workshops and improved communications and last but not least to develop a programme of public and schools outreach.

3. Emerging fields in the trading zone

EUROMARINE
INTEGRATION OF EUROPEAN MARINE RESEARCH NETWORKS OF EXCELLENCE

3.1. Intra-generational (plasticity) and inter-generational (adaptation) evolution and forecasting the future of living marine resources. Contribution of genetic adaptation, including epigenetics, in ecological decadal time frames

Marine ecosystems deliver a diverse range of natural resources among which food and chemicals are key elements. The former are the living organisms themselves while the latter are mostly the products that the organisms synthesize. Humans exploit both, causing a severe impact on the stocks of many target organisms. In addition to direct human exploitation, marine ecosystems are subject to natural and anthropogenically driven environmental change particularly through climate-induced changes in physical properties (i.e. circulation, temperature and light), CO_2-induced ocean acidification (i.e. calcite dissolution and impacts on reproductive success), increase in concentration of xenobiotics, etc. Consequently marine organisms face several environmental challenges throughout their (often complex) life histories, as they grow and develop.

Organismal responses to changes in their ecosystems are multiple and complex. Phenotypic plasticity or acclimation may protect, to a certain extent, their fitness thus retarding, or paving the way to, the selection of more fitted genotypes (Ghalambor *et al.*, 2007). In others, plasticity may decrease their fitness, thus making them more vulnerable to changes. On the other hand, organisms with very low plasticity often form populations of different genotypes, generally cryptic but sexually compatible, whose relative abundance is a possible response to environmental changes (e.g. Langer *et al.*, 2009). It is also crucial to note that many marine organisms often have complex life-history strategies with several quite distinct forms and features, occupying quite different ecosystem niches. For example, in many crustaceans and echinoderms, the larval period is planktonic while the adult phase benthic.

Understanding and quantifying the adaptive response of marine organisms to the evolutionary process at all levels of biological organisation is then essential if we are to improve our capacity to understand and project the future state of key marine resources and of earth system in general.

Existing models of marine ecosystems and their resources are mostly focused around either ocean biogeochemical cycles or fisheries. While these models project future biological responses to environmental change and in some cases allow organisms to acclimate following their physiology, (Le Quere *et al.*, 2005; Follows & Dutkiewicz, 2011), only in few cases (Solidoro *et al.*, 2010) do they attempt to incorporate adaptation, plasticity or evolution. The main reason for this limitation is the lack of knowledge of the molecular and genetic mechanisms underlying plasticity or on the link between genotypic diversity and biological traits of the corresponding individuals, not to mention the complex mechanisms ruling genome modifications. Modern molecular approaches, e.g. transcriptomics, may significantly improve our understanding of regulative responses of organisms and may provide insight on mechanisms that can be later formulated and parameterized to be included in coupled numerical models. Moves towards developing models which explore concepts such as generic, gene-based, individual-based models of evolving ecosystems have already been made. Currently such models are at the stage of being useful heuristic tools for exploring ideas but are insufficient to build reliable scenarios. Bridging this gap requires focused experimentation on key organisms at all levels of biological organisation and a close interaction with modellers (Allen & Polimene, 2011). On one hand experimental biologists and bioinformaticians are crucial players in providing information on adaptation, plasticity and evolution. On the other hand modellers are the only ones who can analyse the implications of those processes in the functioning of ecosystems at spatial and temporal scale and with a complexity that goes well beyond any realistic experimental setup.

3.2. Dealing with complex interactions including tipping points, regime shifts and shifting assemblages

Natural oscillations induce variations around the average states of equilibrium in marine systems. These variations, combined with constant anthropogenic pressures (e.g. climate variation, overexploitation, habitat degradation) have put many ecosystems near a tipping point, leading to massive restructuring of species composition, trophodynamics and ecosystem services provided to human populations. Indeed, tipping points occur when a combination of (often small) events or processes (ecological drivers) interact in a nonlinear fashion leading to a sudden and drastic change in the system. These, mainly irreversible phenomena, summarized as regime shifts, often induce massive losses (e.g. 'cod collapse' in 1983 in the North Sea, decreased biodiversity, blooms of toxic algae), but can also be beneficial (e.g. increased biodiversity, immigration of commercially exploited species).

Given the essential roles that oceans and coastal areas play in planetary function and human well-being, the grand challenge is, therefore, to be able to identify intrinsic resistance and resilience and to recognize critical symptoms that signal an imminent regime shift. To do so, we first need to study and model historical oscillations, the original and new equilibrium states and the resilience of marine ecosystems. In addition, periods of change in the past may help to identify tipping points. This is crucial to explore and quantify ecosystem changes in the future equilibrium that is expected for 70 % of marine ecosystems, using the now well-known climate change scenarios, ocean acidification and decreasing oxygen availability. Recently developed pelagic ecosystem based models, coupled with atmosphere-ocean models, offer the opportunity to explore ecosystem responses according to different types of scenarios. After their thorough validation, they can be applied in a new set of Representative Ecosystem Pathway scenarios (REP). These REP would cover well defined scenarios from 'business as usual' up to a 'global protection' scenario without anthropogenic pressure. Projections made according to each scenario will offer the possibility to outline an optimal pathway for ecosystem and economic sustainability to guide political stakeholders. These objectives require a multidisciplinary effort of marine scientists (modelers, biogeochemists, microbiologists, ecologists, climatologists and paleoclimatologists, economists).

Regime shifts reflect profound changes in the structure of ecosystems at the level of entire food webs, from bacteria to top predators (end-to-end). Information concerning the evolution of communities is hitherto sketchy and the available time-series do not focus on more than one or two biological compartments. In order to decipher underlying non-linear mechanisms, information must be gained simultaneously on the biodiversity and biogeochemistry of all the compartments of interest for food webs in the context of environmental changes (climate vs. changes in biogeochemistry; can one happen without the other?). New data describing the current evolutions of food webs end-to-end will be essential for testing the robustness of new generation physical/biogeochemical/ecological models addressing the prediction of environmental changes in critical/sensitive ocean areas. Such an approach is particularly relevant to match the expectations of IPBES.

3.3. Effects of global warming, acidification, sea level rise, hypoxia and biodiversity change on ecosystems

One of the major lessons learned over the past few decades of research is that the evolution of climate and global environmental quality in the next century will be intimately linked to biogeochemical interactions and to human activities as drivers of biogeochemical fluxes. Our ability to manage and improve the quality of both natural and human systems will depend ultimately on our understanding of these interactions. The scientific basis of forecasts of future climate, climate variability, and quantitative estimates of uncertainty in future projections will only be provided by a continuous merging of fundamental science in ocean physics, biogeochemistry, biology, ecology and atmospheric physics and chemistry.

Many important questions remain, such as the relationship between ocean biota and cloud radiative properties, man's impact on oceanic nutrients, the fate of the ocean's oxygen minimum zones (OMZs), the rate and impact of ocean acidification, and the ocean's influence on aerosols and atmospheric reactivity. Biological productivity underlies the availability of marine living resources. Ocean acidification and deoxygenation are impacting these marine resources (Stramma *et al.*, 2011) and in particular marine biodiversity. There is accumulating evidence that climate change combined with future ocean acidification is particularly likely to affect pelagic microbial communities and benthic organisms (Turley *et al.*, 2010). As the ocean continues to absorb heat from anthropogenic climate warming, its oxygen content is expected to decline because surface heating reduces gas solubility, and inhibits mixing of O_2 rich surface water into the deeper ocean where O_2 is continually removed by microbial respiration (Stramma *et al.*, 2008; Keeling *et al.*, 2010, Deutsch *et al.*, 2011). The use of genomics has allowed for further investigation of the functioning of these OMZ marine ecosystems for instance in revising the nitrogen-loss pathways in the OMZ off Peru (Lam *et al.*, 2009). Moreover, OMZs are key regions in the climatic gas budgets such as CO_2, N_2O, CH_4, DMS, halogenated compounds, impacting on climate variability. Multi-stressors research needs to be conducted to evaluate synergy between the different factors and their combining roles.

Fig.11. A grand challenge is to be able to identify intrinsic resistance and resilience and to recognize critical symptoms that signal an imminent regime shift. The cod collapse in 1983 in the North Sea is an example of a regime shift that induced a massive loss.
© VLIZ

3.4. Marine rhythms of life and their alterations. Chronobiology at tidal, diurnal, seasonal, annual and decadal scales: from molecule to ecosystem function

The oceans are in constant change. These changes are largely driven by the regular cycles of the solar system (external forcing such as day/night, tides, seasons and Milankovitch cycles) and the coupled ocean-atmosphere system (internal forcing, such as El Nino Southern Oscillation (ENSO) and the North Atlantic Oscillation). Marine organisms have adapted to these cycles at many levels by developing mechanisms to anticipate and adjust to them. Depending on the species, behavior, reproduction, physiology and cellular processes, are tuned to environmental cycles with differing periods, resulting in a range of biological rhythms (e.g. tidal, daily, seasonal, annual, decadal and longer). Periodic changes of external stimuli - such as light or pressure - provide cues for these rhythms.

In addition to the cellular, multi-cellular and population levels, these environmental cycles are reflected on the level of whole ecosystems and have impacts on global scale ecological functions (e.g. ENSO). In fact, even external cycles on time scales of 105 years have been shown to impact ecosystems in a consistent manner.

However, despite their widespread occurrence and fundamental importance impacting on every level of marine life, studies on marine rhythms are scarce. In order to understand marine biological processes they need to be explored now at the multidisciplinary level, reflecting the complexity of their impacts. The knowledge and skills represented in the three former NoEs, ranging from genomics and molecular biology to ecosystem analyses and computational modelling will provide the necessary framework to tackle and understand marine rhythms with all their complexity. Moreover, full quantification of the natural cycles is required to improve projections for the consequences of anthropogenic perturbations. Such a re-focus will be crucial to understand the principles, interactions and evolution of rhythms that govern a broad range of prokaryotes and eukaryotes, including ourselves.

Fig.12. Marine ecosystems provide a range of services with socio-economic benefits of significant value to Europe. Evidence is growing that human induced changes in marine biodiversity and ecosystem functioning can, in turn, impact strongly on services and direct economic benefits to society, such as productive fisheries, aquaculture and tourism.
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3.5. Valuation of goods and services delivered by marine ecosystems

Marine ecosystems provide a range of services with socio-economic benefits of significant value to Europe (Austen *et al*., 2011; Bateman *et al*., 2011; Beaumont et al., 2007). Many of the benefits are accrued directly by coastal human populations and visitors, but also indirectly by all of European society. Marine ecosystems have huge global economic importance (Costanza *et al*., 1997) and ongoing research continues in order to understand in more detail the variety of ecosystem services provided by marine ecosystems, their monetary value as well as their wider social and health values for which monetary valuation is not always appropriate. Evidence is growing that human induced changes in marine biodiversity and ecosystem functioning can, in turn, impact strongly on services and direct economic benefits to society, such as productive fisheries, aquaculture and tourism (Worm *et al.*, 2006, Beaumont *et al.*, 2007). There are trade-offs among the different ecosystem services. For example, inshore fishing can boost local food consumption and tourism but can negatively affect support and regulation services whilst seabirds and mammals that are important for tourism and recreation compete with humans for fish as food or are trapped in fishing nets.

Sound science including development of robust valuation methodologies at appropriate spatial and temporal scales will be needed to support sustainable market development of ecosystem services such as carbon sequestration (blue carbon) and carbon trading, fisheries, energy from the sea, biofuels, and blue biotechnology. Society needs knowledge concerning the sustainability of ecosystem services, how their values (monetary and non-monetary) will change, and the implicit trade-offs among different ecosystem services under different policies, regulations and management actions that support the multiple uses of the marine environment such as food provision, transport, energy and leisure and the maintenance of clean, healthy, productive and biologically diverse seas.

Greater understanding is needed of the links between marine biodiversity, ecosystem function and provision of ecosystem goods and services to quantify and model the capacity of marine ecosystems to deliver the goods, services and benefits, to understand what impacts will change this and model the consequent changes in ecosystem values (monetary, societal and health). This would also support marine planning by providing understanding of impacts of different human activities and environmental change on marine ecosystems in socio-economic terms.

Very little data has been collected across Europe specifically for the purpose of quantifying marine ecosystem services, their benefits and values and any changes that are occurring. Such data is required, with consideration and understanding of the appropriate spatial and temporal scales, to have any degree of confidence in absolute values, the transferability of the values to other places, or to be able to scale up or down the values to different sized areas of study or to different scenarios. There is even less research data on the social dimensions (e.g. of identity, sense of place, community) of ecosystem services.

Social scientists, including economists, have much to offer to marine ecosystem research and management, especially in supporting trade-off analysis, decision-making and for understanding the conflicts arising from decisions. Ultimately the human dimension will partly determine the success of any marine initiative, so it is important to develop awareness of how individuals and society will respond to changes in the marine environment. To better engage social scientists, marine policy needs to recognise this and explicitly incorporate social objectives. In turn, social scientists need to be better educated into the importance of the marine environment for society, in a language that focuses on people. There also needs to be greater understanding of the importance and value of research that does not lead to quantifiable findings, but offers rich insights into human actions and behaviour.

3.6. Restoration and conservation of sustainable marine ecosystems

The oceans and seas are under threat due to a number of direct human activities, of which fishing, habitat loss and pollution are of major concern. Marine ecosystems are also highly sensitive to climate change (global warming, ocean acidification, hypoxia, etc.). Synergies, combination and feedbacks of single pressures on the marine environment may result in amplified impacts. Perception of impacts differs from habitat to habitat. While pressures in the densely populated coastal margins are very obvious, other impacts have so far eluded human understanding, for example knowledge of and impacts on, the vast deep-sea and open-ocean. However, recently, the perception of damage and its extent are becoming apparent. With the growing exhaustion of land and coastal resources many economic activities have migrated or are on the verge of migrating offshore. Gas and oil extraction are moving off the shelves to depths of 3000 m to 5000 m. Commercial mineral exploitation in the deep-sea floor is under serious consideration and CO_2 sequestration is planned at the experimental level.

Due to the diversity, level of action, spatio-temporal scale of the threats and the potential cascading effects of the impacts, the need for knowledge of the multidimensional structure and functioning of an ecosystem as a whole has never before been so vital or significant.

The discipline that provides the knowledge to conserve oceanic biodiversity and ecosystems is marine conservation biology. This young and multidisciplinary discipline deals primarily with the conservation of biodiversity and habitats together with the reliable functioning of ecosystems. It is a pragmatic discipline increasingly founded on theoretical grounds. It aims at deducing from general ecological and evolutionary principles strategies and measures to protect the environment; it also relies strongly on socioeconomics and governance.

Marine conservation initially focused effort on constraints on exploited living resources, especially those lacking an ecosystem approach. Conservation initiatives are increasingly built on the establishment of marine protected areas (MPAs) (sensu lato). These are some of the most promising tools to conserve the marine environment, although they have been slow to implement (currently less than 1 % of the ocean is protected). Limited experimental evidence continues to slow down equivocal evidence. Empirical observations and modelling increasingly show that marine protected areas are efficient tools to rebuild overexploited populations and habitats. They also prevent the degradation of significant areas of the oceans. Even if the effects of global climate related stressors cannot be controlled at the local level, reducing local stresses in key ecosystems can improve their resilience to additional stressors. A coherent network of MPAs may bring benefits from spill-over effects to adjacent areas. It is well accepted that the prospects to protect the whole ocean are slim. Important features of MPAs include their topology (appropriate sizing and spacing), such that communities may complete their life cycles.

MPAs are incorporated in Marine Spatial Planning strategies, with a perspective on the long-term viability of the environment (restoration of good environmental status). Complementary measures to conserve the ocean include the regulation - and enforcement - of activities such as shipping, building, prospection, fishing and naval exercises. Conservation biology has been involved in the restoration of polluted habitats, of populations suffering from excessive exploitation, and of advising on the sustainable human interference with habitats. Ecological engineering may be used, although with variable success, to restore a highly degraded environment (e.g. oil spill clean-up with bacterial seeding, reef (re)construction, mangrove reforestation and estuarine oxygenation). The ultimate aim of conservation biology is to contribute to a balanced delivery of ecosystem services through the conservation of biodiversity, habitats and the full range of natural biogeochemical and biotic processes.

4. References

Allen, J.I., Polimene, L. (2011) Linking physiology to ecology: towards a new generation of plankton models. Journal of Plankton Research, 33: 989-997.

Austen, M.C., Malcolm, S.J., Frost, M., Hattam, C., Mangi, S., Stentford, G., Benjamins, S., Burrows, M., Butenschön, M., Duck, C., Johns, D., Merino, G., Mieszkowska, N., Miles, A., Mitchell, I., Smyth, T. (2011) Marine. In: The UK national ecosystem assessment technical report (UK NEA, 2011). Publishers: UNEP-WCMC.

Bateman, I.J., Abson, D., Beaumont, N., *et al.* (2011) Economic values from ecosystems. Chapter 22. In: The UK national ecosystem assessment technical report. UK NEA, 2011. Publishers: UNEP-WCMC.

Beaumont, N.J., Austen, M.C., *et al. (*2007) Identification, definition and quantification of goods and services provided by marine biodiversity: implications for the ecosystem approach. Marine Pollution Bulletin, 54: 253-265.

Costanza, R., *et al.* (1997) The value of the world's ecosystem services and natural capital. Nature, 387: 253-260.

Deutsch, C., Brix, H., Ito, T., Frenzel, H., and Thompson, L. (2011) Climate forced variability of ocean hypoxia. Science, doi: 10.1126/science.1202422.

Follows, M.J. and Dutkiewicz, S. (2011) Modelling diverse communities of marine microbes. Annual Review of Marine Science, 3: 427-451.

Ghalambor, C.K., McKay, J.K., Carroll, S.P., Reznick, D.N. (2007) Adaptive versus non-adaptive phenotypic plasticity and the potential for contemporary adaptation in new environments. Functional Ecology, 21(3): 394-407.

Glöckner, F.O., Stal, L.J., Sandaa, R.A., Gasol, J.M., O'Gara, F., Hernandez, F., Labrenz, M., Stoica, E., Varela, M.M., Bordalo, A., Pitta, P. (2012). Marine Microbial Diversity and its role in Ecosystem Functioning and Environmental Change. Marine Board Position Paper 17. Calewaert, J.B. and McDonough, N. (Eds.). Marine Board-ESF, Ostend, Belgium.

Keeling, R.F., Körtzinger, A., and Gruber, N. (2010) Ocean deoxygenation in a warming world. Annu. Rev. Mar. Sci., 2: 199-229.

Lam, P., Lavik, G., Jensen, M.M., van de Vossenberg, J., Schmid, M., Woebken, G., Gutierrez, D., Amann, R., Jetten, M.S, and Kuypers, M.M. (2009) Revising the nitrogen cycle in the Peruvian oxygen minimum zone. PNAS, 106, 12: 4752-475.

Langer, G., Nehrke, G., Probert, I., Ly, J., Ziveri, P. (2009) Strain-specific responses of *Emiliania huxleyi* to changing seawater carbonate chemistry. Biogeosciences, 6: 2637-2646.

Le Quere, C., Harrison, S. P, Prentice, I. C., *et al.* (2005) Ecosystem dynamics based on plankton functional types for global ocean biogeochemistry models. Global Change Biol., 11: 2016-2040.

Querellou, J., *et al.* (2010) Marine biotechnology: a new vision and strategy for Europe microbial diversity and its role in ecosystem functioning and environmental change. Marine Board Position Paper 15. Calewaert, J.B. and McDonough N. (Eds.). Marine Board-ESF, Ostend, Belgium.

Riebesell, U., Fabry, V. J., Hansson, L., and Gattuso, J.-P. (Eds.) (2010) Guide to best practices for ocean acidification research and data reporting, 260 p. Luxembourg: Publications Office of the European Union.

Solidoro, C., Cossarini, G., Libralato, S., and Salon, S. (2010). Remarks on the redefinition of system boundaries and model parametrization for downscaling experiments. Progress in Oceanography, 84: 134-137.

Stramma, L., Johnson, G.C., Sprintall J. and Mohrholz (2008) Expanding oxygen minimum zones in the tropical oceans. Science, 320: 655-658.

Stramma, L., Prince, E.D., Schmidtko, S., Luo, J., Hoolihan, J.P., Visbeck, M., Wallace, W.R., Brandt, P., and Körtzinger, A. (2011) Expansion of oxygen minimum zones may reduce available habitat for tropical pelagic fishes. Nature Geoscience, 2, doi: 10.1038/NCLIMATE1304.

Turley, C., Brownlee, C., Findlay, H.S., Mangi, S., Ridgwell, A., Schmidt, D.N. and Schroeder, D.C. (2010) Ocean acidification. In MCCIP Annual Report Card 2010-11, MCCIP Science Review, 27pp. www.mccip.org.uk/arc.

Worm B., Barbier, E. B., Beaumont, N., *et al.* (2006) Impact of biodiversity loss on ocean ecosystem services. Science, 314: 787-790.

5. List of Abbreviations

ASSEMBLE	Association of European Marine Biological Laboratories
BEF	Biodiversity and Ecosystem functioning
CFP	Common Fisheries Policy
EBA	Ecosystem Based Approach
EBM	Ecosystem Based Management
EMBRC	European Marine Biological Resource Centre
ENSO	El Nino Southern Oscillation
EPOCA	European Project on Ocean Acidification
GES	Good Environmental Status
GFP	Green Fluorescent Protein
GOOS	Global Ocean Observing System
ICES	International Council for the Exploration of the Sea
IMTA	Integrated Multitrophic Aquaculture
IOC	Intergovernmental Oceanographic Commission
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
MPA	Marine Protected Areas
MSFD	Marine Strategy Framework Directive
NGS	Next Generation Sequencing
NoE	Networks of Excellence
OECD	Organisation for Economic Co-operation and Development
OMZ	Oxygen Minimum Zones
REP	Representative Ecosystem Pathway scenarios

EUR-OCEANS	www.eur-oceans.eu
MarBEF	www.marbef.org
Marine Genomics Europe	www.marine-genomics-europe.org