As climate change and manmade drivers continue to place stress on marine ecosystem dynamics, understanding the complexity of responses will help manage future change. **Professor Icarus Allen** and **Jessica Heard** describe efforts to provide knowledge and tools to support the implementation of effective strategies to ensure the sustainability of the European seas

Future-proofing marine ecosystems

Firstly, can you offer a brief outline of the main aims of the MEECE project?

The implementation of the Marine Strategy Framework Directive (MSFD) requires Member States to develop strategies to achieve a healthy marine environment and make ecosystems more resilient to climate change in all European marine waters by 2020 at the latest.

The specific goals of MEECE are to improve the knowledge base of marine ecosystems and their response to climate and anthropogenic driving forces, and develop innovative predictive tools and strategies to resolve their dynamic interactions.

What key drivers of change are you taking into account when analysing marine ecosystem evolution?

MEECE addresses both climatic drivers of change (such as temperature, circulation, stratification and acidification) and direct anthropogenic drivers (such as eutrophication, pollution and fishing).

MEECE has adopted a regional approach to eight European regional seas (North West Shelf, Barents, North, Baltic, Biscay, Adriatic, Aegean and Black) along with the Benguela Upwelling, from a global perspective. Scenario definition and validation are crucial to model design in MEECE – we have defined a common suite of climate-forced and anthropogenic driver scenarios. In addition, we evaluated the performance of global climate models for each region and as a consequence defined a range of methodologies for downscaling climate model outputs regionally. We have also defined core model metrics (outputs and validation methods) for the MEECE scenarios; the choice of core outputs being informed by mapping model outputs onto MSFD key descriptors.

How do you assess model accuracy to enable confident application of your simulations to science and policy?

As a matter of policy, MEECE rigorously evaluates core model outputs to test that they are fit for purpose. We also need to understand model uncertainty, which is a combination of the uncertainty in our understanding of natural variability, and model structural and forcing uncertainty. Ideally, we would run an ensemble of simulations to explore uncertainty, but the computing resources do not exist for this. Therefore we run targeted scenarios which bound the ranges of likely forcing and perturbations.

What decision-making tools are you developing to support the EC Marine Strategy and the Maritime and Common Fisheries Policies?

Some of the modelling tools can be applied to management strategy evaluation by running targeted scenarios that explore management options. At this stage, the models are in research mode and require experts to run them. Further refinement in close collaboration with users is required to convert candidate models to operational tools. In addition, we have developed expert systems for invasive species and pollution which synthesise environmental and biological data into indicators of environmental status.

How do you translate your findings from specific regions into a more universal outlook for marine management?

While all regions are in practice subjected to all drivers, in reality some are more sensitive to certain drivers than others. For example, enclosed basins like the Baltic or Black Seas are more sensitive to eutrophication impacts than climate, unlike seas with a direct ocean connection.

We have to take a comparative approach – comparing the same outputs between regions to understand the differences. We must also investigate the issues specific to each region. A report summarising our findings is in preparation. The MEECE Model Atlas will allow visualisation of the results.

How does knowledge transfer form a key part of MEECE?

The MEECE knowledge transfer team intend to facilitate the dissemination of research-based knowledge, expertise and skills between the project partners and wider users. Effective knowledge transfer requires communication between MEECE scientists and global users (policy makers, advisory bodies, research managers, conservation and user groups, and management bodies), and results in the production, dissemination and use of research-based knowledge in decision making and enterprise. The key MEECE target groups include decision makers in science and policy areas, small and medium enterprises interested in the application of knowledge and the interested public.

Lastly, can you offer some thoughts on what ultimate impact you hope MEECE will have?

The expected impacts are twofold: firstly, to improve the knowledgebase on marine ecosystems and the way they are impacted by the many driving forces, either anthropogenic or natural; and, secondly, to provide input to governmental and non-governmental actors in the development of innovative tools and strategies for the rebuilding of degraded marine ecosystems, protection and sustainable use of the sea and its resources, through the perspective of the ecosystem approach.

Saving the seas

Furthering knowledge of marine ecosystem processes is vital to improving marine management. To address this, the EU-funded **MEECE** project has garnered expert studies and tools to support understanding of the current state, and likely future evolution, of these ecosystems in European seas and inform policies for their protection

CLIMATE CHANGE IS placing significant stress on the world's seas and their ecosystems. In addition, fishing has heavily reduced fish stocks in parts of the oceans, while pollution from human marine activities such as shipping, and land-based activities such as farming, exacerbate the situation further for the delicate ecosystems and marine food webs that support marine life. In Europe, there is a real danger that some marine species will be irretrievably lost.

The EU Marine Strategy Framework Directive (MSFD) aims to ensure that Member States develop action plans that will efficiently protect the European marine environment, in cooperation with other EU states and countries outside the Union. In support of this, the Member States are required to provide an assessment of their marine environments and set out what a 'Good Environmental Status' (GES) means for them, along with strategic targets and measures by which the States will monitor their future evolution.

The drivers of change for planktonic and benthic ecosystems are the focus of these assessments:. These are: ocean temperature, circulation, stratification and acidification, pollution, overfishing, invasive species and eutrophication. Compliance with the MSFD depends on the ability of Member States to accurately interpret the vulnerabilities of marine ecosystems and the ways in which they might adapt to environmental factors and human activities. Accordingly, the European Union Seventh Framework Programme for Research and Technological Development (FP7) has sponsored the Marine Ecosystem Evolution in a Changing Environment (MEECE) project as a means to support Member States in achieving their obligations.

MEECE OBJECTIVES

The primary goal of MEECE is to provide input to the development of innovative tools for assessing GES and to facilitate understanding of the implications, so as to expedite implementation of the MSFD by informing strategies for dealing with the effects of change. "Underpinning the delivery of the MSFD is the scientific challenge of investigating and understanding the sensitivities and potential responses of marine ecosystems to both climatic change and the direct effects of human activity," explains Jessica Heard, the Project Manager of MEECE. "Without understanding how an ecosystem might respond to these multiple drivers, we shall find it very difficult to manage marine ecosystems." MEECE has therefore applied a combination of data collection, computer-aided simulations, expert systems and targeted research to acquire and share the comprehensive knowledgebase and predictive tools required to support decision making about marine ecosystems.

The MSFD is regionally focused; as a result, the MEECE project focuses on key marine regions of the EU: the Adriatic, Barent, Baltic, Black and North Aegean Seas, the North East Atlantic including the North Sea, the Bay of Biscay and the Benguela Upwelling. Users of the MEECE knowledge base and toolkits include a global spread of policy makers, advisory bodies, research institutes, consultancies, conservation groups, NGOs, industry and coastal and maritime management bodies. There are 21 European partners and one African partner involved in the project. Because of the large variety of stakeholders and potential users, a User Advisory Group represents the interests of different types of users – and society at large – acting as a focal point for the project to obtain input about the specific needs of each. The project maintains a Stakeholders' Contact Database which allows rapid and targeted dissemination of MEECE products and facilitates searches of stakeholder information. The User Advisory Group consists of a set of stakeholders representing different sectors, supplying information that ensures the project offerings are relevant. The Group also aids MEECE's efforts by informing the consortium of user priorities.

MODELS AND THE MEECE MODEL ATLAS

Modelling is a central part of the group's work: "This allows us to describe the state of a system and how it may evolve, representing the dynamics of the pressure-state relationship so we can assess the risk of negative indicator events," Scientific Coordinator Professor Icarus Allen details. The project evaluated a number of modelling systems, selecting 11 for further development during the MEECE project. Allen explains: "If we are to use models either for science or policy, then we need to be able to understand and articulate their quality. We therefore needed to assess model applicability to understand how well the model fits the data in space and time".

The model systems selected may be used on their own or integrated with the others to produce end-to-end ecosystem simulations. The full suite of models developed during the project have been collated to form a Model Library, complete with user guides available at www.meece.eu/Library.aspx.

Using the MEECE models it is possible to obtain information regarding up to eight of the 11 GES descriptors for a particular regional sea: biodiversity, non-indigenous species, fish, shellfish, food webs, eutrophication, sea floor and contaminants. The project has improved the means by which the systems might be joined for end-to-end use by providing various coupling tools. They now support, for example, scenarios concerning the abundance and distribution of particular commercial marine species and scenarios for assessing biomass and the productivity of key species in marine ecosystems. Distribution and dispersal of nutrients and contaminants from the Aegean to the North Sea can also be modelled for the purpose of assessing the impacts of eutrophication on habitat condition.

"A key legacy of the project will be the MEECE Model Atlas," asserts Heard. The Model Atlas has

been developed in collaboration with the MEECE User Advisory Group and provides access to the many simulations that have been obtained over the last four years, for different seas according to different drivers and indicators, via a web portal. The web-based Atlas will give non-modelling experts access to model outputs in a user-friendly manner, it can be interrogated by region across a range of variables displaying decision support outputs for present and future scenarios.

MEECE KNOWLEDGE BASE AND KNOWLEDGE TRANSFER

MEECE seeks to ensure that project outputs are presented in a way that is relevant and meaningful and has placed a strong emphasis on knowledge transfer to society, through the dissemination of research-based knowledge, expertise and skills: "Since the project started in 2008, MEECE scientists have published 58 papers, with a further 22 submitted, and they have delivered more than 180 presentations of project work," highlights Heard. MEECE has also produced a library of fact sheets that highlight key project findings and outputs, which include both scientific reports and reports about aspects of the project itself.

In addition to knowledge transfer via its products, MEECE has sought to train a new generation of ecosystem modellers to ensure that expertise is developed for future generations. Last year, more than 35 students were trained in a dedicated week-long summer school. The summer school was designed to expand the students' knowledge of the state of the art of marine ecosystem simulation and share methodologies for interpreting the outputs.

The MEECE project will be presented to the EU Joint Research Centre biodiversity workshop on biodiversity descriptors in Brussels in November; with the launch of the Model Atlas also planned for this event.

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MEECE

MARINE ECOSYSTEM EVOLUTION IN A CHANGING ENVIRONMENT

OBJECTIVES

To use a combination of data synthesis, numerical simulation and targeted experimentation to further understand how marine ecosystems will respond to multiple climate change and anthropogenic drivers.

PARTNERS

Plymouth Marine Laboratory, UK (Coordinator) • **Bolding & Burchard Hydrodynamics**; **Danish Institute for Fisheries Research**, **Technical University of Denmark**; **Syddansk Universitet**, Denmark • **Institut de Recherche pour le Développement**; **Centre National de la Recherche Scientifique**; **Commissariat à l'énergie atomique**, France • **University Hamburg**, Germany • **Hellenic Centre for Marine Research**, Greece • **Università di Bologna**; **Università del Piemonte Orientale**, Italy • **Klaipeda University Corpi**, Lithuania • **Universitetet i Bergen**, Norway • **University of Cape Town**, South Africa • **Fundación AZTI-AZTI Fundazioa**; **Instituto Español de Oceanografía**, Spain • **Wageningen IMARES BV**, The Netherlands • **Institute of Marine Sciences**, **Middle East Technical University**, Turkey • **Centre for Environment, Fisheries and Aquaculture Science**; **Natural Environment Research Council**; **Sir Alister Hardy Foundation for Ocean Science**, UK

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PROFESSOR ICARUS ALLEN specialises in the development of complex marine system models for hypothesis testing and forecast, model skill assessment and ecotoxicology. He has been involved in over 35 national and EC scientific projects.