Marine Ecosystems Research Programme

NERC SCIENCE OF THE ENVIRONMENT

Department for Environment Food & Rural Affairs

Second project briefing to Defra: Integrating data and models to better understand the consequences of changes in marine ecosystems for the services they deliver to society

(MB0130: NERC Marine Ecosystems Research Programme)

Nobel House, 27th September 2017

In attendance from MERP: *Paul Somerfield, Michaela Schratzberger, Jessica Heard, Tom Webb, Mike Heath, Francis Daunt, Mel Austen, Tara Hooper, Jorn Bruggeman, Axel Rossberg, Kelvin Boot, Miriam Grace*

MERP Policy Briefing Defra Participants	Policy Area
Caron Montgomery	Marine Natural Science Research, Evidence & Monitoring Team
Laura Harland	Marine Evidence Team
Randolph (Randy) Velterop	Marine Evidence Team
Sunil Israel	Marine Evidence Team
Dominic Pattinson	Marine Environment Policy
John Clorley	MPA Management and International Marine Biodiversity
Amanda Desmond	Marine Planning and Licensing Team
Phillip Stamp	CFP Management Team
Arvind Thandi	CFP Management Team
Ross Deadman	Domestic Fisheries and Reform
Zac Nugent	Future fleet policy
Marilena Pollicino	Marine Economics
Frazer Quelch	Marine Economics

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Purpose of the briefing

NERC and Defra jointly fund the 'Marine Ecosystems Research' programme (MERP) which emphasises:

- The critical importance of robust ecosystem science related to marine food webs to help us balance our relationship with a changing planet.
- The need to manage ecosystems to continue providing the benefits we rely on (i.e. focus on ecosystem services throughout).
- The benefits of partnership working when commissioning, collecting, delivering and using scientific evidence.
- The value of sharing resources (incl. data).

The purpose of this briefing was to discuss MERP research activities with policy customers and to highlight policy-relevant MERP outputs. Following the first MERP briefing held at Defra in February 2016, we aimed to:

- Examine the utility of existing MERP science outputs to policy-makers.
- Help the MERP consortium to maximise policy-relevance of research products (i.e. ensure that appropriate and accessible outputs are delivered).
- Identify opportunities for the MERP consortium to provide scientific advice proactively to policy-makers.

AGENDA

1. **Welcome and introductions** *(Caron Montgomery)* **10.30 – 10.35am**

2. **The Marine Ecosystems Research Programme (MERP): *Background/Introduction*** *(Paul Somerfield)* **10:35 – 10:50am**

3. **Overview of Defra policy needs and issues** *(Laura Harland)* **10:50am – 11:00am**

4. **Policy-relevant MERP outputs using specific examples** *(MERP consortium members - each presenter will have 2-3mins to introduce each example followed by 40mins discussion)* **11:00am – 12:00**
    a) **Connecting ecosystem services and understanding Natural Capital** (PML, CEH, Cefas, Glasgow University, NOC, Queens University Belfast, QMUL, SAHFOS, SAMS, University of Sheffield, University of Strathclyde) – Melanie Austen/Tara Hooper
    b) **Synthetic mapping of the northwest European Shelf sedimentary environment for applications in marine science** (University of Strathclyde) – Mike Heath
    c) **Ecosystem service trade-offs between wildlife recreation and industrial activities** (CEH, Bangor University, SAMS, University of Glasgow, RSPB, Sea Watch Foundation) – Francis Daunt
    d) **Impact of fishing on the richness/diversity of large marine species** (QMUL, PML, University of Sheffield) – Axel Rossberg
    e) **The level of ocean productivity at which top-down effects become strong** (QMUL, Cefas, University of Strathclyde, SAMS) – Axel Rossberg
    f) **Best available estimates for MSFD indicator recovery times and quantification of residual uncertainty** (University of Sheffield, QMUL, Cefas, University of Strathclyde, SAMS) – Axel Rossberg
    g) **MERP contribution to ICES advice on trade-offs between managing fishing effort to improve MSFD indicators of seabed integrity, and the values of catches and landing** – Mike Heath
    h) **Model scenarios for assessing ecosystem-wide consequences of climate and policy change** (PML, Cefas) – Jorn Bruggeman
    i) **Maximising benefits from living Natural Capital** (University of Strathclyde, Bangor University, Cefas, CEH, PML, SAMS) – Mike Heath
    j) **Linking data across MERP modules and work packages** (University of Sheffield and all MERP partners) – Tom Webb

5. **Next Steps for MERP** *(Paul Somerfield)* **12:05pm – 12:20pm**

6. **Science to Policy Translation** *(Caron Montgomery)* **12:20pm – 12:30pm**

CLOSE

Summary of the meeting

Caron Montgomery (Member of MERP Executive Board) chaired the meeting. In her introduction she stressed that her hope was for the briefing to enable the development of relationships, by making introductions which could be taken forward after the briefing.

Following brief personal introductions, Paul Somerfield gave a short presentation describing the programme.

Laura Harland responded with a presentation describing Defra's current policy needs and issues. Understanding the marine ecosystem remains a key policy and evidence need. Evidence is needed on distribution, state and trend of marine ecosystem components; the ecology, functioning and food webs of marine ecosystems; and the services, goods and benefits provided by the marine ecosystem. Defra needs to understand how marine ecosystems might respond to environmental change through natural ocean processes, climate change and pressures from human activities. There is a need to develop more realistic marine ecosystem models to better enable advice to policy makers to explore the impacts of environmental change on marine ecosystems and test potential management solutions. The MERP priority list of policy questions remains relevant. Discussion highlighted the fact that the policy environment is in a rapid state of development. Ongoing discussions include how the functions currently performed by European institutions will be undertaken in the future including who will be the target of environmental/fisheries reporting after the UK leave the EU.

Mel Austen presented the conceptual model of links between MSFD, ecosystem components and ecosystem services developed in MERP. This was followed by a brief discussion around testing the ideas in MERP (e.g. the Cardigan Bay case study in WP3), Defra's 25 year plans, the SWEEP project, the North Devon Pioneer, marine spatial planning and natural capital assessments and species protection. It was clear that MERP was embedded in much of this.

Mike Heath described how existing data on seabed composition from a range of sources had been merged with different models to produce a new synthetic data product. This product is far in advance of the type of seabed composition data and maps previously available, both in terms of the scale and accuracy of its coverage and in the number of variables included. Gridded maps of various parameters were shown. It was immediately apparent in discussion that the new products have wide applicability of policy relevance, from better habitat mapping to inventorying carbon to providing background rates of natural disturbance for fishing impact studies.

Francis Daunt presented a range of work and maps about seabird and cetacean populations, including field maps and colony maps, showing how MERP has brought together different data and models (e.g. energetics) to derive useful predictive maps. The discussion revolved around the usefulness of such information in various contexts, such as marine spatial planning, siting of (energy) infrastructure and MPAs, decommissioning and cumulative effects. The discussion also covered social concepts such as cultural values, sense of place and seascapes. It was discussed that some of the data underpinning the products was 'old', but the response was that the maps are predominantly predictive about habitat preference so whilst abundances may have changed since the 80's the seabirds habitat preference will not, so data is still robust. Linking different types of data (e.g. sediment maps and seabird maps) was briefly discussed. This is part of what MERP aims to achieve.

Axel Rossberg described a new index based on the sizes of species in assemblages (the diversity spectrum) and showed how in initial analyses it appears to discriminate regional seas in a way that correlates with fishing pressure/disturbance. Initial discussion involved technical details such as corrections for correlation, where information on species (OBIS) and sizes (MERP trait explorer) had come from, and how alternative explanations for patterns had been assessed. It was explained that there was still much research to be done, not only on the effects of different uses of the sea on the index but also on the effects of alternative gear types. No trends were observed for specific species as they hadn't been examined.

Axel Rossberg then presented a modelling study showing the level of ocean productivity at which top-down effects become strong, and why. The effects of fishing are more severe when productivity is high. Discussions concluded that this work could be very useful going forward as Defra are reviewing indicators and targets in 2018, and therefore could have an impact on fishing policy.

Axel then went on to describe results using Bayesian analysis of results from the MERP ensemble to estimate recovery times and their associated (un)certainties for a range of MSFD indicators following reductions in fishing. Feedback was very positive. Ideas around model uncertainty are difficult to convey, but those present were able to understand and discuss the outcomes. Technical details of the simulations (e.g. baselines) were discussed, as were correlations with other indicators such as seabirds (not assessed). The relevance to OSPAR was noted, especially in terms of comparing different indicators/components.

Mike Heath described MERP's contribution to ICES advice on trade-offs between managing fishing effort to improve MSFD indicators of seabed integrity, and the value of catches and landings. The

overall finding was that fishing impact is greatest in least trawled areas which also contribute little to the overall value of landings. The work with the MERP model (spatial StrathE2E) looked at the cumulative impacts to show that everything is connected from sediments to seabirds and also at impact of different spatial areas (heavily impacted vs lower impacted). Changes have a ripple effect through the ecosystem so we need to model broadly to understand trade-offs of food web effects and changing fishing distribution. John Clorley (MPA Management and International Marine Biodiversity Team) pointed out that this work clashes somewhat with the approach advocated by NGOs who argue to protect the highly impacted areas so that they can recover. There followed a discussion around fishing effort displacement options –displacement from one heavily impacted area to another heavily impacted area is probably acceptable, but we should avoid displacement to currently low impacted areas as they will be greatly affected. This idea of restricting fishing to core areas to reduce wider impacts is quite new. In discussion it was agreed that while this work could be useful in planning scenarios the spatial resolution is quite course, so may it not be that applicable to MPA areas.

Jorn Bruggeman presented model scenarios for assessing ecosystem-wide consequences of climate and policy change, based on a coupled ERSEM-MIZER modelling system so we can look at nutrients to fish. Simulations show that a 30 % reduction in nutrients could lead to a 10 % reduction in fish biomass. Discussion focused on links to top predators and scenarios.

Mike Heath then presented work from MERP WP3 on putting together a system to look at maximising benefits form living marine Natural Capital and potential trade-offs between ecosystem services. This work brings together ecological modelling with monetary and non-monetary information, linking humans with the marine environment to help look at management systems and options. Discussion focused on the difficulty of measuring and modelling different services and aspects of Capital, for example fishery yields vs biodiversity. There were questions about the methodology for measuring non-market monetary values, for example by using travel costs, and comparing these with non-monetary values such as ‘sense of place’. The project has engaged extensively with a wide range of stakeholders to help identify contrasting scenarios of management and attitudes to economic yield vs Natural Capital values which will be explored using models. The results will be reflected back to the stakeholders towards the end of the project.

Tom Webb gave the final presentation, showing how in WP3 we are bringing together highly diverse data and information in a structured way to examine cumulative effects of pressures on the marine ecosystem, and how to manage them. The link between this work and OSPAR/ICES was clear in discussion.

Paul Somerfield closed the presentation with a short overview, saying that feedback on how to get our messages across to policy stakeholders, and to know when we had done so, was a clear goal of the programme. The main focus over final months will be work on cumulative impacts, trade-offs and stakeholder workshops. The model ensemble is now ready and working, so we can look at many types of modelling going forward. The MERP group expressed its openness to continued engagement with Defra. In discussion one suggestion was for a questionnaire to help connect people with those interested in their area of work. It was also agreed that it would also be good to include regulators and advisors as they will also be interested in the work of MERP (and able to communicate it to Defra).

Caron Montgomery then addressed policy translation. She said that the AVOID 2 programme provides some good examples of communication products - http://www.avoid.uk.net/. Communications with non-policy stakeholders such as fisherman requires a different approach, for example really short 1 min video to explain what models can do for them, so we could consider this. It is very important to get the 'so what' message across, that is really what policy and other stakeholders are interested in, so it is most important to focus on this. The 'so what' message should come first. She concluded by reiterating that the briefing is intended to be the start of an engagement process, so we should build on it.

The meeting then broke up, with a number of focused smaller discussions following.

Actions

- Follow up questionnaire to maintain connections between Defra customers and MERP scientists. **Questionnaire complete and circulated to Defra contacts 16 Oct 2017**
- Agree date for half day Stakeholder Event in London April 2018 – **Date agreed for 25th April**
- For general information please visit the MERP website (www.marine-ecosystems.org) follow MERP on Twitter (@merp_updates) or contact the Programme Office (marine.ecosystems@pml.ac.uk). For more detail please contact the relevant MERP scientist (http://www.marine-ecosystems.org.uk/Contact/MERP_Scientists) or contact the Programme Office.

Annex 1: MERP/Defra Briefing Note

www.cefas.co.uk

Second project briefing to Defra: Integrating data and models to better understand the consequences of changes in marine ecosystems for the services they deliver to society (MB0130: NERC Marine Ecosystems Research Programme)

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Appendix 2. MERP priority list of policy questions from various sources. The questions are directly linked to policy needs from Defra's perspective. 30

1. Purpose of the briefing

NERC and Defra jointly fund two R&D programmes that address key knowledge gaps in marine ecosystem research, the 'Shelf Seas Biogeochemistry' (SSB) and 'Marine Ecosystems Research' programme (MERP). Both programmes emphasise:

- The critical importance of robust ecosystem science related to marine biogeochemical cycles (SSB) and marine food webs (MERP) to help us balance our relationship with a changing planet.
- The need to manage ecosystems to continue providing the benefits we rely on (i.e. focus on ecosystem services throughout).
- The benefits of partnership working when commissioning, collecting, delivering and using scientific evidence.
- The value of sharing resources (incl. data).

The purpose of this briefing is to discuss MERP research activities with policy customers and to highlight policy-relevant MERP outputs. Following the first MERP briefing held at Defra in February 2016, we aim to:

- Examine the utility of existing MERP science outputs to policy-makers.
- Help the MERP consortium to maximise policy-relevance of research products (i.e. ensure that appropriate and accessible outputs are delivered).
- Identify opportunities for the MERP consortium to provide scientific advice proactively to policy-makers.

2. Preparation for the briefing on 27th September 2017, Nobel House, Defra

In order to make best use of the 2-hour meeting, we ask Defra policy customers to:

- Familiarise themselves with this briefing note and visit the MERP website (http://www.marine-ecosystems.org.uk/).
- Come prepared for a discussion on the types and formats of scientific information that is useful in their policy area.

Usefulness and uptake of existing and future MERP outputs are the main focus of the briefing rather than scientific detail.

For a list of MERP scientists participating in the briefing see Appendix 1.

3. What is the problem?

Over a decade ago, the Millennium Ecosystem Assessment drew attention to the importance of the direct and indirect contributions of ecosystem services in supporting human well-being. Since then, the scientific community amassed powerful evidence that human actions are leading to declines in many ecosystem services. As a result, the protection of ecosystem services now forms an important part of environmental management practice, designed to ensure ecosystem services are conserved for human benefit. When some classes of these services are used by humans at an unsustainable rate, the stocks of resources which generate ecosystem services (i.e. Natural Capital) may be depleted.

Bringing ecosystem services into the active management of marine ecosystems requires an understanding of the key processes which couple the ecological state of ecosystems with the provision of goods and services valued by society that ultimately determine Natural Capital. The focus of MERP lies in understanding marine food webs, and in particular how interactions and changes in feeding relationships amongst organisms affect the delivery of ecosystem services. MERP scientists integrate environmental, social and economic dimensions of this understanding to define options for the sustainable use (present and future) of aquatic living and non-living resources and related processes.

3.1 Marine food webs

Food webs are complex networks of interacting organisms through which energy and materials move. They are often studied and modelled in terms of the flow of energy between different organisms through the feeding of one organism on another (Figure 1). These models are basically a snapshot of "who eats what or whom" in the ocean. Change may be driven from the bottom of the feed web, for example increased nutrients may increase plant growth, and in turn increase the amount of fish. Alternatively, change may be driven from the top of the food web by reducing the numbers of predators through fishing or other mechanisms, and therefore allowing larger numbers of prey to survive.

A healthy and stable ecosystem is one that is able to sustain the energy flow between trophic levels within a food web. When positions in the food web are eliminated (as a result of natural or man-made change) trophic relationships are lost or put at risk and the ecosystem may experience imbalance. This can have important knock-on effects on the delivery of ecosystem services.

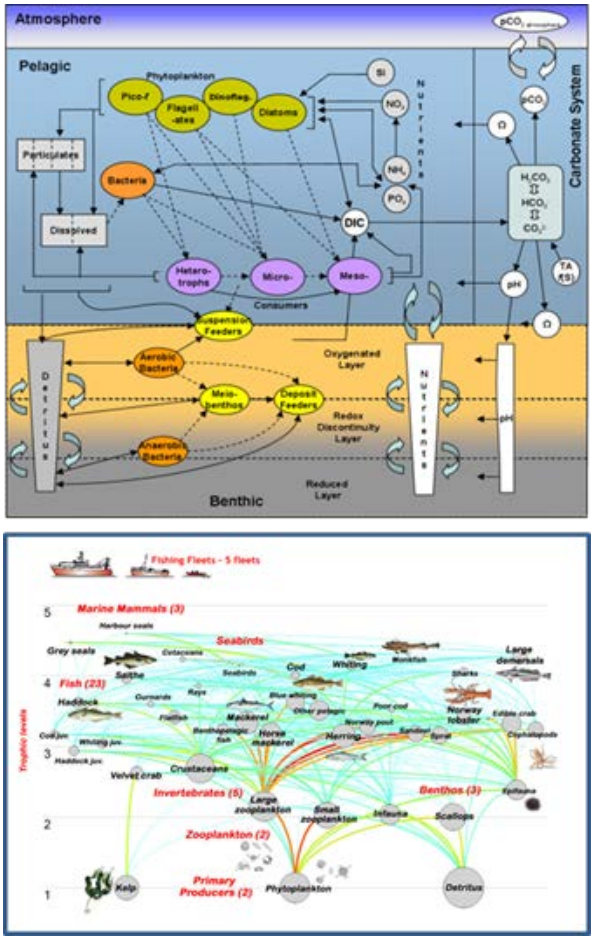


Figure 1. Schematic illustrations of food webs in models. Top: Functional-group biomass model focusing on the base of the food web in coastal seas (ERSEM). Bottom: Mass-balance model focusing on higher trophic levels and commercial species (Ecopath) to the west of Scotland.

4. MERP aims and funding

MERP is designed to improve understanding of the processes governing the dynamics of marine food webs and how changes in them affect the sustainable delivery of ecosystem services.

Specifically, MERP aims to

- Understand how marine food webs and the services they provide (e.g. food production and recreation) are regulated by natural mechanisms or human pressures.
- Integrate the improved understanding of food web regulation (see section 1. above) with existing ecosystem models and explore the impact of environmental change on the structure, function and services associated with marine food webs.
- Apply new model developments to test the impact of potential management solutions on the structure and function of marine food webs.

This £6m programme is co-funded by NERC (~ 85 %) and Defra (~ 15 %). Overall it will be active for 5 years, concluding in April 2019. Consistent with the scientific aims of the programme, it comprises three major elements: 1) to deliver scientific understanding of how changes in food webs drive changes in ecosystem service provision at different scales of space and time, 2) developing and improving NERC's marine ecosystem modelling capability, 3) addressing how different management scenarios may influence the sustainable provision of ecosystem services. The work is being delivered by a consortium of over 50 scientists working in 15 organisations from across the UK.

5. MERP science and policy-making decisions

Identifying, describing, understanding and quantifying feeding relationships amongst marine organisms through space and time were key objectives during the earlier stages of the programme. Existing and new data and knowledge, and modelling results brought together by MERP scientists over the past 3 years now allow us to show trends in the distribution of food web components under varying environmental regimes and to develop scenarios reflecting future states of marine food webs and ecosystem service provision on spatial and temporal scales that are relevant to management and policy. These include scenarios that take account of impacts of climate change or different management regimes.

MERP scenarios capture different policy options being considered by decision-makers, which are then translated by models into consequences for marine ecosystems, and the benefits they provide to society and to quality of life. Scenarios and models depend on data and knowledge for their construction and testing (Figure 2).

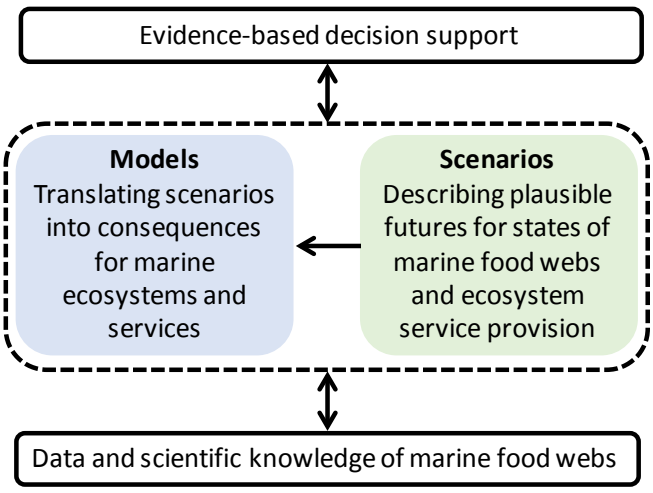


Figure 2. Overview of the roles that data, knowledge, models and scenarios play in MERP research

MERP research has been aligned with a dynamic list of key policy questions from various sources including policy needs identified by the MERP Stakeholder Advisory Group (SAG), discussions at Marine Science Coordination Committee (MSCC) level surrounding the contribution of shelf seas models to policy development and a gap analysis by the Marine Management Organisation (see Appendix 2).

This allowed us to focus MERP work on addressing high-level questions, including "What is the state of food webs (or its components) in relation to specified targets?", "What are the effects of natural and anthropogenic change on the state of marine food webs and the services they provide?", "What are the likely future states of marine food webs and ecosystem service provision under scenarios reflecting management situations in UK waters?" (Appendix 2).

6. Specific examples of policy-relevant MERP outputs

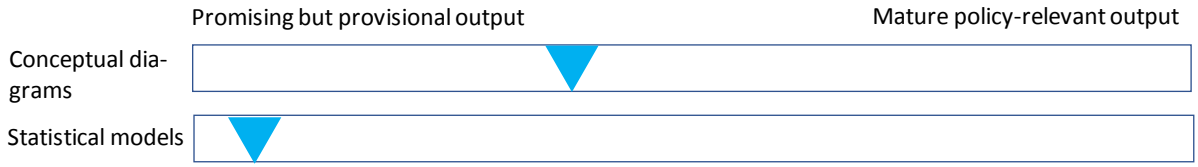
Regular discussions with the Defra Project Officer indicated that Defra colleagues are particularly interested in brief examples of science outputs that they can use in specific policy contexts. The following examples are therefore tailored to specific policy relevance, rather than presented in a more general sense.

The role of MERP science is to provide information to those having to make decisions, including the public. We are therefore explicit about the uncertainties around the scientific evidence we present. Demonstrating the credibility of model outputs is particularly important. Within MERP, this is achieved by quantitatively comparing model outputs with spatio-temporally extensive observed data. Challenging models with data and exploring the parameter sensitivities reveals where models perform well against data and where they do not.

MERP science is not a uniform entity. It is a collection of concepts, techniques and processes that has evolved throughout the project and continues to evolve. In order to help decision-makers to navigate through the specific examples, we indicate where specific research outputs sit along a continuum ranging from "promising but provisional in nature" (i.e. working draft that requires refinement) to "mature policy-relevant output" (i.e. version ready to guide decision-making and policy development).

Figure 3. Hypothetical diagram indicating where a specific MERP research output sits along a continuum ranging from "promising but provisional in nature" (i.e. working draft that requires refinement) to "mature policy-relevant output" (i.e. version ready to guide decision-making and policy development). Each example of MERP science output is accompanied by such a diagram.

Connecting ecosystem services and understanding Natural Capital (PML, CEH, Cefas, Glasgow University, NOC, Queens University Belfast, QMUL, SAHFOS, SAMS, University of Sheffield, University of Strathclyde) – Melanie Austen/Tara Hooper



Our understanding of how ecosystems support and deliver ecosystem services tends to be built on linear chains of evidence, often presented as tables or diagrams. The idea is that if some elements of Natural Capital changes, then this will influence the flow of particular services. Ecosystems, however, are highly complex, and in reality individual services do not exist in isolation. This means that they consist of numerous interacting elements, and these interactions include many positive and negative feedbacks. Thus, the links between ecosystem components and the services they provide are complex. Understanding the interactions among critical elements of Natural Capital and services, how these are affected by different pressures and management measures, and where major trade-offs between services exist, is essential for defining options for the multiple use of marine resources.

Headline findings and significance

- MERP scientists considered how elements of the marine ecosystem contribute to supporting the services of leisure and recreation, food provision, biological control and bioremediation of nutrients, and how those elements interact with each other.
- Much of the evidence gathered to document and monitor change in marine ecosystems for other purposes (e.g. GES) can be linked to changes in services. A conceptual framework was developed, illustrating key links among ecosystem components, processes and ecosystem services, which can be used to highlight trade-offs between multiple services.
- The conceptual framework was further developed to include potential threats and management measures to mitigate those threats.
- The conceptual frameworks are used to develop statistical and numerical models of the interactions among ecosystems and services, and understanding of how the regulation of key ecosystem services is affected by top-down and bottom-up processes in marine food webs.

Policy implications

- The concept of ecosystem services is increasingly used in formulating policy, but our understanding of how changes in ecosystems affect services is rudimentary. The ultimate aim of this work is to improve our ability to manage marine ecosystems with understanding of how management actions may alter services.

Type of products policy-makers could use

- Diagrams based on the conceptual frameworks (Figure 4) allow a decision-maker to visualise the key interactions between different elements of Natural Capital and multiple ecosystem services simultaneously. They show where changes in Natural Capital might influence supply of different ecosystem services, where ecosystem services may depend on different elements of Natural Capital, or where a change in Natural Capital may affect provision of multiple other ecosystem services. Figure 5 guides the decision-maker to consider how management measures might directly or indirectly affect ecosystem services.
- The conceptual diagrams provide frameworks for numerical or statistical models. These are being developed within MERP as tools for examining trade-offs between ecosystem services that result from different management scenarios

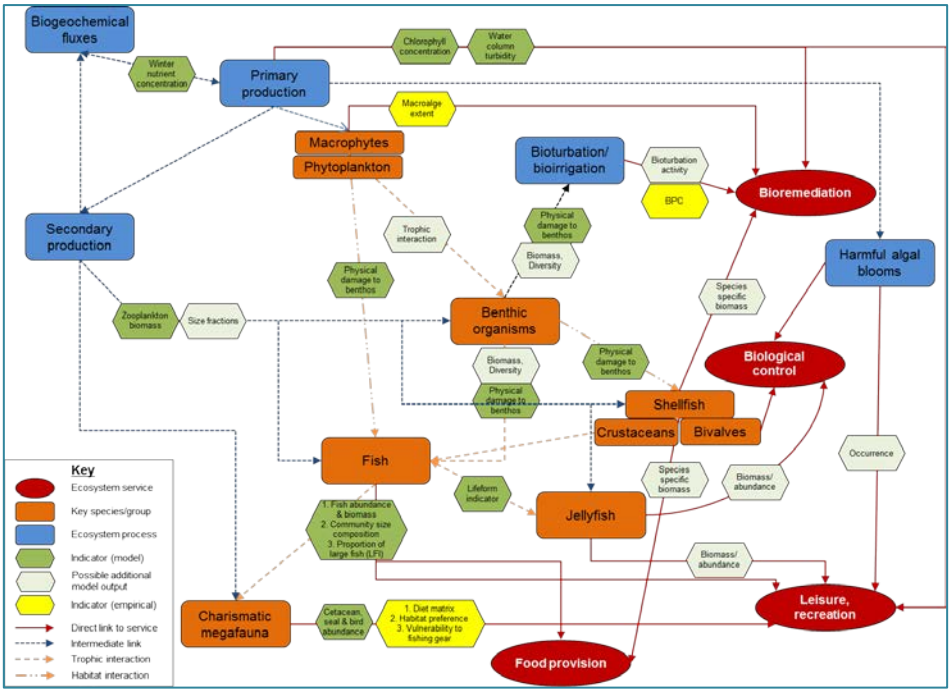


Figure 4. Conceptual diagram of how Natural Capital elements and flows link to ecosystem services. Interactions between different elements of Natural Capital may affect multiple ecosystem services.

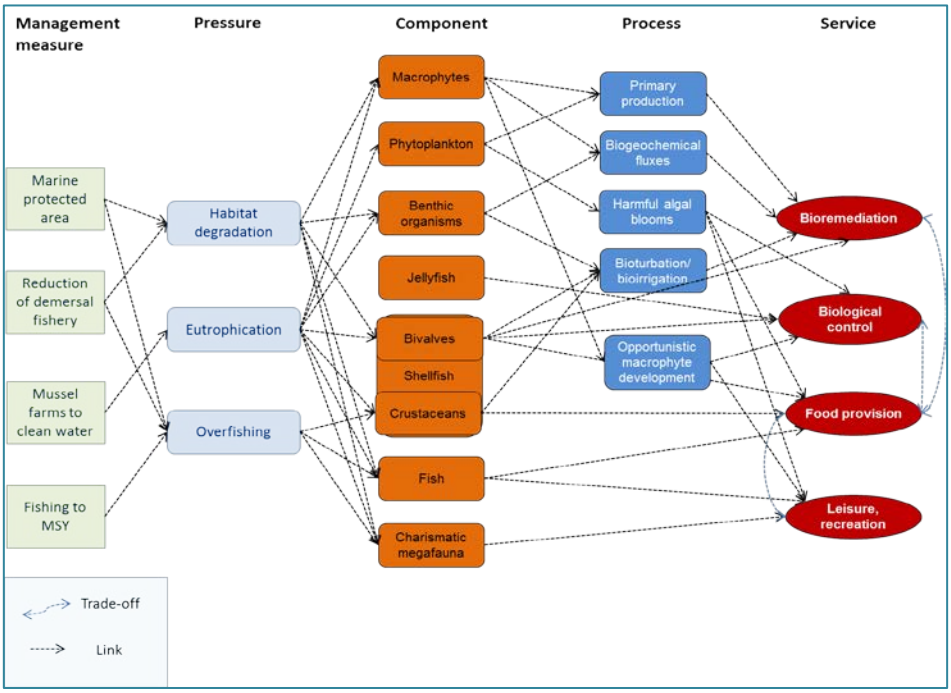


Figure 5. Conceptual diagram extended to include example pressures and management measures, indicating how changes might directly or indirectly affect services

Synthetic mapping of the northwest European Shelf sedimentary environment for applications in marine science (University of Strathclyde) – Mike Heath

It is commonly assumed that mapping of seabed sediments is a 'job done' as a result of several national and European-scale projects. However, the outputs from these projects are entirely in terms of the area distributions of discrete seabed habitats or whole sediment classes, e.g. fine muddy sand. Whilst these are essential for some marine planning tasks, they are not suitable for other tasks, such as the configuration of ecosystem models, which require data on continuous measures of sediment properties. We have created a **MERP data product** by compiling international data sets on individual sample-by-sample measurements of sediment composition, grain size, and carbon and nitrogen content for a large part of the NW European shelf from the Bay of Biscay to the northern limits of the North Sea and the Faroe Islands. We used a combination of gridding where the data density was high, and a machine-learning algorithm to predict the sediment data for areas where there were no samples, to produce an integrated atlas of a range of continuous properties of the seabed (Figure 6).

Headline findings and significance

- The data products synthesise large-scale information about the physical environment of the seabed, both in terms of the characteristics of sediment and the wave and tidal regimes which cause disturbance.
- Using field estimates of the sediment composition of the seabed, we are able to map, with high confidence, the sediment composition of the North Sea and British territorial waters, and we are able to make credible statistical predictions of the sediment composition in other regions.
- Of particular note is our mapping of exposed and thinly covered bedrock (Figure 7). In some regions, e.g. west of the Outer Hebrides, our results give a very different perception of the extent of exposed rock comparted to traditional maps.

Policy implications

- The compiled data sets of sediment composition and disturbance regime are, as far as we know, the most extensive that exist over such a large spatial scale.
- A number of applications exist for these data sets, including habitat mapping and quantification of anthropogenic disturbance on the seabed.

Type of products policy-makers could use

- A range of gridded data products available are gridded maps of:
  - mud, sand and gravel percentages by weight of the sediment,
  - median grain size of the whole sediment and separately for the sand and gravel fractions,
  - porosity and permeability of the sediment,
  - organic carbon and nitrogen content of sediments,
  - mean and maximum depth-averaged tidal velocity and wave-orbital velocity at the seabed,
  - monthly mean natural disturbance rates of the whole sediment

  These digital data gridded at ⅛-degree resolution are open access and available to download, along with a full description of the methods used (www.earth-syst-sci-data-discuss.net/essd-2017-88/).

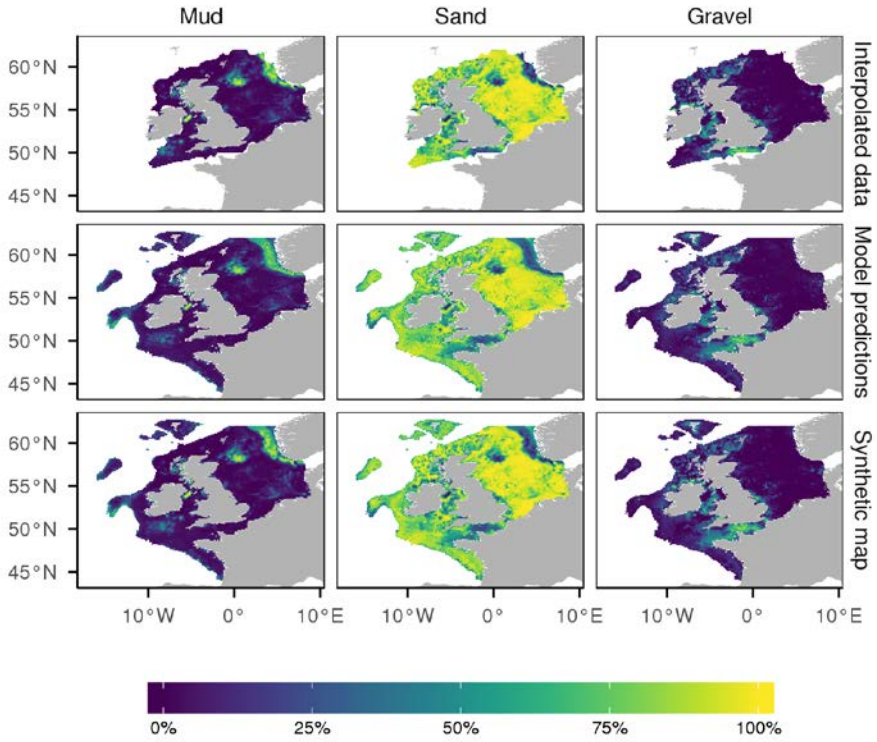


Figure 6. Derivation of the synthetic maps of sediment percentages. The interpolated map uses bilinear spline interpolation of sediment data over the region. The model prediction map shows the sediment percentages using a random-forests machine learning algorithm which relates the percentage to the bed shear stress and the distance to the coast. The synthesized map merges the two, using spatial interpolations where we have data, and the predictions where we do not.

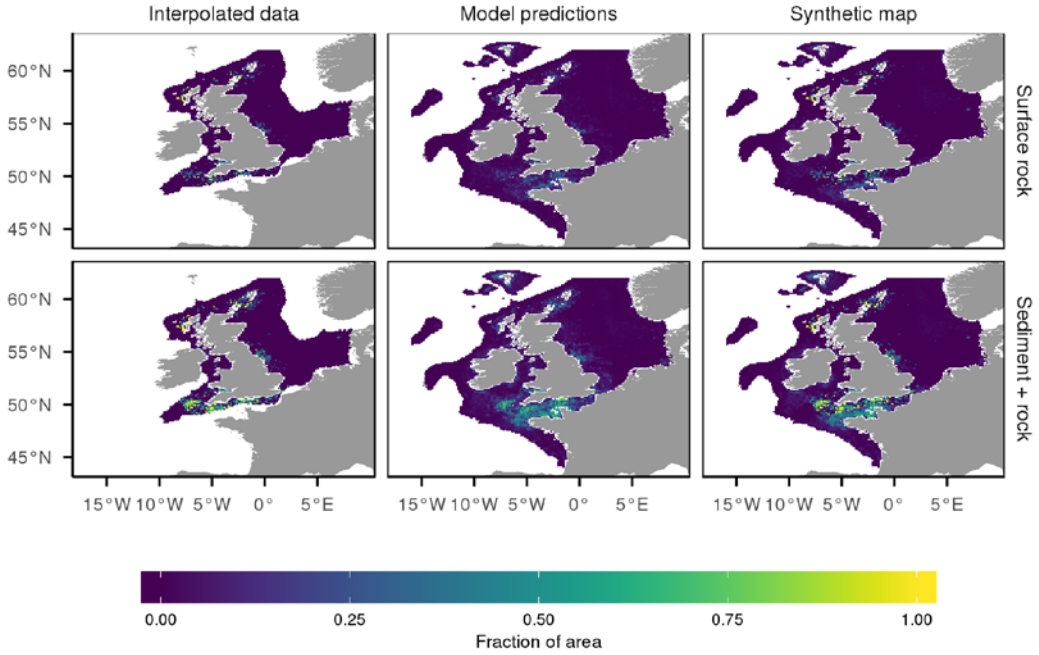


Figure 7. Derivation of the synthetic maps of area-proportions of exposed bedrock, and of rock covered by up to 5cm of sediment. The interpolated map uses bilinear spline interpolation of sediment data over the region. The model prediction map shows the rock area proportions using a random-forests machine learning algorithm which relates the percentage to the bed shear stress and the distance to the coast. The synthesized map merges the two, using spatial interpolations where we have data, and the predictions where we do not.

Ecosystem service trade-offs between wildlife recreation and industrial activities (CEH, Bangor University, SAMS, University of Glasgow, RSPB, Sea Watch Foundation) – Francis Daunt

Top predators have a direct influence on the provisioning of competing ecosystem services including wildlife tourism, fisheries and offshore renewable energy developments, through the interplay between human activities and top predator distribution, abundance and behaviour. MERP scientists have produced a series of distribution maps for each of the main UK seabird and cetacean species to capture monthly and interannual variation in top predator diversity and abundance throughout UK waters. Models have been used to identify the major environmental drivers of variation in space and time. Breeding season distribution maps of seabirds have been combined with energetics models to map predation pressure and overlap with offshore renewable developments for four seabird species (black-legged kittiwake, European shag, razorbill and common guillemot).

Top predators play a crucial role in cultural values and sense of place in coastal communities and directly affect livelihoods through tourism and recreation. Social science research on cultural values, experiences and identities is producing a documentary film based on the results of 40 stakeholder interviews conducted with representatives of the regulatory, provisioning and tourism/recreation sectors, in the Southwest of England and West Coast of Scotland. Stakeholders contributed information about their experiences and knowledge relating to ecosystem services and identified potential trade-offs between wildlife recreation and other activities in the marine environment and preferred marine management strategies that minimise competing interests. Stakeholders identified various aspects of Natural Capital important to them and the role of biodiversity in enhancing or detracting from their capacity to benefit from ecosystem services.

Headline findings and significance

- Analyses based upon collation of 2.18 million km of transect surveys from >50 research groups spanning 8,000 days (1989-2017), yielding 4.89 million animals of 127 top predator species. Maps can be created from these data including monthly density maps for seabird and cetacean species (Figure 8) and predation pressure for species of conservation concern (Figure 9).
- The identification of the main environmental drivers accounting for spatio-temporal variation in top predator abundance provides predictive power for effects of climate change and changes to predator-prey relationships.
- Stakeholder knowledge and experiences demonstrates close linkages between culture and natural environment that shape acceptance of potential ecosystem service trade-offs.

Policy implications

- Maps will (1) aid marine spatial planning by identifying important areas for protected species and (b) benefit assessments of the impacts of fishing (through competition and bycatch), noise production and offshore renewable developments.
- Stakeholder experiences and knowledge will inform potential management strategies and highlight trade-offs between ecosystem services.

Type of products policy-makers could use

- Maps of seabird and marine mammal density and diversity hotspots in UK waters, including predation pressure on commercially important forage fish in shelf seas.
- Documentary synthesising the shared values and competing interests of stakeholder interests from the tourism, leisure, recreation, provisioning and regulatory sectors.

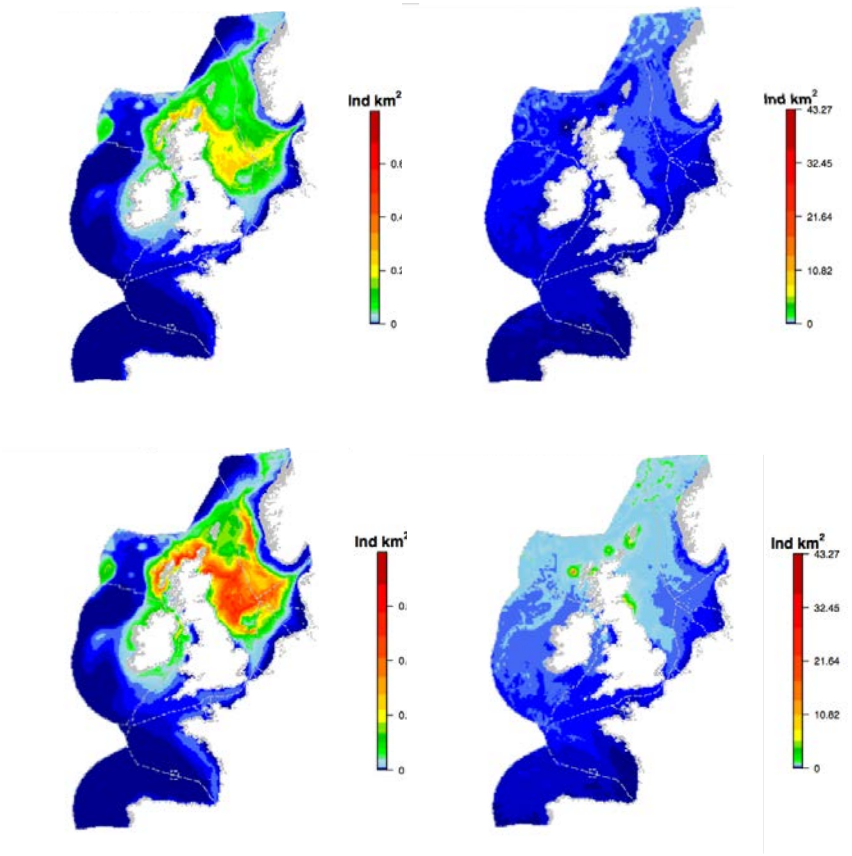


Figure 8. Sample top predator species density maps: Left: White-beaked dolphin in January (upper), June (lower); Right: Atlantic Puffin in January (upper), June (lower)

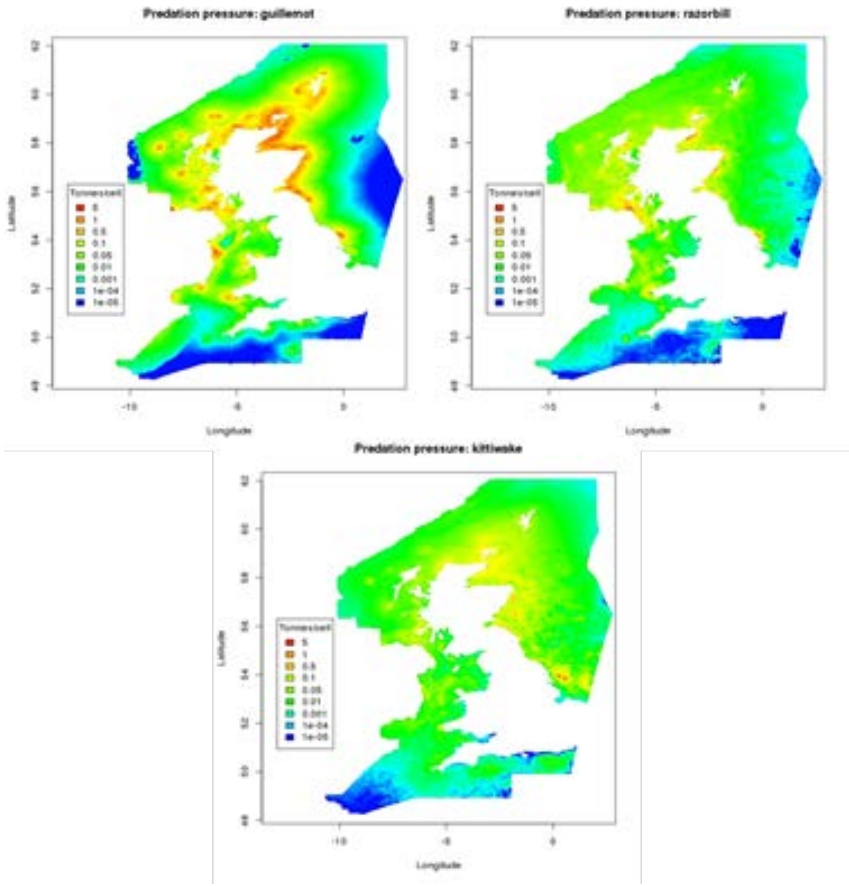


Figure 9. Predation pressure from breeding seabirds (tonnes/km^2) exerted in UK waters during the breeding season (May – August).

Impact of fishing on the richness/diversity of large marine species (QMUL, PML, University of Sheffield) – Axel Rossberg

This information is awaiting publication please contact Axel Rossberg (a.rossberg@qmul.ac.uk) for further details.

The level of ocean productivity at which top-down effects become strong (QMUL, Cefas, University of Strathclyde, SAMS) – Axel Rossberg

This information is awaiting publication please contact Axel Rossberg (a.rossberg@qmul.ac.uk) for further details.

Best available estimates for MSFD indicator recovery times and quantification of residual uncertainty (University of Sheffield, QMUL, Cefas, University of Strathclyde, SAMS) – Axel Rossberg

This information is awaiting publication please contact Axel Rossberg (a.rossberg@qmul.ac.uk) for further details.

MERP contribution to ICES advice on trade-offs between managing fishing effort to improve MSFD indicators of seabed integrity, and the values of catches and landings – Mike Heath

The European Commission's Directorate-General for Environment (DG ENV) asked ICES to "*Evaluate indicators for assessing pressure and impact on the seafloor from bottom-contacting fishing. Using this assessment, demonstrate trade-offs in catch/value of landings relative to impacts and recovery potential of the seafloor.*" Work to produce the ICES advice began in 2016 with the use of international vessel monitoring system (VMS) and logbook data to generate maps of fishing intensity (effort per unit of area). These formed the basis for three interconnected workshops in 2017 – WKBENTH, WKSTAKE, and WKTRADE – which culminated in the ICES advice.

The WKBENTH task was to evaluate ways of modelling the sensitivity of different seabed habitats to pressure, and produce maps and indicators for measuring what effect fishing has on the seabed. WKSTAKE took these maps and indicators and, along with information on catches and values of landings, brought together stakeholders to explore how trade-offs could occur. Finally, WKTRADE considered how to inform managers of these trade-offs. The University of Strathclyde contributed to the WKTRADE workshop, with a series of North Sea case study simulations using the MERP StrathE2E end-to-end ecosystem model.

StrathE2E has two linked components – and ecology model and a fishing fleet model. The ecology model represents the entire food web and simulates the changes over space and time of biomass and production in coarse groupings of marine organisms ranging from microbes to megafauna, and including nutrients, detritus and the effects of physics and active migrations of the larger organisms. The fishing fleet model compiles spatial patterns of activity, seabed abrasion rate, and discard rates of up to 12 different fishing fleets, into the inputs that are needed by the ecology model.

Headline findings and significance

- For the North Sea, static analysis assuming no indirect food web or other interactions, showed that expelling seabed-abrading fishing gears from the areas contributing the least 5-10% of landed value would be the most efficient way of generating a substantial gain in seabed habitat indicators. A high proportion of these areas are in UK waters.
- StrathE2E was used to explore the indirect effects, i.e. via food web interactions, arising from the proposed displacement of fishing activity. Results from a baseline model with 2003-2013 'status-quo' fishing activity distributions, were compared with those from a scenario model with fishing activity expelled from the least heavily fished areas and redistributed across the rest of the region. The definition of 'least heavily fished' was the area accounting for the lowest 20% of seabed abrasion rate. In general, the scenario simulation involved relocating seabed contact gears from the shallow inshore waters into deep muddy and deep sandy habitats.
- Comparison of the baseline run with the redistribution scenario results, revealed complex indirect effects above and beyond the direct effects on the seabed integrity. These arose through cascading food web processes and extended even to birds and mammals. Due to the complexity of the food web, these are not easily foreseen or predicted.
- In terms of simulated effects on overall catch and landing by fishing fleet sectors, the redistributing of activity had a detrimental effect on the static gears which were not subjected to relocation (creels, gill-nets and long-lines), and on the catch of Nephrops by prawn trawlers. All other gears benefited from increased catches overall (pelagic fisheries which do not make significant contact with the seabed, otter and beam trawls, demersal seine, shrimp and scallop fisheries).

Reliability of the results

The performance of the ecology model has been tuned to a wide-ranging assemblage of 'reference state' observed data on the North Sea, including spatial distributions, spanning all aspects of the ecosystem from plankton to benthos, fish and fish yields, and birds and mammals. The tuning involved around 100,000 replicates of the model runs with random selection of parameter values, to converge on the 'best fit' combination. As a result we can confidently say that this model cannot do any better at reproducing the reference state of the North Sea. The model performed best at explaining the landings data from the various fisheries, and the biomass distributions of fish and zooplankton, and least well at explaining the spatial distributions of phytoplankton. Making the process of parameter optimisation computationally feasible, involved trading-off spatial and taxonomic detail in the model so that it could run fast enough. So StrathE2E cannot give advice at the scale of e.g. cod and whiting biomass or length distributions, only at the scale of all demersal fish

biomass. It should be used to scope the broad direction of change in the ecosystem resulting from a management action, not the species-level details.

The model is so far designed to provide predictions of the state in which the ecosystem is expected exist in the long-term under stable environmental conditions and rates of exploitation. So, for example, it can provide meaningful estimates of long-term sustainable yields. It's performance at predicting short-term changes in ecosystem state has not yet been evaluated.

Policy implications

- As a result of the MERP modelling input to WKTRADE, the ICES advice was issued with the caveat that "*interconnectivity of all marine life through food webs means that every management decision will have an effect, sometimes in opposing directions, on every part of the system. It is important that these further ecological consequences are taken into account to reduce the risk that management produces unwanted results*".
- The advice could be significant for the UK since a high proportion of the least-heavily fished seabed areas are located in UK waters. Hence, the trade-off involved in enacting the proposals would be between improving the seabed status of the North Sea as a whole, versus restricting access to areas of UK waters for bottom-contact gears and displacing the fleet sectors affected into fishing grounds elsewhere.

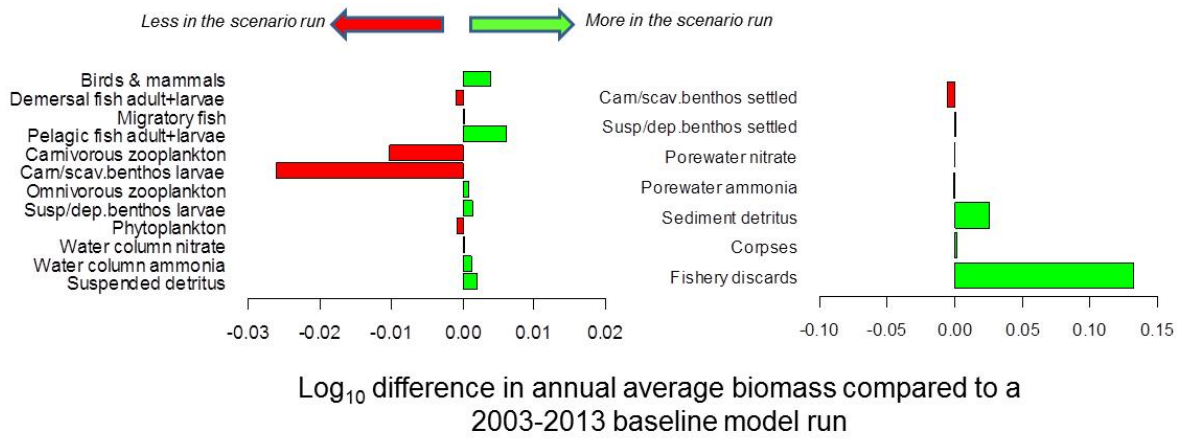


Figure 15. Whole North Sea effects of redistributing the activity of seabed-scraping gears away from the 20% LEAST impacted habitats, on the whole North Sea annual averaged mass of components of the StrathE2E ecosystem model. Red bars indicate that expelling fishing activity from the least heavily fished areas caused a REDUCTION in mass compared to the 2003-2013 baseline. Green bars indicate that expelling the fishing activity resulted in an INCREASE in mass across the North Sea as a whole.

Model scenarios for assessing ecosystem-wide consequences of climate and policy change (PML, Cefas) – Jorn Bruggeman

Numerical models are quantitative descriptions of marine ecosystems that link policy-relevant indicators and ecosystem services to their external drivers (e.g. climate, fisheries etc). Uniquely, models allow us to explore and predict how changes in external drivers (e.g management measures) propagate through marine ecosystems, and ultimately affect metrics with immediate societal relevance. MERP modellers trace the impact of ecosystem drivers, via hydrodynamics, nutrients, plankton and benthic invertebrates, to higher trophic levels (HTLs) including fish. This is done through a number of model scenarios in which the ecosystem drivers are systematically changed. MERP builds on results from the Shelf Seas Biogeochemistry (SSB) programme, which developed a spatially explicit model system for the UK seas (NEMO-ERSEM) and a number of scenarios (incl. climate change, riverine nutrient reduction, Marine Protected Areas). Results from these scenarios drive an ensemble of HTL models in MERP, focusing on fish communities subject to fisheries pressure. This creates an integral framework for assessing the impact of climate and policy change throughout the marine ecosystem, from nutrient regeneration and carbon sequestration to food provision.

As example, Figure 16 shows results from a spatially explicit model of size-structured fish communities, driven by temperature and plankton fields provided by SSB. The fish model simulates biomass and landings for 100 different size classes of fish (1 mg – 100 kg), but does not distinguish individual fish species. Results provide an assessment of the present-day marine ecosystem, including the distribution of plankton and fish biomass (top panel). Scenario simulations subsequently allow us to judge how policy measures such as a 30 % reduction in riverine nitrogen cascade through the system to ultimately affect fish (bottom panel). Here, a decrease in fish stocks of up to 7.5 % can be expected, with large size classes disproportionally affected.

Headline findings and significance

- An integrated model system links key ecosystem drivers (climate, river management, fisheries management) to a wide variety of indicators and ecosystem service metrics – from physics to fish. Model results are spatially explicit, with UK Shelf Seas covered at 7 km resolution.
- The impact of climate change and specific management actions is explored through scenarios that quantify the sensitivity of fish communities to bottom-up (riverine nutrients) and top-down (fisheries pressure) drivers.
- Further analysis of the model ensemble will deliver consensus model projections and estimates of uncertainty.

Policy implications

- Management plans that involve riverine nutrients and fisheries – for instance, MPA proposals – can be evaluated prior to implementation to estimate their impact on fish communities. Scenario outputs provide information on both the magnitude and spatial range of these impacts.

Type of products policy-makers could use

- Maps of projected ecosystem properties, including hydrodynamics, lower trophic levels, and fish. These cover UK seas between 1980 and 2015, and a further period up to 2050 based on RCP 8.5 climate projections. Nutrient and trawling scenarios cover a period from 2000 to 2015.

- Elasticities that quantity how a relative change in nutrients affects different components of the marine ecosystem, specifically, different size classes of fish.

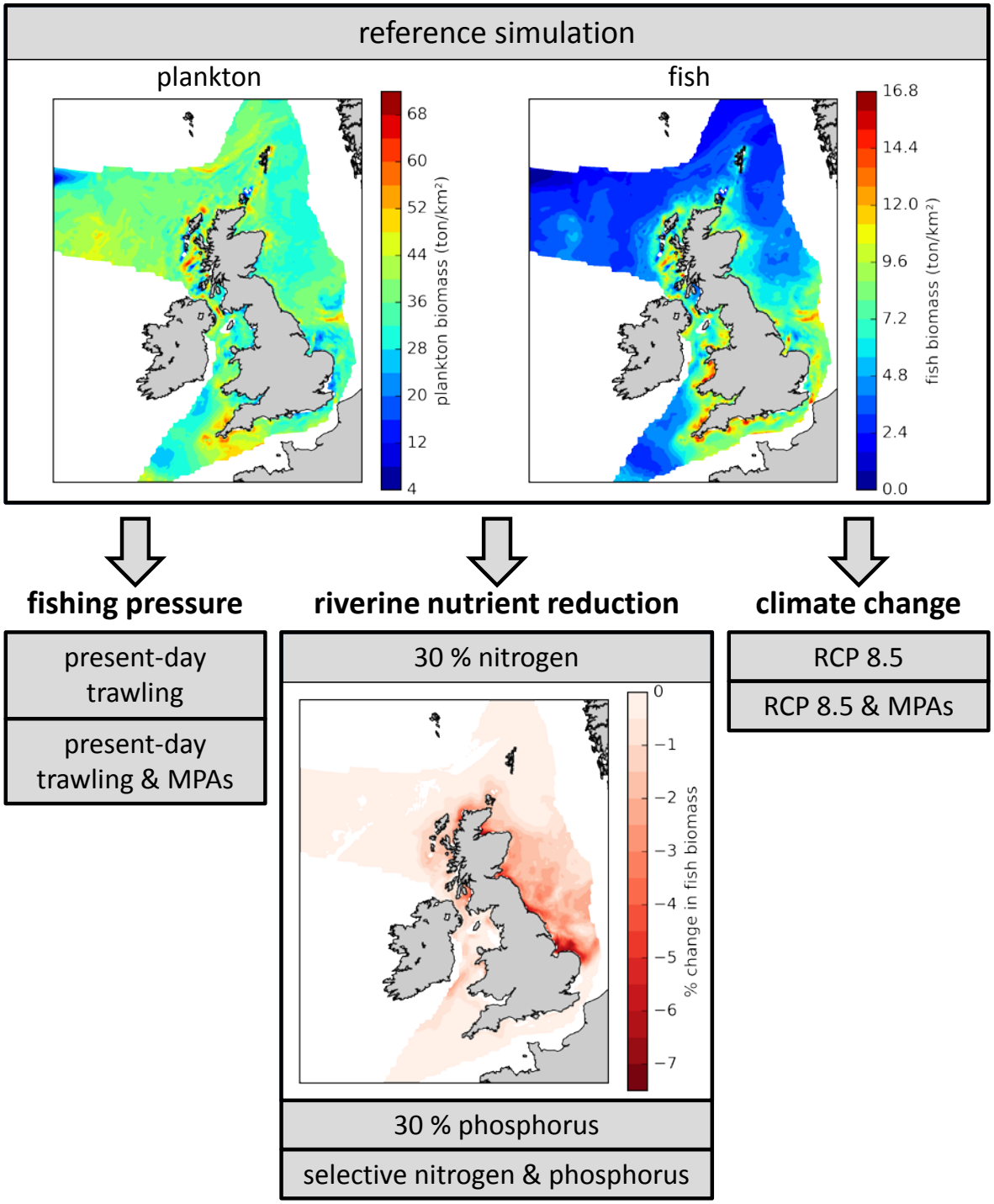


Figure 16. An overview of the reference (top) and scenario simulations (bottom) used in MERP to determine the sensitivity of fish communities to external drivers.

Maximising benefits from living marine Natural Capital (University of Strathclyde, Bangor University, Cefas, CEH, PML, SAMS) – Mike Heath

Work in the final phase of MERP identifies strategies for using provisioning (food) and tourism, leisure and recreation (TLR) services provided by the living Natural Capital sustainably. Trade-offs are likely to cause conflict between economic (e.g. fishing) and cultural (e.g. wildlife watching) sectors of society. MERP scientists: a) assess the monetary and non-monetary implications of potential trade-offs; b) determine the ways in which trade-offs may be exacerbated or alleviated by social, economic and cultural factors which underlie user conflicts; and c) work with stakeholders to scope the potential of a range of marine management options, including ways of implementing marine protected areas (MPAs) to alleviate conflicts, and work towards maximising the overall value of Natural Capital.

Experiments on the coupled social-economic-ecological system are being done to test hypotheses about alternative management controls, and to support future management and policy decisions. Virtual systems based on mathematical and statistical models of particular marine regions (i.e. the west of Scotland and the Celtic Sea) are used to link models of the marine ecology in these regions with models representing the economic and cultural valuation of living marine ecosystem services, and models representing the management measures to regulate human activities affecting the marine ecology (e.g. constraints on commercial fisheries). Output from this coupled system will be used to support evaluation of cultural values that cannot be parameterised in models.

Headline findings and significance

- Almost 300 stakeholders have been identified and categorised by type and region, then scored for power and interest. This is being used to assess how to engage effectively with stakeholders.
- Three stakeholder workshops have been held, presenting different views of the future and identifying stakeholder preferences, to examine trade-off between management approaches.
- A series of video interviews have been done to identify aspects of ecosystem value that cannot be given a monetary value (e.g. landscape, water quality). A 45-minute film has been created to illustrate the range of perspectives and will be used to develop a survey.
- An approach has been developed for integrating biological, economic, and social components into ecosystem models, that will allow the trade-offs between management measures to be assessed in terms of biological sustainability and value (Figure 17).
- Visualisations are being developed to illustrate trade-offs between risk, sustainability, and value, and products identified for inclusion in the Cefas MSFD Assessment Tool (CefMAT).

Policy implications

- Stakeholder experiences and knowledge will inform potential management strategies.
- Models will support the management of marine recreational fisheries through incorporating changes in value in response to different management measures.
- The integrated models will help to develop management approaches that maximise the value to society and are palatable to the stakeholder communities.

Type of products policy-makers could use

- Functions that link changes in value of a resource to different management approaches.
- Maps from models of exploitation and value in response to competing management scenarios.

- Understanding of shared values and competing interests of stakeholder from the tourism, leisure, recreation, provisioning and regulatory sectors.

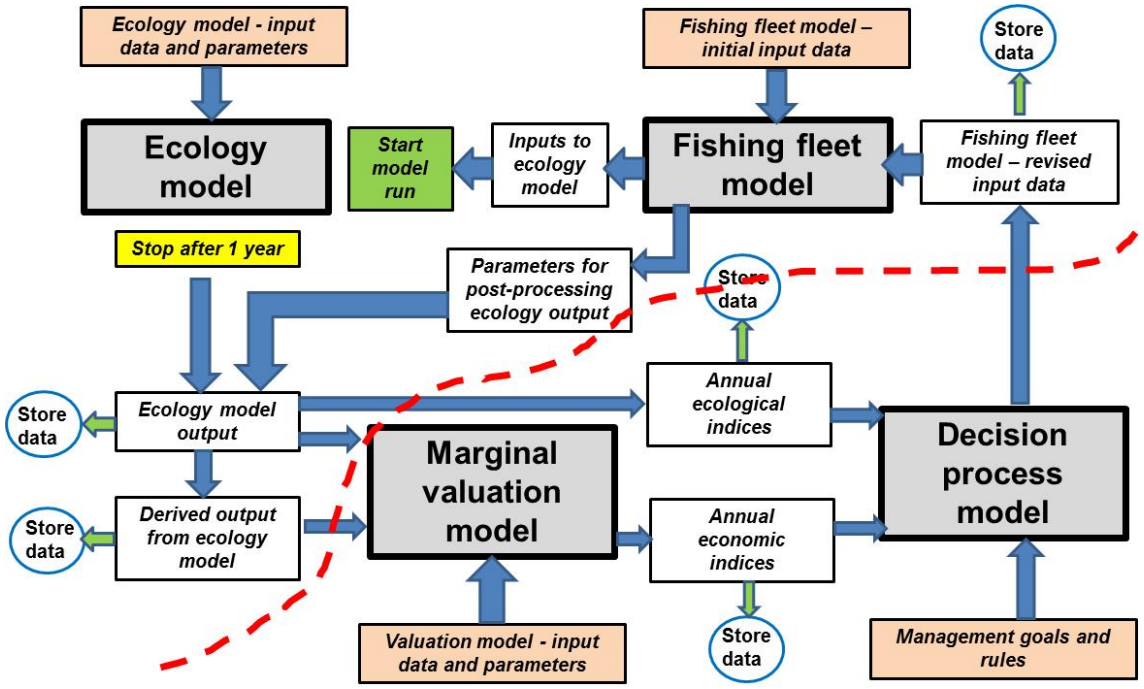
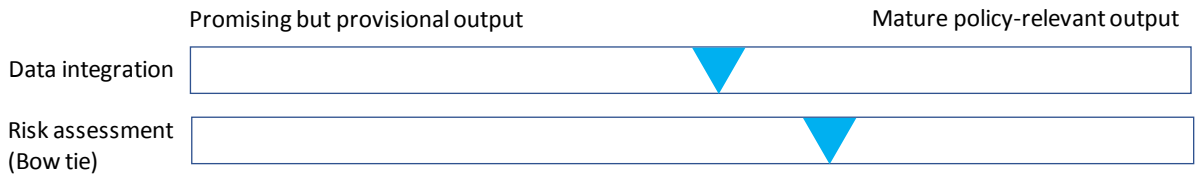


Figure 17. Integrated ecosystem management strategy evaluation scheme. Components above the red dashed line are all available in an existing ecosystem model (StrathE2E), and the marginal valuation and decision process model are being developed.

Linking data across MERP modules and work packages (University of Sheffield and all MERP partners) – Tom Webb



MERP has benefited from a range of initiatives including Defa's Open Data initiative which is helping to open up the large stock of survey data held by Cefas, as well as EU and global programmes aimed at mobilising data on marine ecosystems. MERP's focus has been on combining data of different provenance, in particular linking data derived from large datasets with datasets that have compiled within MERP from literature sources and from new field measurements and observations.

MERP scientists are currently refining maps of top predator distributions and densities, as well as occurrences drawn from a wide range of sources of > 8000 species, almost all of which have been assigned to a major functional group, with body sizes and other biological trait data also compiled for several thousand species. Ecological data is being enriched with physical parameters derived from ERSEM hindcasts (e.g. using mean temperature for each month from 1981 to 2015, resolved through the water column, to assign an environmental temperature to each occurrence record located in time and 3D space), as well as the University of Strathclyde sedimentary environment maps so that organisms can be linked more reliably to their environment by taxonomy and/or traits.

This same data structure facilitates the generation of indicators and links these to other spatio-temporal datasets, in particular on human pressures such as the distribution of fishing effort, offshore renewables, shipping and sesimic data, all of which has been compiled recently. This final phase of MERP work focuses on cumulative impacts. Similar to OSPAR a risk assessment approach is adopted, using Bow Tie Analysis, which simplifies the many complex interactions between pressures and impacts in marine ecosystems. First, a key 'issue' (framed in terms of changing state of an indicator, e.g. 'Decline in Seal Population and Distribution') is identified, which forms the central 'knot' of the bow tie. This is then linked to a series of 'causes' (pressures) and consequences, with the cumulative effects of both preventative and mitigation management actions also considered (Figures 18 and 19). Where possible, empirical data described above are used to populate these bow ties. However, data gaps inevitably occur. To address these, MERP scientists are working with stakeholder communities to harness their expert knowledge to increase confidence in some of these lesser-studied linkages.

Headline findings and significance

- Improving and integrating data on interacting components of the marine ecosystem has led to more comprehensive data (by collecting of tens of thousands of additional biological records including poorly monitored groups of species), enriched data (by linking major groups of species with data documenting their relationships with their living and physical environments) and ease of access to data (via a flexible and powerful tool using open source software).

Policy implications and type of products policy-makers could use

- It is currently unclear to what extent environmental change could result in radically altered communities, comprising species with novel mixtures of biological traits. Empirical evidence from analyses of MERP's trait-based data, for example, will help identify which (combinations of) species and their biological traits drive wider system resilience and ecosystem service provision.
- By linking bow ties created for different indicators, we can identify cumulative effects and relationships between pressures, consequences, and management actions.

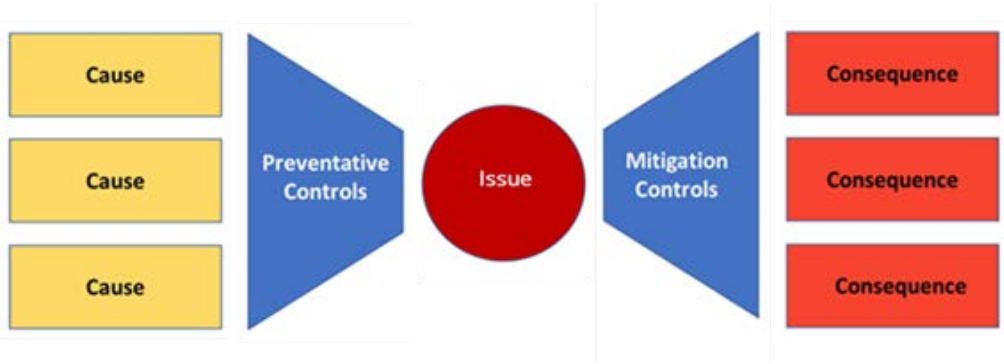


Figure 18. Example Bow Tie showing how an Issue (e.g. changing status of an indicator) can be linked to multiple causes and multiple consequences, with the impacts of both preventative and mitigation controls also considered.

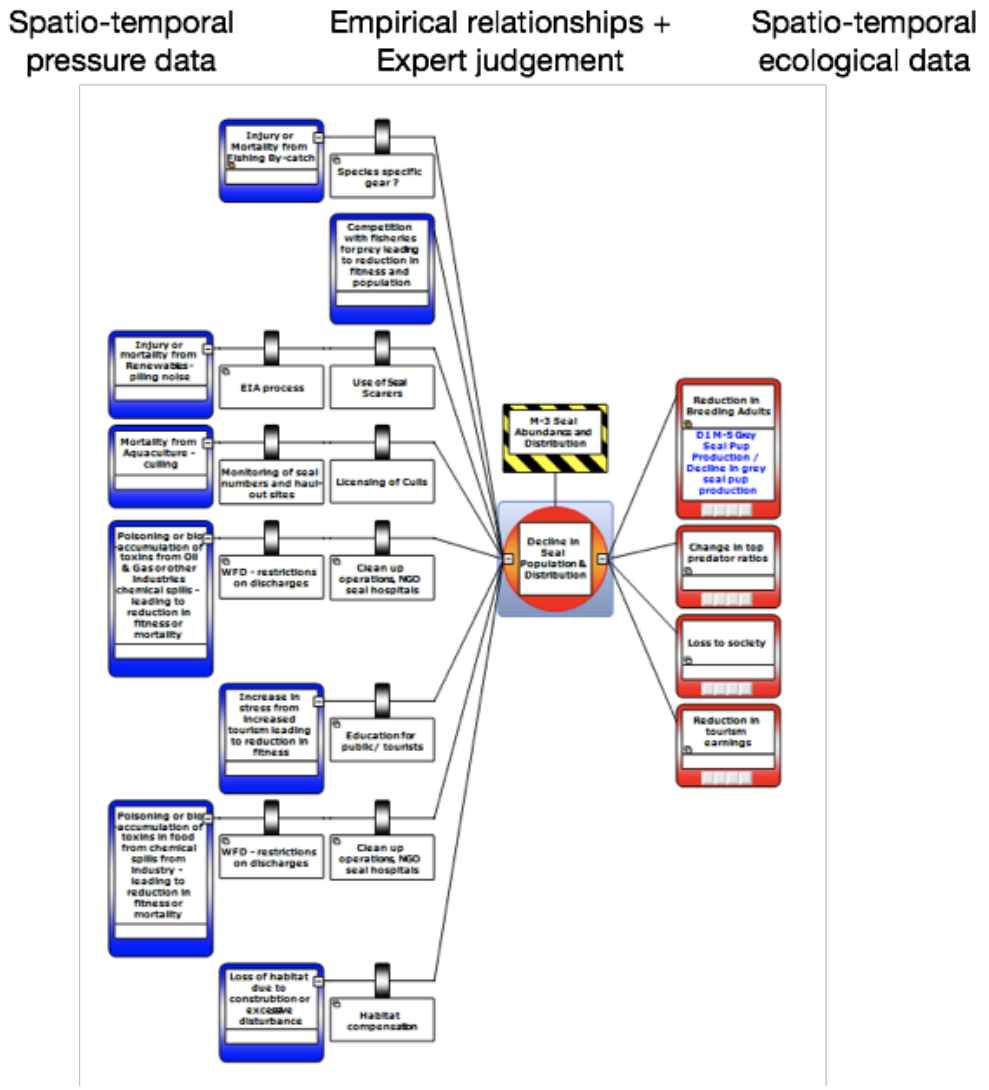


Figure 19. Draft Bow Tie for a change in state of OSPAR Common Indicator M-3 (Seal Abundance and Distribution) showing multiple causes (blue boxes) and consequences (red boxes), as well as the points in these chains of impact at which various preventative management actions would act. Multiple Bow Ties are being refined using MERP data on pressures, ecological trends, and incorporating expert judgement from scientific and stakeholder communities.

Appendix 1. MERP participants (in alphabetical order).

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Appendix 2. MERP priority list of policy questions from various sources. The questions are directly linked to policy needs from Defra's perspective.

High-level Defra policy needs

1 Develop and implement Good Environmental Status under the MSFD.
2 Develop knowledge of marine ecosystem and food webs.
3 Develop more realistic marine ecosystem models.
4 Improve ability to advise and act on uncertainty in the marine environment.
5 Develop knowledge of marine ecosystem functioning and how to assess recovery.
6 Quantify and promote the value of goods and services provided by the marine ecosystem.

Specific Defra policy needs

7 Develop, validate and operationalise remaining identified GES indicators.
8 Improve understanding of marine food webs to better understand interactions.
9 How are prevailing conditions changing, and how are they affecting sea life, and the environment?
10 How is the status of UK seas progressing towards the objectives, and whether the measures taken to address the pressures are working?
11 Improve understanding on population abundance, distribution and biology of vulnerable species (cetaceans, seabirds, elasmobranchs etc.).
12 What are the benefits of the MPA network (contribution to GES, wider environmental benefits, valuation, carbon storage etc.?

State of food webs (or its components) in relation to specified targets
Are we achieving GES for MSFD Descriptors 1, 4 and 6 at regional scales?[1, 7, 10]
Are we achieving Conservation Objectives (COs) for species and habitats at local MPA scales?[12]
What is the relationship between ecosystem services and Good Ecological/Environmental Status?[6]
Identification of areas of particular importance to fish populations[2, 3, 5, 8]
How can we define and describe biodiversity hotspots?[2, 5, 8]
How are populations of vulnerable species (cetaceans, seabirds, elasmobranchs etc.) distributed in space and time?[8, 11]
Where do key foraging areas for sea birds occur in space and time?[8]
Effects of natural and anthropogenic change on the state of marine food webs and the services they provide
How does the removal (e.g. by tidal lagoon projects) or alteration (e.g. by towed fishing gears) of benthic habitats affect populations of marine mammals and birds (those mammal and bird species included in Habitats and Birds Directives)?[5]
What are the impacts of removal or change of fish prey species on marine bird and mammal populations (Habitats and Birds Directives)?[8, 9]
How to evaluate cumulative impacts, especially for mobile species (to ultimately create the ability to carry out strategic assessments through marine planning or SEA that consider the capacity of marine mammal and bird populations to cope with cumulative impacts across their biogeographic range)?[10]
How do impacts on rare and/or threatened habitats and species affect ecosystem services (especially for BAP/OSPAR habitats and species but also Habitats Directive/SSSI habitats and species)?[6]
Future state of marine food webs and ecosystem service provision under scenarios reflecting management situations in UK waters
What are the effects of changes in fisheries management on the environment, in particular through food web effects?[2, 3, 4]
What are the responses of indicators to specific management measures for MSFD descriptors?[1, 7, 10]
What are future changes in ecosystem services in response to different management scenarios?[6]
What is the impact of (multiple) MPA closures on fisheries and recreation?[12]