Biodiversity Theme Action Plan

Marine Food Webs and their Impacts on Ecosystem Services
Council approved £5.5m for this action

The diversity of life in marine ecosystems is exceptional; while only one animal phylum is exclusively terrestrial, 21 phyla are marine endemics[1]. The functional roles of this marine biodiversity underpin major ecosystem services, including food production, climate regulation through the cycling of carbon and other macronutrients, and a range of cultural values (e.g. recreation, tourism) that rely on the natural environment to a far greater extent than on land. Biodiversity in marine ecosystems is experiencing ongoing environmental change[2]: ecosystem restructuring generated by fisheries[3]; eutrophication, pollution and other environmental degradation[4]; climate-driven changes[5] and growing human consumption and pressures (e.g. marine renewables). Understanding the consequences of these changes, and designing, testing and refining potential management solutions to address them, is clearly important for the long-term delivery of services from marine ecosystems[6].

Marine food webs play a key role in regulating these ecosystem services but there are important gaps in our knowledge and understanding of these functional roles and the way they might respond to environmental change. First, although there is evidence that marine food webs are affected by both 'bottom-up' (e.g. biophysical factors affecting primary productivity) and 'top down' (e.g. top predators modifying the biomass of lower trophic levels) processes[7], existing knowledge is much greater for lower trophic levels and associated biophysical factors. This means it is currently difficult to understand the relative roles of these processes and hence the extent to which environmental change cascades through marine food webs and affects ecosystem services. Second, these 'bottom up' and 'top down' processes are inherently scale-dependent. For example, small-scale changes in seabed topography, waves and currents can produce 'hotspots' of primary productivity that then affect the spatial distribution and abundance of higher trophic levels; large-scale removal of top predators through fishing or other activities can have a range of impacts across scales. Scale-dependence is poorly understood, however, making it difficult to quantify the large-scale impacts on ecosystem services of changes at small spatial scales (e.g. marine conservation zones); and *vice versa*. Third, it is unclear how functional diversity affects the way marine food webs regulate ecosystem services. This is potentially important because there is growing evidence that the loss of biodiversity from marine ecosystems can adversely

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[1] May, R.M. Biological diversity: differences between land and sea. *Philosophical Transactions of the Royal Society of London* B 343, 105 (1994); Venter, J. C. et al., Environmental genome shotgun sequencing of the Sargasso Sea. *Science* **304** (5667), 66 (2004).
[2] Halpern, B. S. et al., A global map of human impact on marine ecosystems. *Science* **319** (5865), 948 (2008); Hoegh-Guldberg, O. and Bruno, J. F., The impact of climate change on the world's marine ecosystems. *Science* **328** (5985), 1523.
[3] Smith et al. Impacts of fishing low-trophic level species on marine ecosystems. *Science* **333,** 1147 (2011).
[4] Diaz, R.J. & Rosenberg, R. Spreading dead zones and consequences for marine ecosystems. *Science* **321,** 926 (2008); Ross, P.S. Fireproof killer whales. *Can. J. Fish. Aquat. Sci.*, **63,** 224-234.
[5] Beaugrand, G., Luczak, C., and Edwards, M., Rapid biogeographical plankton shifts in the North Atlantic Ocean. *Global Change Biology* **15** (7), 1790 (2009); Dulvy, N.K. et al. Climate change and deepening of the North Sea fish assemblage; a biotic indicator of warming seas. *Journal of Applied Ecology* 45, 1029 (2008); Hoegh-Guldberg, O. & Bruno, J.F. The impact of climate change on the World's marine ecosystems. *Science,* **328,** 1523 (2010).
[6] Pinsky, Ml. et al. Unexpected patterns of fisheries collapse in the World's oceans. PNAS 108, 8317 (2011); Palumbi, S. R. et al., Managing for ocean biodiversity to sustain marine ecosystem services. *Frontiers In Ecology And The Environment* **7** (4), 204 (2009).
[7] e.g. Ware, D. M. and Thomson, R. E., Bottom-up ecosystem trophic dynamics determine fish production in the northeast Pacific. *Science* **308** (5726), 1280 (2005); Scott, B. E. et al., Sub-surface hotspots in shallow seas: fine-scale limited locations of top predator foraging habitat indicated by tidal mixing and sub-surface chlorophyll. *Marine Ecology-Progress Series* **408**, 207; Ferretti, F. et al. Patterns and ecosystem consequences of shark declines in the oceans; Baum, J. & Worm, B. Cascading top-down effects of changing oceanic predator abundances. *J Anim. Ecol.*, **68,** 299 (2009); Frank, K.T. et al. Transient dynamics of an altered large marine ecosystem. *Nature* **477**, 86 (2011).

affect ecosystem functioning and services[8]. Improving our understanding in these three areas would facilitate the development of more realistic marine ecosystem models, which in turn would provide important tools for exploring the impacts of environmental change on marine ecosystems, and testing potential management solutions.

Description of the Action: This action has been designed to address the key knowledge gaps outlined above. It has three main goals:

1. Improve our understanding of how the regulation of key ecosystem services such as food production, macronutrient cycling and cultural values by marine food webs are affected by the relative roles of 'top down' and 'bottom up' processes, scale-dependence in these processes and functional diversity at different trophic levels.

2. Integrate the improved knowledge and understanding gained in Goal 1 with existing ecosystem models to explore the impact of environmental change on the structure, function and services associated with marine food webs across scales.

3. Apply the models developed in Goal 2 to test the impact of potential management solutions, such as marine conservation zones, on the structure and function of marine food webs across scales, and explore the efficacy of specific indicators of good environmental status.

These goals will be addressed through an integrated project located in the NE Atlantic. While it would be feasible in principle to locate the action in a number of areas, including the Southern Ocean and tropical systems, the NE Atlantic offers a number of distinct advantages that adds significant value to the science proposed in this action. These include (i) a number of existing long-term regional datasets collected by a range of organisations (e.g. NERC, CEFAS, Marine Scotland), (ii) existing ecosystem modelling capability, (iii) existing data on the distribution of human pressures on the marine environment, (iv) new datasets being generated through the monitoring of marine conservation zones and human activities, (v) the opportunity to link the action with related NERC marine programmes (Ocean acidification, Ocean-Shelf Edge Exchange, Shelf Seas Biogeochemistry) in terms of both the science and KE, (vi) the opportunity to align associated programmes in organisations such as CEFAS and Marine Scotland with the proposed action, and (vii) the policy relevance of the research and its potential, therefore, to have impact across a range of users.

Although there is clearly considerable on-going activity and associated data in the NE Atlantic region, the step-change envisaged by the proposed action is to provide the focus for integrating existing data and coupling this with targeted new data collection to improve our understanding of the whole ecosystem, rather than just parts of it. From a whole ecosystem perspective, activity to date in the NE Atlantic region has tended to be fragmented and focused on components of the system (e.g. specific habitats or issues such as fishery management), which largely reflects the interests and responsibilities of individuals and organisations working in the region. There is widespread recognition among the research and policy communities that this situation needs to change and that a whole system perspective is now required. This is because it is becoming increasingly clear that human activities and environmental change that affects part of the ecosystem (e.g. fisheries management) can have much wider consequences for biodiversity and ecosystem services than previously thought due to interactions through food webs. Recent policy-related research has produced detailed

[8] Worm, B. et al., Impacts of biodiversity loss on ocean ecosystem services. *Science* **314** (5800), 787 (2006); Danovaro, R. et al., Exponential decline of deep-sea ecosystem functioning linked to benthic biodiversity loss. *Current Biology* **18** (1), 1 (2008).

spatial data on human pressures on the marine environment in the NE Atlantic region that provides important contextual information for designing the integrated biodiversity and ecosystem science needed. Furthermore, a wide range of large-scale data (e.g. EO, acoustic surveys) has become more readily available in recent years. What is missing is a mechanism to bring existing data together, target new data collection, and integrate data and models all within a common framework. The proposed action is designed to provide the investment needed to support this integration.

Goal 1 provides the scientific context for the integration envisaged in the previous paragraph. It can only be addressed by the novel combination of existing long-term data and new field-based and experimental observations with recent theoretical advances from marine and terrestrial ecology to explore how food webs respond to specific 'bottom up' or 'top down' perturbations. In particular, simple ecological theory can be used to generate predictions about the fate of marine ecosystems under different past or future scenarios of 'bottom up' (e.g. temperature, acidity, prey abundance) and/or 'top down' (e.g. predator abundance, exploitation) control[9]. Testing these predictions using spatially-nested sampling designs across environmental gradients, combined with a macro-ecological approach that explicitly considers the linkages from local to regional spatial scales, will require an integrated, interdisciplinary approach. A major challenge which will be addressed will be to translate an understanding of the dynamics of marine ecological communities into the currency of ecosystem services, which will require, among other things, understanding the complex relationships between trait-based and taxonomic descriptions of marine biodiversity. Goal 2 will need to be addressed through links with existing marine ecosystem models (e.g. ERSEM, ATLANTIS, NEMO), which are already being developed and applied in the NE Atlantic region through current programmes. It is envisaged that this work will include novel statistical approaches and theory. This goal also provides an opportunity to bring into the action concepts and expertise from the terrestrial ecology community in the UK, which has made major contributions to relevant research areas such as food web theory and macro-ecology in recent years. Goal 3 will involve the integration and application of work done in Goals 1-2 and will be developed with input from users via KE activities. Since all these goals have parallels with the goals of the BESS programme, there is a wider opportunity here to share and develop concepts, approaches and insights across the terrestrial and marine communities by putting in place links between the proposed action and BESS.

Existing investments and national capability: Although NERC has invested about £10M in RM funding to support work on marine biodiversity and ecosystem function since 2000, this work is not duplicated by the proposed action. Most projects have been focused on specific biodiversity-ecosystem function questions at particular scales rather than the more integrated work envisaged by the proposed action. The proposed action builds on recent marine research programmes, such as Quest-fish (www.quest-fish.org.uk) (ended 2010), (GLOBEC (www.globec.org) (ended 2010) and Oceans 2025 (www.oceans2025.org) (ending 2012), and complements ongoing programmes such as IMBER (www.imber.info/index.html), ICED (www.iced.ac.uk), EMECO (www.emecogroup.org/), HERMIONE (www.eu-hermione.net), EuroSITES (www.eurosites.info), ESONET (www.esonet-emso.org), MarBEF+ (www.marbef.org), EuroMarine (www.euromarineconsortium.eu), EMODNet (http://bio.emodnet.eu/) and EUR-Oceans (http://vds1719.sivit.org/eoc/). NERC supports significant national capability through the Marine RCCs, including research capacity, modelling, long-term datasets and facilities. The proposed action will provide an opportunity to integrate some of this capability across the Marine RCCs. There is also significant

[9] Jennings, S. et al. Global-scale predictions of community and ecosystem properties from simple ecological theory. *Proceedings of the Royal Society B: Biological Sciences* **275**, 1375 (2008).

capability in HEIs in the marine sciences, but also more broadly within the UK ecological community. The proposed action will draw on long-term observational systems around the UK (e.g. Western Channel Observatory, International Bottom Trawl Surveys, SAHFOS CPR surveys, PAP Sustained Observatory).

Action investments and delivery mechanism: A 5-year, £5.5M programme is proposed to meet the scientific goals of the action. Funding at this level is required to support field-based observations including ship time; mesocosm and small-scale experiments in the field and laboratory; the compilation, management and analysis of existing data and new data generated by the project; model development and application; and KE activities. The action would be let as a single consortium grant to ensure the required degree of integration between goals and activities. It is difficult to be precise at this stage about the balance of funding between activities (e.g. working with existing data, collecting new data, model development) because this will ultimately depend on the specific focus (e.g. biodiversity groups and associated ecosystem processes/services, human activities, etc) of the science. The action is designed so that data analysis (Goal 1) informs modelling work (Goal 2), which in turn provides the basis for applied studies (Goal 3). Initial community development work would be required particularly with respect to identifying potentially important datasets held across the science and policy communities, and facilitating the formation of new, inter-disciplinary research groupings.

DEFRA have pledged £1M to support joint activities associated with this action, and will support additional internal funding bids during the commissioning process. During this phase we will seek to maximize partnership opportunities with others (e.g. CEFAS, Marine Scotland) through the alignment of activities in a similar way to the Shelf Seas Biogeochemistry Programme.

Routes to impact: The proposed action impinges on a wide range of policy areas in the UK, Europe and Internationally. The goals of the action would support marine planning under the Marine and Coastal Access Act (MCAA); the development of indicators of good environmental status for the Marine Strategy Framework Directive (particularly biodiversity and food web indicators); and understanding the impacts of renewable energy developments and marine conservation zones. Scientific relevance to marine renewable energy implementation and long-established sectors such as oil and gas means the proposed action would be of interest to the private sector. Additionally, the scientific objectives directly address some knowledge gaps identified by NGOs active in this area (e.g. the WWF-Cymru PISCES project and the 5-year 4M Euro 'Celtic Seas Partnership' proposal led by WWF-UK to the EU Life+ initiative, with contribution from the NERC Shelf Sea Biogeochemistry programme [outcome of bid due in June 2012]). Hence there is an opportunity to align programme outcomes with ongoing ecosystem management programmes and stakeholder interests.