Modelling Marine Ecosystem Services under the Scenarios

1 Introduction

Mapping of marine ecosystem services presents a number of additional challenges compared to terrestrial systems. In particular, mapping of habitats and other features that contribute to ecosystem services in the marine environment is at a much coarser scale compared to terrestrial habitats (Medcalf et al, 2012; Cefas & ABPmer, 2010, and see Figure 1) which makes accurate mapping of differences in service delivery more problematic. Scientific understanding of the ecosystem services provided by marine and coastal habitats is poor (Austen et al, 2008; Bournemouth University & ABPmer, 2010; Potts *et al.*, 2013). Marine ecosystem services are provided by a combination of abiotic and biological factors, including processes occurring in the water column, such that habitat features on their own are unlikely to be a sufficient basis for mapping the delivery of all services (eftec and ABPmer, in prep.). In addition, the effect of human pressures on the delivery of marine and coastal ecosystem services is not well understood (Austen et al, 2008; ABPmer & eftec, 2012); and the open nature of marine systems and wider public rights of access also mean that the effects of human pressures on ecosystem service delivery can be more significant than in terrestrial environments.

In the light of these issues, mapping of marine and coastal ecosystem services will necessarily be challenging and require a wide array of information, much of which is not currently available at high spatial resolution.

2 Development of Conceptual Framework

In simple terms, a spatial model of marine ecosystem services can be conceived in terms of two components – a baseline model, which seeks to provide a map of current ecosystem service delivery and a dynamic model, which can represent changes in ecosystem service delivery as a result of changes in human (or natural) pressures in space and time.

The information requirements to support the development of a baseline model are likely to include:

- An understanding of the factors that contribute to delivery of individual ecosystem services (Austen et al, 2008). These are likely to include aspects of seabed habitats (for example, secondary productivity contributes to fish production (Kedra et al, 2013)), but also abiotic factors (for example, subtidal sandbanks can play a role in natural hazard protection (e.g. Stansby et al, 2006)) and water column processes (for example, water column primary productivity contributes to the productivity of pelagic fish species (Jennings et al, 2008));
- An understanding of the total quantity/value of service delivery;
- Mapping of the current spatial distribution and relative intensity of the contributing factors. For example, where secondary productivity of benthic habitats contributes to fish production, information is required on the relative productivity of those habitats (an indicative map of sea bed habitats in UK seas is presented in Figure 2);

- An understanding of whether and how the state (quality) of the contributing factors influences their contribution to the delivery of an ecosystem service, for example, the extent to which bed disturbing fishing gears might affect secondary productivity of sea bed habitats and thus affect their fish production function (Medcalf et al, 2012);

To develop a dynamic model capable of responding to changes in human (or natural) pressures over time, additional information is required, including an understanding of how human (or natural) pressures may change in space and time, and we will describe sources for these data in section 3 below.

The ecosystem services framework adopted in this study is based on work undertaken for the UK NEA WP4 study (Turner et al, in prep, See Figure 1.). This framework explicitly links ecosystem structure, processes and functioning to outcomes in the form of services which to contribute to human wellbeing/ welfare. This classification differs slightly from that presented in the original UK NEA report (Austen, 2011) as it has been updated to increase its relevance to the marine environment. The main differences between these two frameworks are the expansion of intermediate services.

Within the ecosystem service classification framework basic ecosystem structure and processes link with intermediate services and final services which can lead to goods (benefits) that are consumed by humans, or which are essential for human survival. The intermediate service category has been developed to avoid double counting. For example, in assessing the use of seaweed as food, both the harvestable value (good/benefit) and the primary production (intermediate supporting service) that results in saleable biomass could be double counted thereby overestimating the value of the resource.

An intermediate service benefits humans indirectly and a final ecosystem service benefits humans directly. The good or benefit is the realisation of the direct impact from the service on human welfare. It should be noted that the further application of physical and human capital is also required in some contexts before ecosystem service derived goods and benefits can be enjoyed. For example, saltmarsh will provide sea defence functions without further investment whereas catching fish off-shore requires investment in *inter alia* boats and fuel to realise the ‘good’. However, the model described here is concerned with the assessment of the current level of ecosystem services supported, regulated or provided by benthic habitats (underpinned by ecosystem processes and intermediate services) and the change in this in response to changes in pressures.

To simplify the modelling process it would be preferable to measure any change in the level of an ecosystem service at the point of the final service or good/ benefit. In practice, however, there are a number of ecosystem services for which this is not possible and it is therefore necessary to base the assessment of change at the level of either structure and process or intermediate services. The main reasons for this can be summarised as:

- The final good/benefit may be currently under-utilised e.g. harvesting of macroalgae for biofuel and fertiliser, so that the current value of sales would not assess the potential level of service;
- Direct evidence or data may not exist for the final service (nutrient cycling, waste breakdown and detoxification) although the underlying structure or functions can be valued and the total service can be extrapolated;

- A market for the final good might not exist e.g. in the case of carbon sequestration;
- The ecosystem service is not identified as a final ecosystem service or good or benefit within the framework classification, e.g. the ecosystem service 'Biological Habitat'.

Given that a mixture of goods and benefits, and final and intermediate services need to be incorporated within the model, we have termed these 'contributing factors'. The key contributing factors for each ecosystem service have been identified based on a review of the literature, previous ecosystem service assessments and expert judgement. These have been summarised in a series of simplified tables for each ecosystem service (see section 3 below).

It should be noted that the adoption of the term 'contributing factor' is not an attempt to redefine ecosystem services classifications or terminology. It has been adopted as it is necessary to have a distinct term to describe the different factors captured in the data which are available to support model development. Most, but not all, of these factors are intermediate services, and so adopting an existing term such as intermediate services would be misleading and confusing. An illustration of the relationship between intermediate and final services and goods/benefits in relation to provisioning services is presented in Figure 2.

In simple terms, a spatial model of marine ecosystem services can be conceived in terms of two components – a baseline model, which seeks to provide a map of current ecosystem service provision and a dynamic model, which can represent changes in ecosystem service provision as a result of changes in human (or natural) pressures in space and time.

The information requirements to support the development of a baseline model are likely to include:

An understanding of the key factors that contribute to provision of individual ecosystem services (hereafter termed 'contributing factors'). These are likely to include aspects of seabed habitats (for example, secondary productivity contributes to fish production), but also abiotic factors (for example, subtidal sandbanks can play a role in natural hazard protection) and water column processes (for example, water column primary productivity contributes to the productivity of pelagic fish species);

An understanding of the total quantity/value of service provision;

Mapping of the current spatial distribution and relative intensity of the contributing factors. For example, where secondary productivity of benthic habitats contributes to fish production, information is required on the relative productivity of those habitats (an indicative map of sea bed habitats in UK seas is presented in Figure 3);

An understanding of whether and how the state (quality) of the contributing factors influences their contribution to the provision of an ecosystem service, for example, the extent to which bed disturbing fishing gears might affect secondary productivity of sea bed habitats and thus affect their fish production function;

To develop a dynamic model capable of responding to changes in human (or natural) pressures over time, additional information is required including an understanding of how human (or natural) pressures may change in space and time, and we will describe sources for these data in section 3 below.

A simple schematic of the components of a possible marine ecosystem services model are presented in Figure 4. Subsequent sections of the report outline possible approaches to developing the components of a marine ecosystem services model and seek to illustrate concepts using existing data.

3 Assigning ecosystem service values spatially

Tables 1 to 7 identify suggested key factors contributing to service delivery for selected ecosystem services and available data sets that could underpin mapping, together with information sources that could be used to inform the relative level of delivery for each contributing factor. For example, the level of ecosystem service delivery from a sea bed habitat (e.g. harvestable fish) may be a function of the level of secondary production of that habitat. Information sources on the response of the contributing factor to changes in human pressure are also identified. Owing to the limited scientific understanding of the key contributing factors, these should be treated as working hypotheses, based on current scientific understanding of the functioning of marine ecosystems.

We focus on the following ecosystem services provided by the marine and coastal environment:

- Provisioning: Fish and shellfish (capture fisheries) (Table 1)
- Provisioning: Fish and shellfish (aquaculture) (Table 1)
- Provisioning: Other biological resources (Table 2)
- Regulating: Natural hazard protection (Table 3)
- Regulating: Climate regulation (Table 4)
- Regulating: Clean water and sediments (Table 5)
- Supporting: Nutrient cycling (Table 6)
- Cultural: Tourism & recreation (Table 7).

Information on the response of a given contributing factor to changes in human (or natural) pressure (for example, the sensitivity of the contributing factor) can be combined with a map of existing human pressure to inform an assessment of the current state of this factor and its overall contribution to current service delivery. For example, information on the sensitivity of sea bed habitats to disturbance from fishing gears can be combined with information on the spatial intensity of fishing activity to estimate changes in secondary productivity affecting harvestable fish production.

Challenges remain in estimating the relative importance of different contributing factors. For example, secondary productivity is likely to be particularly important for fish production. However, spawning and nursery areas also play a critical role. Judgements are therefore need to be made on how to combine contributing factors within a model - this could, for example, be based on the relative contribution of different life stages to production.

Information on the sensitivity of sea bed habitats to disturbance from fishing activity is available from Tillin *et al.*, 2010, who developed a sensitivity matrix for MPA features for a wide range of human activities to support the identification of potential management measures for proposed MCZs. Similar matrices have been developed for the Scottish MPA project and for ongoing work to apply Article 6 of the Habitats Directive to commercial fishing activity (Defra, 2013). An important limitation of such matrices is that broad scale habitats may comprise a number of component habitats displaying very different sensitivity levels. In such cases, sensitivity scores are necessarily subject to significant uncertainty. Furthermore, there is a lack of documented information on the sensitivity of abiotic or water column processes as contributory factors to human pressures.

Maps of the distribution and intensity of bed disturbing fishing activity have been produced by a number of studies including Dunstone, 2008; Vanstaen, 2010 and the MCZ Fisheries Model (Finding Sanctuary *et al.*, 2012). These maps have primarily been derived from Vessel Monitoring System (VMS) data on commercial fishing vessels >15 in length, which record the position of these vessels. Using assumptions on when vessels are fishing, information on gear types being deployed and towing speeds, it is possible to estimate the location and intensity of bed disturbing fishing activity (for an example, see Vanstaen (2010)).

A key limitation of such maps is that they tend not to include vessels <15m, which comprise the majority of the UK fleet (although >15m vessels account for the majority of landings and are responsible for the majority of bed disturbing pressure at a national level). In addition, the outputs from such analyses tend to be presented on a spatial grid (commonly 1/200th ICES rectangles, approximately 3x5km), in order to avoid disclosure of information on individual fishing vessels.

Information on the spatial distribution of other pressures is variable in availability and quality. This reflects a lack of data on the location of some activities and uncertainties relating to their intensity. The Defra and Marine Scotland Business as Usual Scenarios Project (ABPmer & eftec, 2012) sought to develop some additional pressure layers, including, for example, changes in sea bed sediment type (associated with construction activity in the marine environment). Government Agencies such as JNCC and Cefas have an on-going programme of work to map human pressures but currently few outputs are available.

4 Exploring how the distribution and intensity of ES values may change over time

Translating the descriptions of the UK NEA scenarios into spatial models of potential changes in marine ecosystem services delivery requires a number of assumptions to be made relating to locations and time periods over which change might occur, and how these changes might influence ES delivery.

These issues have been addressed in a number of ways in previous studies. For example, Hull *et al.* (in press) sought to assess temporal changes in overall levels of delivery of individual ecosystem services in terms of percentage changes relative to a baseline. Changes in spatial distribution and intensity of individual ecosystem services were then assessed based on possible spatial trends using expert judgement.

ABPmer & eftec (2012) sought to evaluate potential changes in the quality of the marine environment over time (expressed in terms of MSFD indicators) based on possible changes in the distribution of specific human pressures within an overall DPSIR framework. This information was then used to model possible changes in ES delivery (see Figure 5 for example of this approach for tidal wave power).

Tallis et al (2013) describe the application of a series of tools that can be applied to inform assessments of changes in ecosystem service delivery within the InVEST (Integrated Valuation of Environmental Services and Tradeoffs) software suite. In particular, the Habitat Risk Assessment (HRA) tool can provide indications of ecological risk based on user input and this can be used with information on ecosystem service delivery to prepare assessments of potential change in response to risk. Villa et al (2009) describe the Artificial Intelligence for Ecosystem Services (ARIES) tool that has been applied in Madagascar to the assessment of changes in ES delivery associated with a number of ES, including sediment regulation, subsistence fisheries and coastal flood regulation.

It is recognised that all of these methods require application of a high level of expert judgement. The approach adopted for UK the implementation of MSFD based on the DPSIR framework is intuitively attractive because it has a sound underpinning. Development of this approach is currently ongoing (eftec & ABPmer in prep).

5 Spatial models

In order to illustrate the application of the conceptual model, we have prepared maps for the time slices of 2015, 2030 and 2060 for a 2008 baseline for the following services:

- Fish and shellfish (capture fisheries);
- Fish and shellfish (aquaculture); and
- Carbon sequestration.

These maps were generated for the *Baseline*, *World Markets* (WM), *Nature@Work*, *National Security* (NS) and *Local Stewardship* (LS), scenarios, as these were felt to sufficiently diverse, in the way that drivers of change would play out under different possible futures, to be a useful set for this preliminary work.

A study area was defined as the UK Continental Shelf (UKCS), modelled as a 2 x 2 km grid, using a British National Grid projection. We used UKCS wide spatial data for all three service types for each time slice (2015, 2030 and 2060). However, only a selection of these are referred to in the text, and in the case of aquaculture and carbon sequestration in most cases an area smaller than UKCS has been shown, to allow the highlighting of coastal change over relatively small areas, which would not be noticeable in a UKCS-wide map.

Fish and shellfish (capture fisheries)

Spatial baseline

Information on the contributing factors supporting fish and shellfish production was not available to this study. An alternative approach was therefore applied which used information on the location of fish capture.

A highly resolved map of spatial variations in catch value is given by Dunstone (2008), using spatial effort data based on Vessel Monitoring System (VMS) position information for vessels over 15 m long, and reported ICES (International Council for the Exploration of the Sea) rectangle positions for non-VMS vessels under 15 m long, and catch value by rectangle. This layer included the following gear classes: dredges, hooks and lines, nets, seines, traps and trawls.

The resolution (minimum cell size) of the original data is 0.05º (degrees) longitude by 0.05º latitude with the area covered by each cell ranging from approximately 21 km^2 at 48ºN to approximately 14 km^2 at 64ºN. These data were re-projected to the British National Grid and resampled to a 2 km x 2km grid.

Temporal and spatial change

Estimates of change in fisheries landings (percentage change relative to 2000 baseline) were made for each scenario for the time steps 2015, 2030, and 2060, based on assumptions about the influence on fish stocks of each of 4 of the UK NEA scenarios and commercial fishing activity. These assumptions were as follows:

- *World Markets* – fish stocks declining, over-exploited. Increase in effort from trawl and dredge fleet. Increasing import of seafood, especially low-quality farmed seafood from Asia;
- *Nature@Work* - fisheries better managed and mostly at Maximum Sustainable Yield and thus more productive. Reduction in effort from trawl and dredge fleet;
- *National Security* - fish stocks in UK waters are protected from foreign vessels and exploited sustainably by UK vessels. However, fish stocks in non-UK waters and stocks that straddle UK waters are assumed not to be managed sustainably, such that overall production declines slightly;
- *Local Stewardship* - production initially declines slightly due to loss of large-scale fleet but increases over time as a result of limited stock recovery. Catch per Unit Effort increases in some cases, declines in others – some localised stock overexploitation in coastal waters.

Expert judgement was used to translate these qualitative descriptions into quantified changes in landings over time (Table 8).

We took account of the fact that the spatial patterns of fisheries could be influenced by changes to existing stocks, the impacts of climate change and displacement in relation to some MPAs and offshore infrastructure developments (e.g. offshore wind farms). However, it was not possible to take account of other potential regional variations in changes in the distribution of stocks and efforts owing to a lack of data to inform such judgements.

Sea temperature and other climate induced environmental factors have been shown to alter fish community structure through changes in distribution, migration, recruitment and growth. The impact of climate change on commercially important UK fish species has been comprehensively reviewed by the Marine Climate Change Impacts Partnership (MCCIP, 2010). However, while cold-water species such as cod and herring will move further north, new warmer-water species will arrive. MCCIP (2010) predicts, albeit with a low level of confidence, that the UK will benefit from climate change with slightly higher fishery yields by 2050 (i.e. + 1-2% compared to present), although the Irish Sea and English Channel may see a reduction. Given the high degree of uncertainty both in the level of climate change and their impacts on fisheries, it is possible that fishermen will adapt their effort and methods to the arrival of new stocks rather than move their activities elsewhere. As a result, it has been assumed that areas that are currently fished will continue to be fished in the future.

For the purposes of the spatial modelling of the data, changes in the distribution of fishing activity were therefore only considered in relation to potential displacement from MPAs (based on proposals for English MCZs) and from future offshore wind farm development areas. It is currently unclear to what extent demersal fishing might be restricted within MPAs or within individual offshore wind development zones. For this modelling exercise, we made the assumption that under all four scenarios demersal fishing would be excluded from all MPAs and all offshore wind farms projected to be developed under the scenarios. It was assumed that all MPAs were in place before 2018. OWF capacity was rolled out based on assumptions about the pace of OWF development within each scenario. The illustrations will tend to significantly overestimate the changes in fishing areas because demersal fishing activity will not be displaced from all MPAs and not all of the offshore wind farm zones will be developed, although it should also be noted that proposals for MPAs in the devolved administrations are still being developed, potentially leading to higher levels of displacement in these regions.

Temporal and spatial projections

The projections for food from fish and shellfish capture fisheries for the baseline and the time steps 2015, 2030 and 2060 is illustrated in Figures 6 for the *World Markets* scenario, and in Figure 7 for base line and 2060 for the four scenarios selected for this study.

The baseline maps indicate the spatial distribution of commercial fisheries value. These distributions show regional concentrations, due to the distribution of some of the key UK fisheries (for example, the inshore waters of the South-West, the Thames Estuary, North West Scotland and east and west of Shetland). It should be noted that, while the baseline indicates locations of fish harvesting, this may be different from areas of fish production. In particular the method that has been applied does not fully take account of spawning and nursery areas, although some harvesting does occur in areas where fish aggregate to spawn.

Differences in the scale of potential total landings over time and between scenarios are evident, especially between *World Markets* and the other scenarios (for example, compare baseline with *World Markets* across the three time slices (Figure 6), and *World Markets* 2060 with *Nature@Work* 2060 (Figure 7). While the number of areas from which fisheries may be displaced varies between the scenarios (reflecting the extent to which offshore wind development might proceed), a striking feature is that most OWF development zones and proposed MPAs are located in areas of currently low fisheries value. While the potential displacement areas are large, they do not particularly impact on the existing distribution of fisheries activity.

Fish and shellfish (aquaculture)

Spatial baseline

The static baseline distribution of fish and shellfish farms were taken from maps prepared for Charting Progress 2 (UKMMAS, 2010). Analysis of fish farm production levels apportioned the total £147m GVA from aquaculture to approximately £134.5m for fin fish and £12.5m for shellfish. This equates to an average revenue of approximately £520k per farm.

Temporal and spatial change

Estimates of change (percentage change relative to 2000 baseline) in aquaculture production were made for each scenario for the time steps 2015, 2030, and 2060, based on assumptions about the influence of the scenarios on aquaculture production:

- *World Markets* – significant increases, focused on production volumes/value, for consumption and export. Production at expense of natural environment and wild fish stocks. Increasing use of non-native species;

- *Nature@Work* - some increase. Better environmental stewardship and development of fish feeds from non-marine sources. Use of some non-native species;
- *National Security* - increases to supplement wild fisheries production, within limits set by availability of finance. Environmental pollution and depletion of wild forage species – herring, mackerel and blue whiting fisheries used to support fish feed industry.
- *Local Stewardship* - greater emphasis on integrated farming-aquaculture practices and cultivation of herbivorous fish and shellfish at local level.

Expert judgement has been used to translate these qualitative descriptions into quantified changes in production over time and to estimate the spatial distribution of these changes (Table 9). In order to model these temporal changes spatially, it was assumed that some of this growth would be due to improvements in aquaculture techniques (fish feed, fish health and farming methods) that would simply increase the output from existing farms rather than increase their spatial extent. The annual increased output due to technological improvements varied from 0.5% to 2% across the scenarios depending on availability of capital under each scenario.

Under *World Markets*, it is assumed that there is a high amount of capital available for investment in new technology, and therefore capacity is projected to increase by 2% annually for the first 20 years and then 1% annually as the market tapers off to 2060. Under *Nature@Work*, although there is capital available, it is assumed that there is less demand for farmed fisheries, therefore capacity increases start at 2% and taper off to 0.5% after 50 years. Under *National Security*, it is assumed that although there is high demand for farmed fish, there is less capital available compared to *World Markets*, therefore capacity increases start at 2% for the first ten years and then decreases to 0.5% annually. It is assumed that there is even less capital available under *Local Stewardship*, which starts of at annual increases of 1% and decrease to 0.5% per year.

The remaining growth (Table 9, Column 5) is assumed to occur through the development of new farms and the farming of new species. Site selection of new fin-fish farms is assumed to be focused on sheltered areas in estuaries and areas of the Scottish coast where there are already existing markets and infrastructure (e.g. fish processing) to support the industry, but there could be a gradual increase in England and Wales as well, as the industry gathers momentum. Likewise, new shellfish farms are assumed to be developed within regions where there were existing farms, including England and Wales as well as Scotland.

Finfish and shellfish farms are dependent on good water quality and suitable current flow. Therefore, a potentially important constraint is that shellfish farms and fin fish farms could not be close together and that all such farms need to avoid existing shipping routes and sewage disposal outfalls. Where it was estimated that there were no more viable sites left within existing areas, offshore farms were created, focusing on offshore wind farms as bases.

Temporal and spatial projections

All scenarios demonstrate a projected expansion of aquaculture, and particularly so in *World Markets*, where commercial fishing landings are projected to show strongest declines. The coastline of the West of Scotland currently host a large amount of aquaculture production and this expands under all the scenarios, but less noticeably *for World Markets* than for the other scenarios (Figure 8). We also forecast an expansion of aquaculture into offshore waters and South of the Scottish border, reflecting the strong growing demand for aquaculture products and the more limited scope for expansion within existing Scottish inshore sites as a result of environmental capacity constraints.

Comparisons of the projected values for the different scenarios over time show the importance of capital investment in the development of this sector. Assumptions about differences in the availability of capital under the different scenarios have a greater influence on the predicted values than changes driven by consumer demand or the price of wild-caught fish.

Carbon sequestration

Spatial baseline

There is no formal published value for carbon sequestration from UK seas. To inform the spatial modelling, an initial attempt has been made to develop a value, based on the following rules:

- Carbon sequestered from the North Sea (as a result of export to deeper waters of The NE Atlantic) was attributed to the northern North Sea (Thomas *et al.*, 2005). This is estimated as 32.4m tonnes carbon p.a;
- No carbon is sequestered on continental shelf at depths <50m, due to remineralisation and active exchange between sea bed and water column (based on an observation in Thomas *et al.* (2005) that no carbon is sequestered in shallow southern North Sea);
- Carbon is sequestered in sediments on continental shelf >50m and continental slope at a rate of 42.4kg carbon ha-1 p.a (based on deposition rate in northern North Sea calculated by Thomas *et al.*, 2005)
- Carbon is sequestered in deep ocean at a rate of 0.18kg carbon ha-1 p.a (Nelleman *et al.*, 2009);
- Carbon is sequestered in areas of saltmarsh at a rate of 210 gm-2 p.a (IUCN, 2009), based on UKSeaMap data ‘Coastal saltmarshes and saline reedbeds (A2.5)’

To prepare an economic valuation, quantities of carbon were converted to tonnes of CO_2 and then multiplied by the price of non-traded carbon (£52 per tonne -2011 value).

Temporal and spatial change

It is difficult to project temporal changes in carbon sequestration over time, owing to the limited current understanding of the factors determining carbon sequestration in UK waters and uncertainties concerning how ocean acidification may influence carbon sequestration, although we are more confident in the limited changes we project for 2030 than for later periods (Table 10).

In the absence of detailed information on how the processes governing carbon sequestration might change in the future, it is not possible to identify how relative values for carbon sequestration might change spatially. The projected changes in overall value across the different scenarios were therefore simply used to adjust each grid cell pro rata.

Temporal and spatial projections

The projections for the four scenarios over time indicate limited changes in the intensity of carbon sequestration. While changes may occur in the period to 2060 (see Figures 9 and 10), the nature and scale of such changes are currently highly uncertain.

The spatial baseline identifies the relative importance of the North Sea carbon pump in contributing to overall carbon sequestration from UK waters. While saltmarsh makes a significant contribution locally (see Figure 10), the small extent of saltmarsh habitats means that it only makes a very minor contribution to that of UK waters as a whole.

The production of these data has highlighted the difficulty of mapping values for UK waters in relation to a process - the North Sea carbon pump - that is operating at the scale of the North Sea as a whole.

6 Key Assumptions, Data Gaps and Uncertainties

Mapping of marine and coastal ecosystem services is in its infancy. Developing a model which can represent the full range of marine ecosystem services and their response to human pressures is a challenging and complex task. Further conceptual development of marine ecosystem service delivery is required, together with an improved scientific understanding of causal relationships and collection of better baseline data.

There are significant gaps in the availability of baseline data at appropriate spatial scales. For example, only 10% of the UK sea bed has been surveyed to a level of detail that can support the development of robust seabed habitat maps (Cefas & ABPmer, 2010). Furthermore, while such maps can describe the presence of habitat features, additional information is required on the condition of these features and the associated ecosystem processes which are important in underpinning ecosystem service delivery (Austen et al, 2008).

The classification of ecosystem services is a rapidly evolving field and much progress has been made over the past 5 years. While the UK NEA Follow-on Project framework developed by Turner et al (in prep) represents current understanding of the key services provided by marine and coastal environments, this framework is likely to continue to evolve over time. Improved understanding of the relationship between supporting and provisioning services is also required to minimise risks of double counting, particularly where valuations of ecosystem services are being calculated. As recognised within the UK NEA (Austen *et al.*, 2011), a number of services currently have no monetary value estimates or their values are highly uncertain.

For a large number of services, mapping remains challenging owing to uncertainty concerning the distribution of contributing factors, their relative importance, and how service delivery varies in relation to changes in the state of these factors. The resulting maps therefore necessarily have a significant level of uncertainty attached to them. For example, our spatial modelling of carbon sequestration is based on a number of assumptions, including assumptions concerning the functioning of the 'carbon pump' in the northern North Sea, which involves water flowing into the Norwegian trench and then into deep ocean layers in the North Atlantic that contains higher concentrations of carbon than waters flowing into the northern North Sea. Further research is required to better understand the processes underpinning the delivery of this service in order to map it with greater confidence.

The level of uncertainly within our spatial models is compounded when calculating possible future change driven by changes in the type and degree of human activity. Complete and robust models of changes in human activity are not available, and possibly will never be, Furthermore,, while the use of scenarios can help to capture some of the uncertainty caused by this, it remains challenging to translate the scenarios into meaningful changes in human activity which in turn may influence the spatial and temporal distribution of service delivery.

Overall, confidence in the model outputs is therefore low, particularly in relation to the long-term. There are significant changes occurring in the use and management of the marine environment, for example major renewable energy developments and the designation of MPAs, which have the potential to influence ecosystem service provision in the marine environment. However, the exact nature and timing of these changes remain uncertain, and the consequences for ecosystem service delivery as a result of these interventions is also uncertain.

7 References

ABPmer & eftec (2012). Designing Business as Usual Projections of the Marine Environment to Inform the UK Implementation of the Marine Strategy Framework Directive.

Assessment materials in support of the Regional Marine Conservation Zone Projects' Recommendations.

Austen, M.C., Burrows M., Frid, C., Haines-Young, R., Hiscock, K., Moran, D., Myers, J., Paterson, D.M and Rose, P. (2008). Marine biodiversity and the delivery of goods and services: identifying the research priorities. Report prepared for UK BRAG.

Austen, M.; Malcolm, S.; Frost, M.; Hattam, C.; Mangi, S. & Stentiford, G. (2011). Marine. *In*: The UK National Ecosystem Assessment Technical Report. *UK National Ecosystem Assessment*. Cambridge: UNEP-WCMC, 459-498.

Beaumont, N.J.; Austen, M.C.; Mangi, S.C. & Townsend, M. (2008). Economic valuation for the conservation of marine biodiversity. *Marine Pollution Bulletin,* **56**, 386-396.

Bolam, S.G.; Coggan, R.C.; Eggleton, J.; Diesing, M. & Stephens, D. (2013). Sensitivity of macrobenthic secondary production to trawling in the English sector of the Greater North Sea: A biological traits approach, *Journal of Sea Research* doi: 10.1016/j.seares.2013.05.003.

Bournemouth University and ABPmer (2010). *Description of the ecosystem services provided by broad-scale habitats and features of conservation importance that are likely to be protected by Marine Protected Areas in the Marine Conservation Zone Project area*. Final Report.

Bruton, T.; Lyons, H.; Lerat, Y.; Stanley, M. & Rasmussen, M.B. (2009). A Review of the Potential of Marine Algae as a Source of Biofuel in Ireland. Sustainable Energy Ireland.

Calado, R. (2006). Marine ornamental species from European waters: a valuable overlooked resource or a future threat for the conservation of marine ecosystems? *Scientia Marina* **70**(3), 389-398.

Calado, R.; Lin, J.; Rhyne, A.L.; Araujo, R. & Narciso, L. (2003). Marine Ornamental decapods – Popular, pricey and poorly studied. *Journal of Crustacean Biology,* **23**(4), 963–973.

Cefas and ABPmer (2010). *Marine Survey Needs to Underpin Defra Policy*. Report to Defra ME5408.

Chassot, E., Bonhommeau, S., Dulvy, N., Mélin, F., Watson, R., Gascuel, D. and Le Pape, O., (2010). Global marine primary production constrains fisheries catches. Ecology Letters Volume 13 Issue 4, Pages 495 - 505

Craft, C. (2007). Freshwater input structures soil properties, vertical accretion, and nutrient accumulation of Georgia and US tidal marshes. *Limnology and Oceanography,* **52**(3), 1220-1230.

de Bello, F.; Lavorel, S.; Díaz, S.; Harrington, R.; Cornelissen, J. H.; Bardgett, R. D.; Berg, M. P.; Cipriotti, P.; Feld, C. K. & Hering, D. (2010). Towards an assessment of multiple ecosystem processes and services via functional traits. *Biodiversity and Conservation,* **19**(10), 2873-2893.

Defra (2013). Revised Approach to the Management of Commercial Fisheries in European Marine Sites – Overarching Policy and Delivery Document, April 2013.

Dunstone, D. (2008). *Development of spatial information layers for commercial fishing and shellfishing in UK waters to support strategic siting of offshore wind farms*. Cowrie Ltd., 2008. www.offshorewind.co.uk/.

Eftec & ABPmer (in prep). *Provision of evidence and analysis on valuing ecosystem services in the context of the marine environment*. Work commissioned by Defra.

Elliott, M.; Hargreaves, J. & Pilgrim, S. (2012). *The UK Fishing Industry in 2011: Landings*. Marine Management Organisation.

Ellis, J.R.; Milligan, S.P.; Readdy, L.; Taylor, N. & Brown, M.J. (2012). Spawning and nursery grounds of selected fish species in UK waters. *Sci. Ser. Tech. Rep., Cefas Lowestoft*, 147: 56pp.

Environment Agency (2007). *Saltmarsh management manual*. Joint Defra/Environment Agency Flood and Coastal Erosion Risk Management R&D Programme. R&D Technical Report SC030220.

Era Ltd. (2009). *An Economic, Social and Cultural Impact Study of the Jurassic Coast. A Summary of Findings.*

Finding Sanctuary (2012). *Irish Seas Conservation Zones, Net Gain and Balanced Seas. Impact*

Foster, N.M.; Hudson, M.D.; Bray, S. & Nicholls, R.J. (2013). Intertidal mudflat and saltmarsh conservation and sustainable use in the UK: A review. *Journal of Environmental Management,* **126**, 96-104.

Hull, S.C., Dickie, I., Tinch, R. & Saunders, J.E. (in press). Issues and challenges in spatio-temporal application of an ecosystem services framework to UK seas. *Marine Policy*.

IUCN (2009): The management of natural coastal carbon sinks. Laffoley, D.d'A. & Grimsditch, G. (eds), IUCN, Gland, Switzerland. 53 pp.

Jackson, E.L.; Langmead, O.; McQuatters-Gollop, A.; Miller, P.; Fox, C.; Hiscock, K.; Tyler-Walters, H. & Saunders, J. (2009). *Development of a marine diversity data layer: review of approaches and proposed method.* Report to the Department of Environment, Food and Rural Affairs from the Marine Life Information Network (MarLIN) Plymouth: Marine Biological Association of the UK subcontracted by ABPMer, Southampton. . Defra Contract No. MB102 Task 2F, Report No. 2.

Kedra, M., Renaud , P., Andrade, H., Goszczko, I. and Ambrose Jr., W (2013). Benthic community structure, diversity, and productivity in the shallow Barents Sea bank (Svalbard Bank). Mar Biol 160:805–819

Koch, E.W.; Barbier, E.B.; Silliman, B.R.; Reed, D.J.; Perillo, G.M.E.; Hacker, S.D.; Granek, E.F.; Primavera, J.H.; Muthiga, N.; Polasky, S.; Halpern, B.S.; Kennedy, C.J.; Kappel, C.V. & Wolanski, E. (2009). Non-linearity in ecosystem services: temporal and spatial variability in coastal protection. *Frontiers in Ecology and the Environment,* **7**, 29–37.

May, V.J. & Hansom, J.D. (2003). Coastal Geomorphology of Great Britain. *Geological Conservation Review Series*, No. 28, Joint Nature Conservation Committee, Peterborough, 754 pp.

MCCIP (2010). *Annual Report Card 2010-2011*. Marine Climate Change Impacts Partnership. Available online: http://www.mccip.org.uk/annual-report-card.aspx.

Nellemann, C.; Corcoran, E.; Duarte, C. M.; Valdés, L.; DeYoung, C.; Fonseca, L. & Grimsditch, G. (Eds.) (2009). *Blue Carbon. A Rapid Response Assessment. United Nations Environment Programme*, GRID-Arendal, www.grida.no.

Norsker, N.-H.; Barbosa, M.J.; Vermue, M.H. & Wijffels, R.H. (2011). Microalgal production - A close look at the economics. *Biotechnology Advances,* **29**, 24-27.

Nottage, A. & Robertson, P.A. (2005). *Salt marsh creation handbook. Royal Society for the Protection of Birds*. RSPB/CIWEM. 128pp.

Potts, T.; Jackson, E.; Burdon, D.; Saunders, J.; Atkins, J.; Hastings, E. & Langmead, O. (2013). *Marine Protected Areas and Ecosystem Services – Linking Conservation and Human Welfare?* VNN Coastal Topic Report.

Pulver, S. & VanDeveer, S.D. (2009). Thinking about tomorrows: Scenarios, global environmental politics, and social science scholarship. *Global Environmental Politics,* **9**(2), 1-13.

RSPB (2010). *The Local Value of Seabirds: Estimating spending by visitors to RSPB coastal reserves and associated local economic impact attributable to seabirds*. The RSPB, Sandy, UK.

Stansby, P., Kuang, C., Laurence, D and Launder, B. (2006**)** Sandbanks for coastal protection: implications of sea-level rise Part 1: Application to East Anglia. Tyndall Centre for Climate Change Research. Working Paper 86.

Taylor, W.A.; Bryden, D.B.; Westbrook, S.R. & Anderson, S. (2010). Nature Based Tourism in the Outer Hebrides. *Scottish Natural Heritage Commissioned Report* No. 353 (Tender 29007).

Thomas, H.; Bozec, Y.; Elkalay, K. & de Barr, H.J.W. (2004). Enhanced open ocean storage of CO2 from shelf sea pumping. *Science,* **304**, 1005-1008.

Thomas, H.; Bozec, Y.; Elkalay, K.; de Baar, H.J.W.; Borges, A.V. & Schiettecatte, L-S. (2005). Controls of the surface water partial pressure of CO2 in the North Sea. *Biogeosciences,* **2**, 323-334.

Thompson, J.R.; Green, A.J.; Kingston, D.G. & Gosling, S.N. (2013). Assessment of uncertainty in river flow projections for the Mekong River using multiple GCMs and hydrological models. *Journal of Hydrology,* **486**, 1-30.

Tillin, H.M.; Hull, S.C. & Tyler-Walters, H. (2010). *Development of a Sensitivity Matrix (pressures-MCZ/MPA features)*. Report to the Department of Environment, Food and Rural Affairs from ABPmer, Southampton and the Marine Life Information Network (MarLIN) Plymouth: Marine Biological Association of the UK. .Defra Contract No. MB0102 Task 3A, Report No. 22.

Turner, K., Schaafsma, M., Elliot, M., Burdon, D., Atkins, J., Jickells, T., Tett, P., Mee, L., van Leeuwen, S., Barnard, S., Luisetti, T., Paltriguera, L., Palmieri, G. Andrews, J. In prep. WP 4: Coastal/Marine Ecosystem Services.

UKMMAS (2010). *Charting Progress 2*.

Vanstaen, K. (2010). Development of an integrated fishing activity data layer for English and Welsh waters, and Development of a GIS toolbox for future inshore fishing activity data analysis. *MB0106:* Report No 5.

Wijffels, R.H. (2008). Potential of sponges and microalgae for marine biotechnology. *Trends in Biotechnology,* **26**(1), 26-31.

Wijffels, R.H. & Barbosa, M.J. (2010). An Outlook on Microalgal Biofuels. *Science*, **329**, 796-799.

FIGURES

Figure1. Ecosystem Services Framework (Source: Adapted from Turner *et al.*, in prep.)

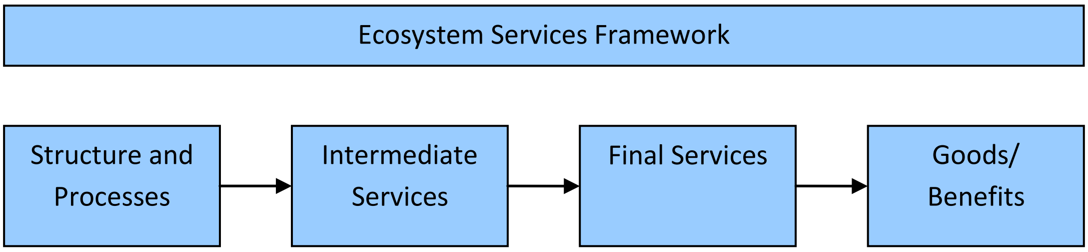


Figure 2. Illustration of the relationship between intermediate and final services and good/benefits for provisioning services

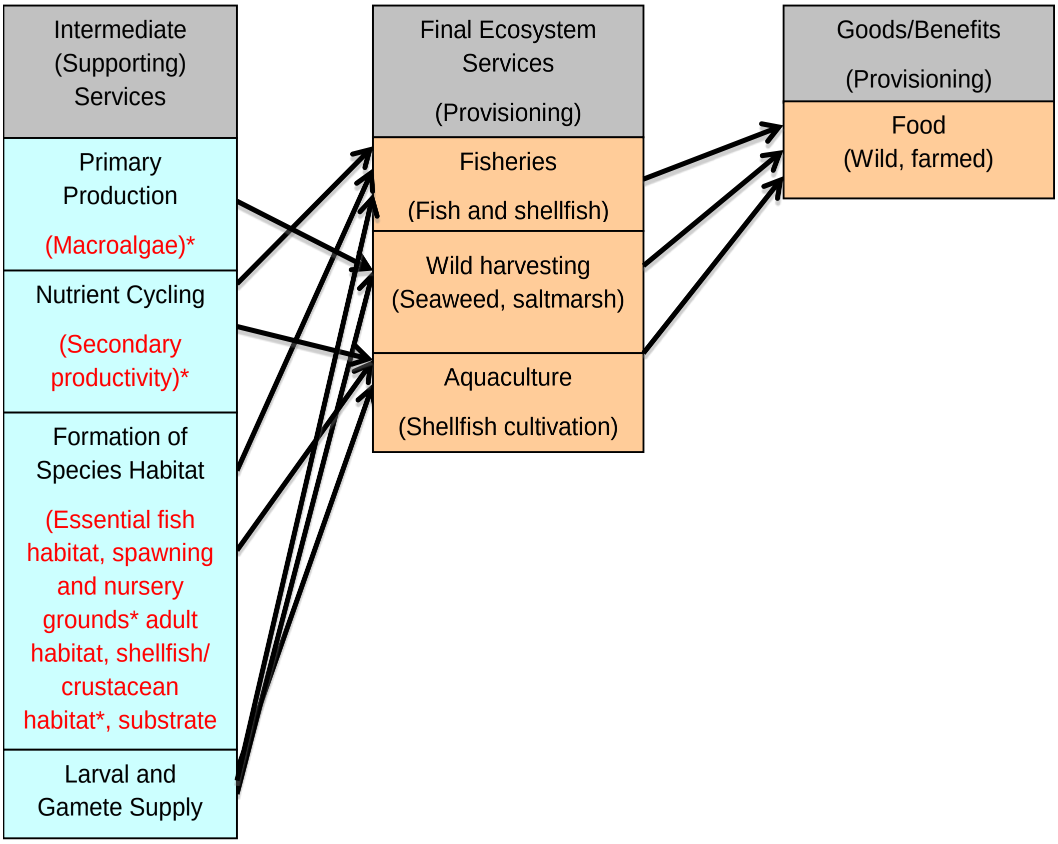


Figure 3. Map of EUNIS Level 3 seabed habitats in UK Seas (from JNCC UKSeaMap/MESH model)

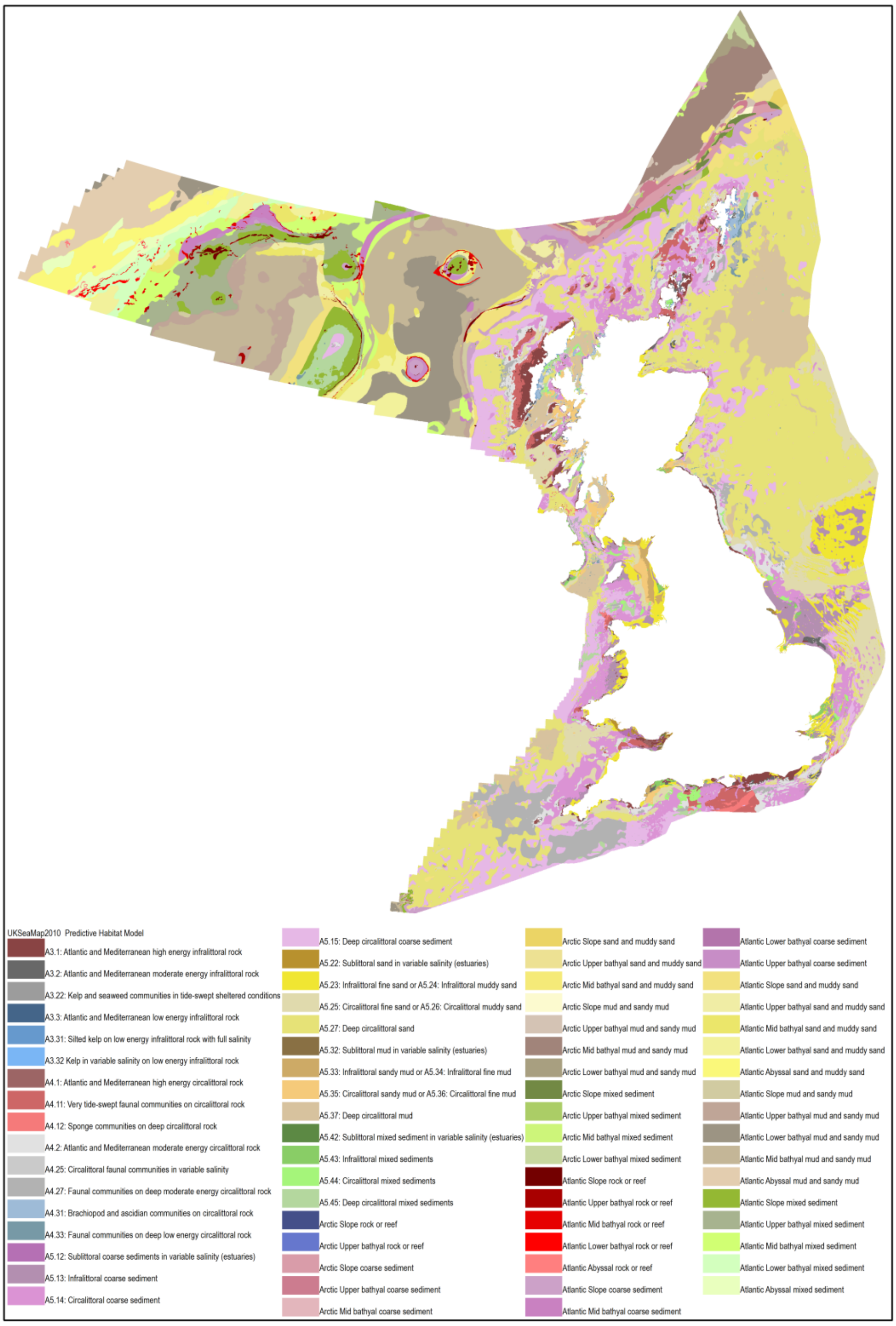


Figure 4 Schematic of conceptual marine ecosystem services model. (L = level of service provision; P = pressure).

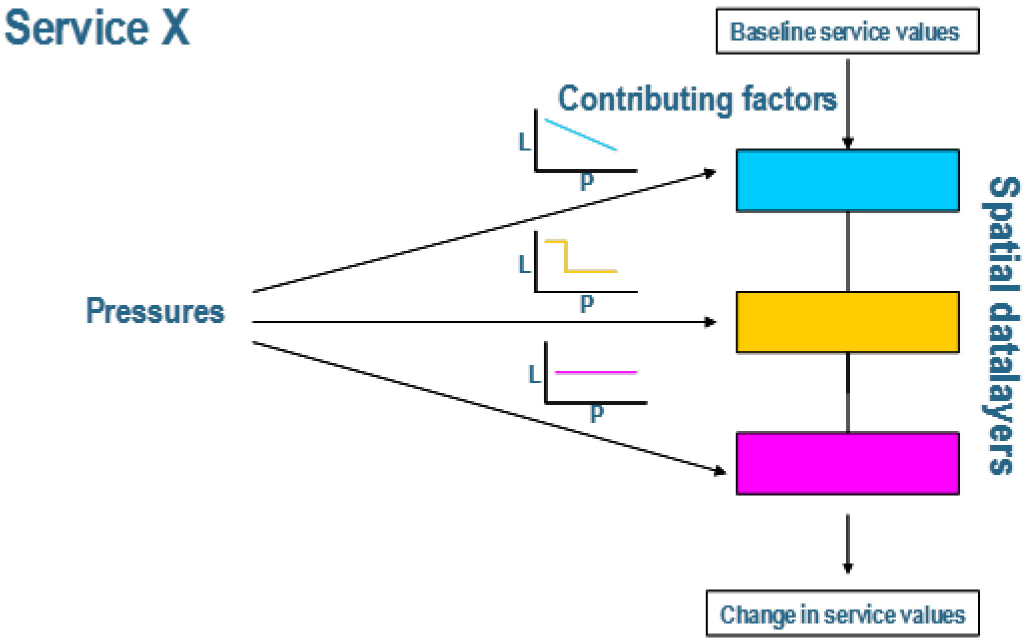


Figure 5. Illustration of application of study assessment framework to tidal range power (from ABPmer & eftec, 2012)

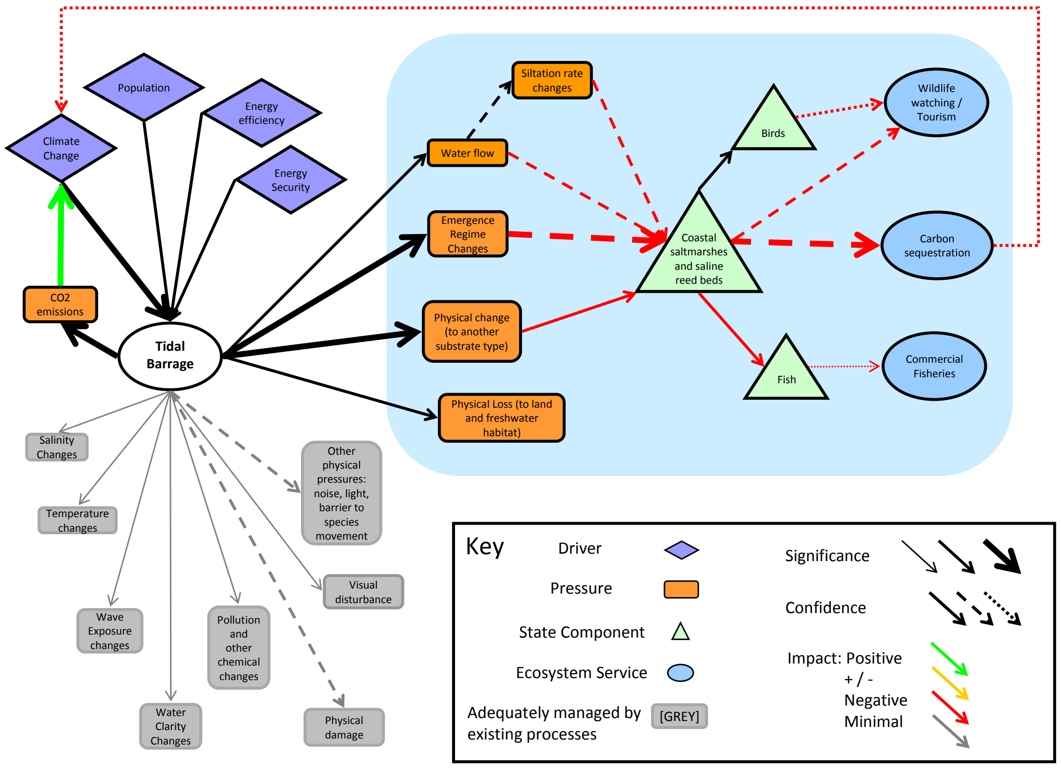


Figure 6. Fish and shellfish landings values (baseline, 2015, 2030 and 2060): *World Markets*

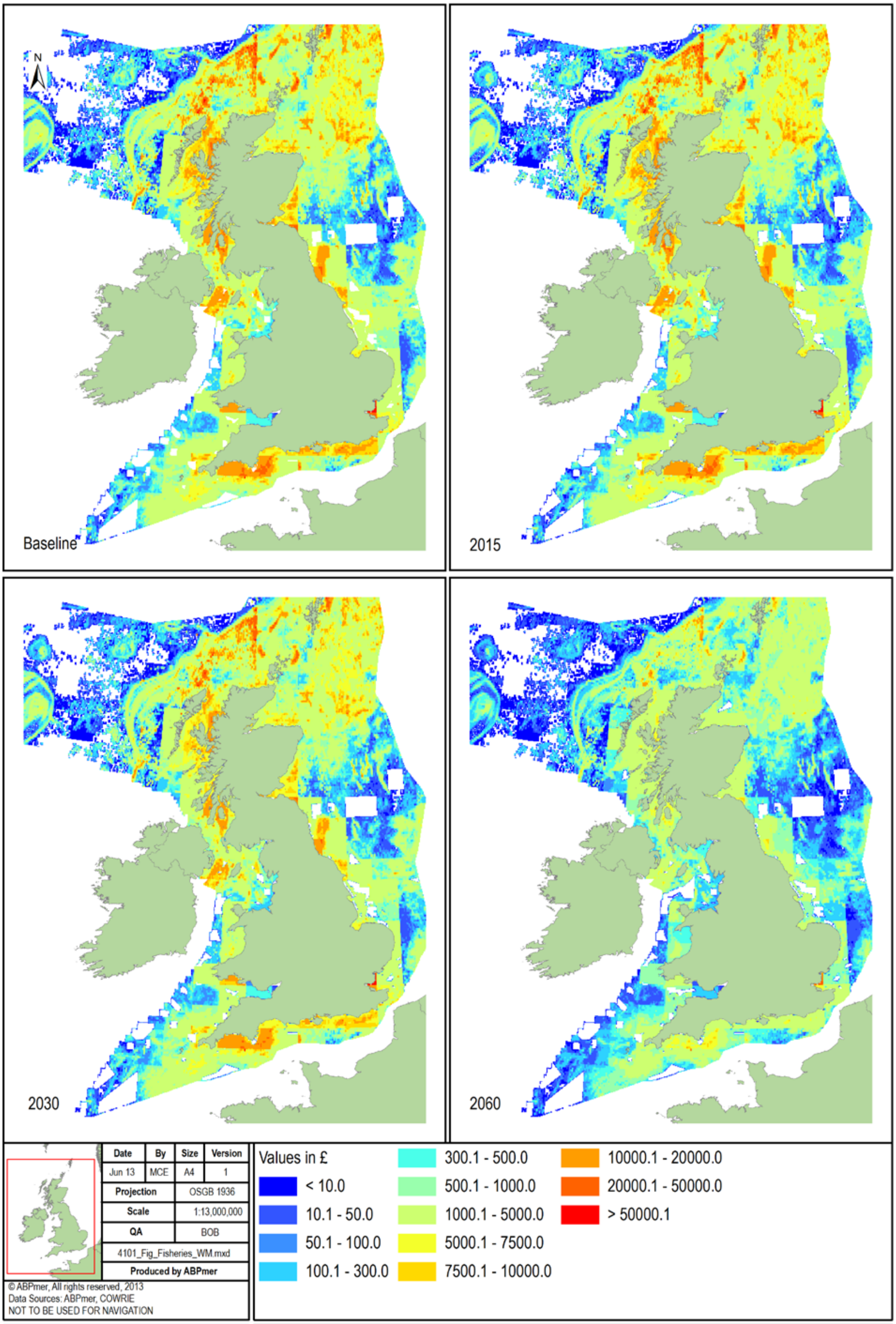


Figure 7. Fish and shellfish landings values, for baseline, and 2060 for *World Markets* (WM), Nature@Work (N@W), *National Security* (NS) and *Local Stewardship* (LS) scenarios.

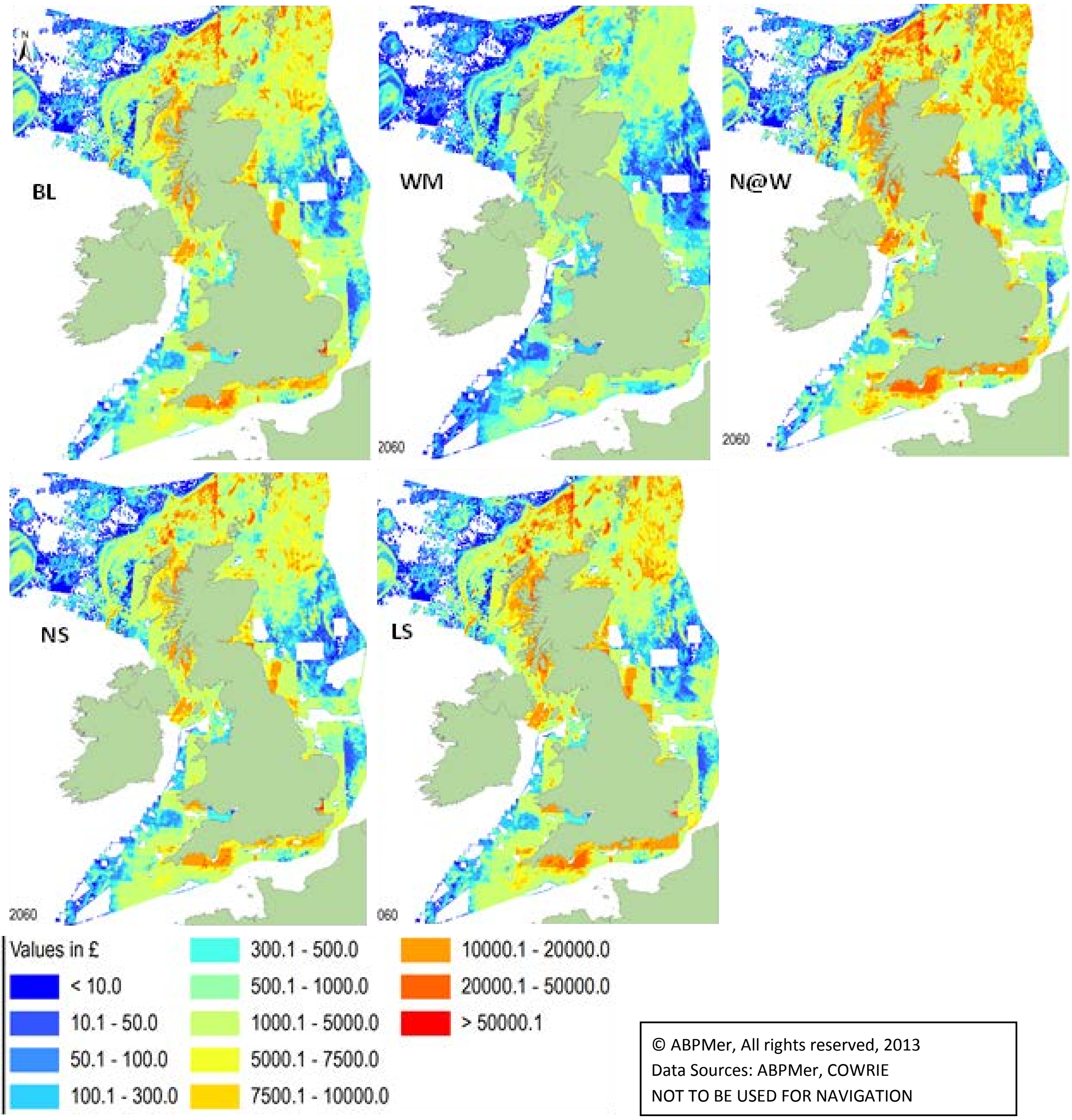
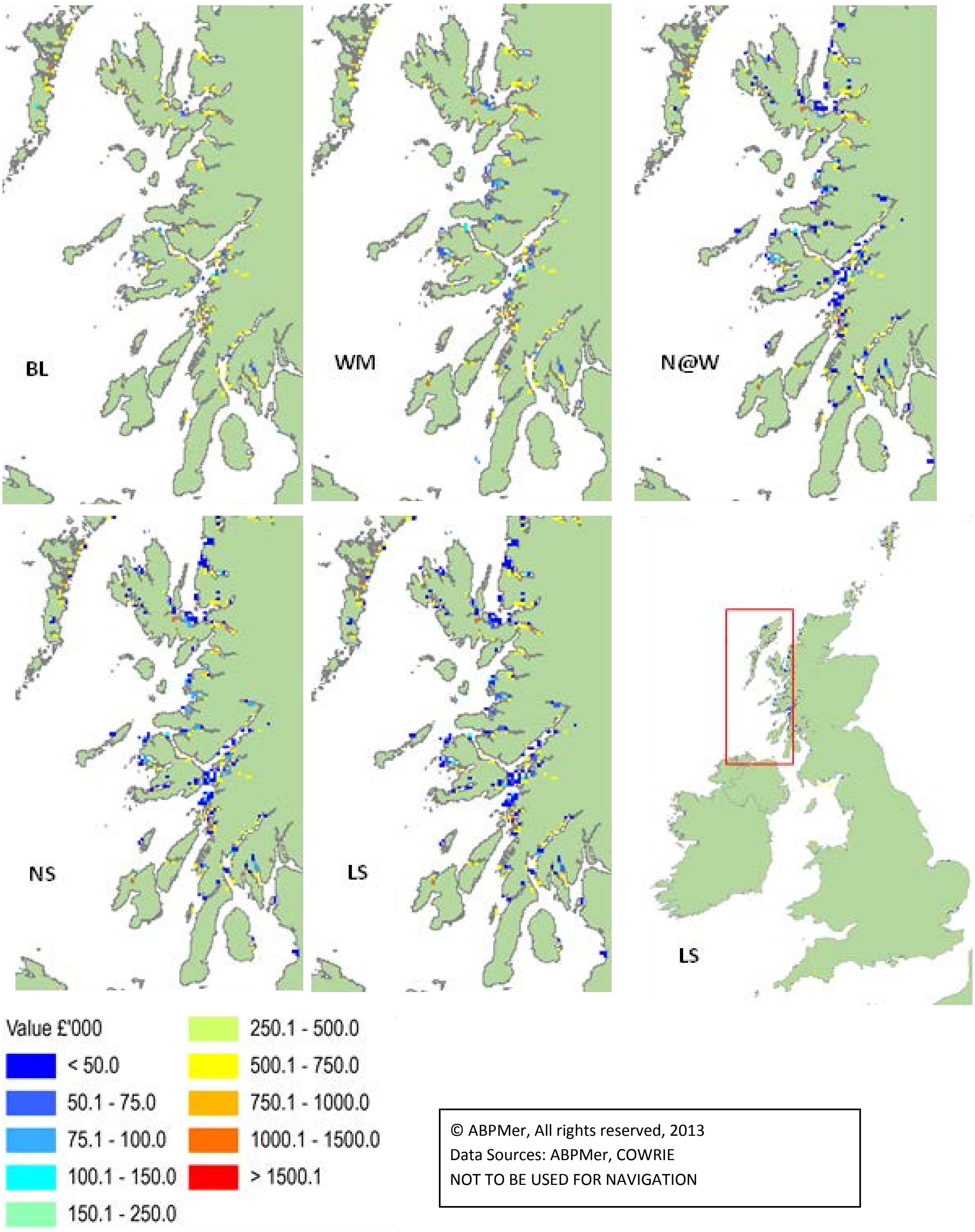


Figure 8. Aquaculture, for baseline, and 2060 for *World Markets* (WM), *Nature@Work* (N@W), *National Security* (NS) and *Local Stewardship* (LS) scenarios, for an area of the Western Coastline of Scotland and bottom right, showing inset area of the other maps, LS for the UK.



Data Sources: ABPMer, COWRIE
NOT TO BE USED FOR NAVIGATION

Figure 9. Carbon Sequestration (baseline, 2015, 2030 and 2060): *World Markets*

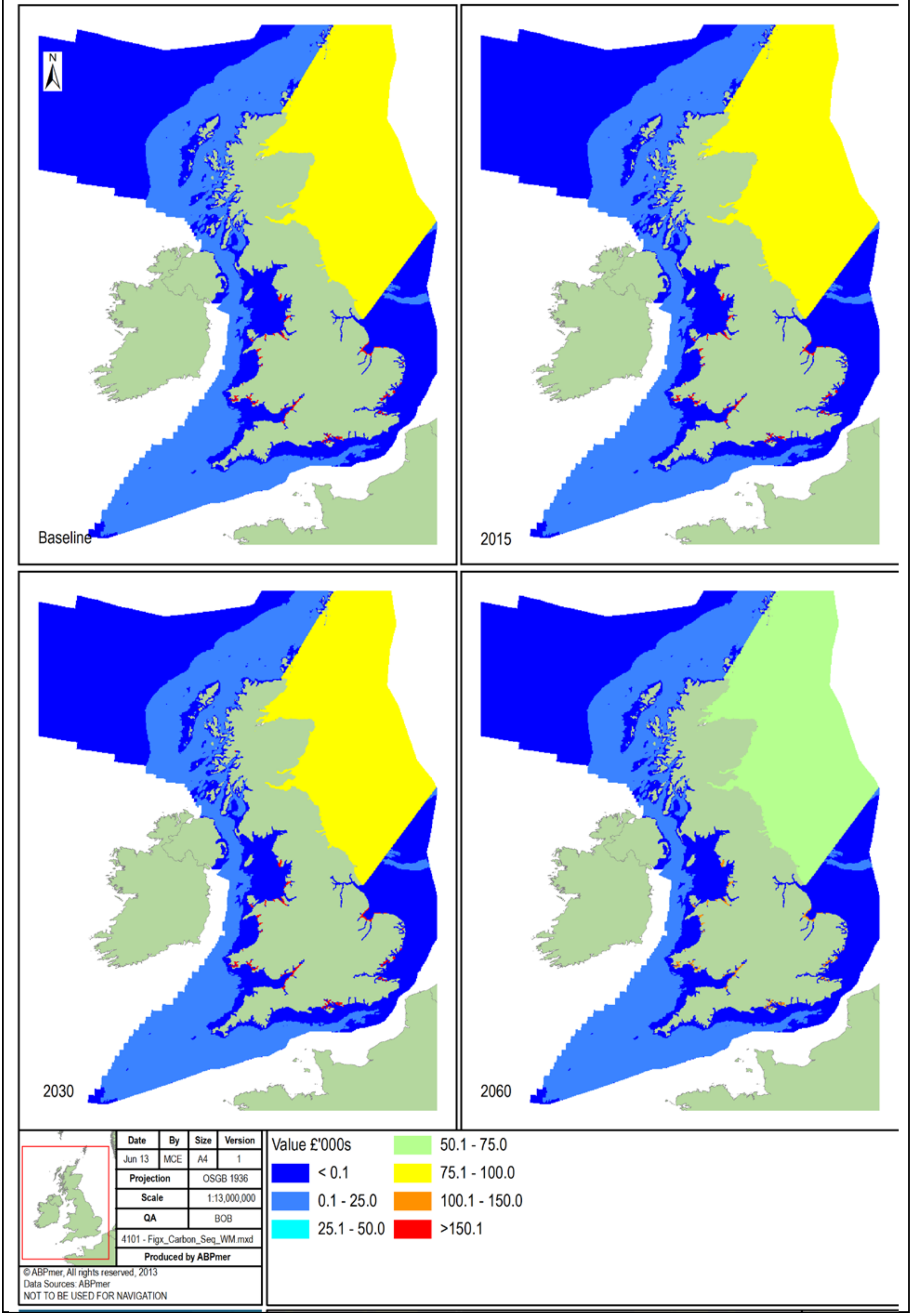
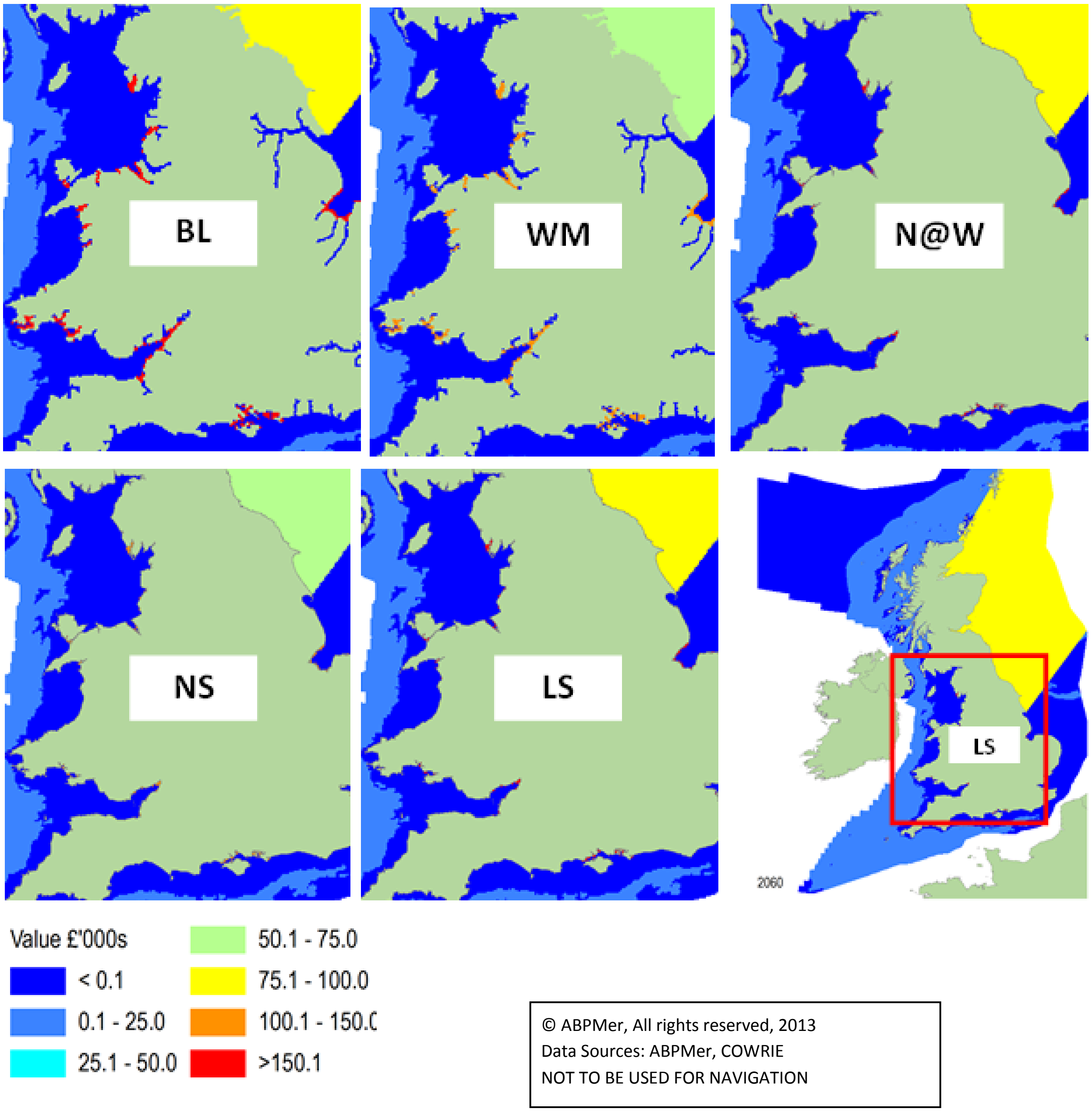


Figure 10. Carbon Sequestration, for baseline, and 2060 for *World Markets* (WM), *Nature@Work* (N@W), *National Security* (NS) and *Local Stewardship* (LS) scenarios, for an area of the UK, and, bottom right, showing inset area of the other maps, LS for the UK.



Data Sources: ABPMer, COWRIE
NOT TO BE USED FOR NAVIGATION

Table 1. Provisioning: Fish and Shellfish (capture fisheries) and Aquaculture

Contributing factors	Spatially defined	Available datasets	Contribution	Relative Contribution	Response / sensitivity to pressures	Marginal Change
Primary productivity in water column	Spatial and seasonal distribution of primary productivity in UK waters	Jackson et al, 2009	Contribution can be based on relative productivity	High (for relevant fish and shellfish)	Change in primary productivity in response to pressure	Based on response to pressure.
Secondary productivity of sea bed habitats	BSH / functional groups that provide this function	UK SeaMap MESH Foster et al. (2012)	Relative contribution made by each BSH / functional group that provides this function (i.e. quantification of secondary productivity). Derived from literature review (e.g. Peterson et al. 2003; Bolam et al. 2013) & data from Stefan Bolam.	High	Change in secondary production in response to pressure. Derived from literature review (e.g. Bolam et al. 2013).	Based on response to pressure.
Spawning grounds	Mapped distribution of spawning grounds of key fish species	Cefas Ellis et al. (2012)	Relative value of different species – landings data (subset of fish species, dependent on data availability).		Change in spawning function of the habitat as a result of pressure.	Based on response to pressure.
Nursery grounds	Mapped distribution of nursery grounds of key fish species	Cefas Ellis et al. (2012)	Relative value of different species – landings data (subset of fish species, dependent on data availability).		Change in nursery function of the habitat as a result of pressure.	Based on response to pressure.
Crustacean / mollusc production	Based on landings data	UK Shellfish landings data (ICES rectangle) Elliot et al. (2012) VMS data (Cefas) Alternatively (for BSH): UK SeaMap MESH	Relative value of different species – landings data (subset of shellfish species, dependent on data availability).		Change in crustacean / mollusc production in response to pressure.	Based on response to pressure.
Aquaculture (fish / shellfish)	Mapped distribution of aquaculture facilities	Cefas	Relative value of different fish / shellfish species – production data (subset of species, dependent on data availability).		Change in aquaculture production as a result of pressure.	Based on response to pressure.

Table 2. Provisioning: Other biological resources

Contributing factors	Spatially defined	Available datasets	Contribution	Relative Contribution	Response / sensitivity to pressures	Marginal Change
Ornamental materials	Based on expert opinion	MB0102 MB0104	Relative value of ornamental materials – based on expert opinion (Valuing Nature Network, subset of species, dependent on data availability) and literature review (e.g. Calado et al. 2003; Calado, 2006).		Change in the production of species of ornamental value as a result of pressure.	Direct relationship between pressures causing mortality and potential provision. Literature search has not found any evidence for the scale of collection and sale.
Biotechnology	BSH / functional groups that provide this function Mapped distribution of biotechnology facilities	MB0102 UK SeaMap UK NEA	Relative value of biotechnology – based on expert opinion (Valuing Nature Network) and literature review (e.g. Wijffels, 2008; Norsker et al. 2011).		Change in biotechnology development as a result of pressure.	Based on response to pressure. Related to institutions rather than species / habitats.
Fertiliser	BSH / functional groups that provide this function	MB0102 UK SeaMap	Relative value of fertilisers – based on expert opinion and literature review		Change in fertiliser production as a result of pressure. Check for information on harvesting. If none, relate to primary productivity – this will also cross-reference to carbon sequestration.	Based on response to pressure.
Biofuels	BSH / functional groups that provide this function	UK SeaMap	Relative value of biofuels – based on expert opinion and literature review (e.g. Burton et al. 2009; Wijffels and Barbosa, 2010).		Change in biofuels development and production as a result of pressure.	Direct relationship between pressures causing mortality and potential provision.

Table 3. Natural Hazard Protection

Contributing factors	Spatially defined	Available datasets	Contribution	Relative Contribution	Response / sensitivity to pressures	Marginal Change
Offshore sand banks	BSH that provide this function	- UK SeaMap - JNCC hold shapefiles of potential sandbank areas around the UK (<20m depth)	Relative area of coastline that provides this function.		Change in the function / extent of offshore sand banks as a result of pressure. The contributing factor of service provision is the abiotic habitat and, barring large scale aggregate extraction, this will not be subject to management.	Based on abiotic response to pressure. Contribution unlikely to change under different management scenarios.
Seagrass beds	BSH that provide this function	- MB0102 - UK SeaMap	Relative area of coastline that provides this function. Minor role due to small spatial scale (UK NEA Chapter 12).		Change in the function / extent of seagrass beds as a result of pressure. Koch et al. (2009) draw attention to non-linearities in wave attenuation which varies tidally, seasonally and over spatial scales.	At a UK scale, the extent of the habitat is the contributing factor of service delivery – marginal change will be based on the response (sensitivity) to pressure.
Saltmarsh	BSH that provide this function	- MB0102 - UK SeaMap - EA Saltmarsh Manual - French (2001) UK NEA (Chapter 11) provides further information.	Relative area of coastline that provides this function. The most extensive areas are along estuaries in Hampshire, N. Kent, Essex, Norfolk, Lincolnshire & Lancashire (May and Hansom, 2003). Valued at £4,600m (EA saltmarsh manual) based on costs of sea defences. Beaumont et al. (2008) values at 0.38 - 0.71 million hectare.		Change in the function / extent of saltmarsh areas as a result of pressure.	Based on response to pressures. Relationship between pressures and service should be linear – based on increase / decrease in saltmarsh extent.

Table 3. Natural Hazard Protection (continued)

Contributing factors	Spatially defined	Available datasets	Contribution	Relative Contribution	Response / sensitivity to pressures	Marginal Change
Littoral muds	BSH that provide this function	- MB0102 (Intertidal mudflats) - UK SeaMap	Relative area of coastline that provides this function. Mudflats dissipate tidal & wave energy to permit net sediment deposition allowing colonisation by saltmarsh/reedbed vegetation on the upper intertidal zone (Nottage and Robertson, 2005).	**High** Extent of mudflats coupled with saltmarsh development.	Change in the function / extent of littoral muds as a result of pressure. Human activities that could impact the delivery of this service are coastal land claim and development and developments that alter water flows or tidal elevation (e.g. large scale barrage schemes).	Marginal change will be assessed based on response to pressure of the abiotic habitat.
Shingle	Spatial contribution according to significant shingle deposits	- UK NEA - Natural England - SNH	Relative area of coastline that provides this function. The most extensive are in the south-east England and north-west Scotland (UK NEA, 2011). Environment Agency (2007) estimates that shingle provides £0.79 billion sea defence value in England (from UK NEA).		Change in the function / extent of shingle beds as a result of pressure. The contributing factor of service provision is the abiotic habitat and, barring large scale aggregate extraction, this will not be subject to management.	Based on abiotic response to pressure. Contribution unlikely to change under different scenarios.
Littoral muds	BSH that provide this function	- MB0102 (Intertidal mudflats) - UK SeaMap	Relative area of coastline that provides this function. Mudflats dissipate tidal and wave energy to a level low enough to permit net sediment deposition and this allows colonisation by saltmarsh or reedbed vegetation on the upper intertidal zone (Nottage and Robertson, 2005).	**High** Extent of mudflats coupled with saltmarsh development.	Change in the function / extent of littoral muds as a result of pressure. Human activities that could impact the delivery of this service are coastal land claim and development and developments that alter water flows or tidal elevation (e.g. large scale barrage schemes).	Marginal change will be assessed based on response to pressure of the abiotic habitat.

Table 4. Climate Regulation

Contributing factors	Spatially defined	Available datasets	Contribution	Relative Contribution	Response / sensitivity to pressures	Marginal Change
North Sea carbon pump	The North Sea Research suggests that the southern and northern North Sea are separate systems.	Thomas et al. (2004)	Greater than vegetated habitats (scale). Basin wide CO_2 uptake by the North Sea is estimated as 1.38 mol C m^{-2} $year^{-1}$ or 8.5 x 10^{12} g C $year^{-1}$. Kuhn et al. (2010) estimated the contribution to CO_2 uptake as 0.98 mol C m^2 yr^{-1}, based on two years (1995-1996).		The driver of service provision is the seasonal stratification and off-shelf transport of carbon rich subsurface water and this will not be affected by, or subject to, management.	Contribution is unlikely to change under different management scenarios (i.e. no marginal change to assess).
Depth of sea bed depth	UK bathymetry	UKHO and others	Carbon sequestered in sediments on continental shelf >50m and continental slope at a rate of 42.4kg carbon ha^{-1} p.a (based on deposition rate in northern North Sea calculated by Thomas et al 2005) Carbon sequestered in deep ocean at 0.18kg carbon ha^{-1} p.a (Nelleman et al, 2009)		Assessed as a function of water depth, therefore only likely to change if water depth changes significantly	Contribution is unlikely to change under different management scenarios
Saltmarsh	BSH that provide this function	MB0102 Marine Institute EA UK NEA	Relative areas of saltmarsh that function in carbon sequestration. Craft (2007) assessed saltmarsh carbon fraction 9 ± 1% and carbon density 190 ± 40 g m^2 per year. Saltmarshes may store 0.64 - 2.19 t/C/ha/yr		Change in saltmarsh function to sequester carbon as a result of pressure. Based on response to pressures, relationship between pressures and service should be linear (based on increases or decreases in extent).	Saltmarshes in accreting systems have potential for long-term carbon sequestration although unknown quantities of greenhouse gases may be emitted (UK NEA assessment).
Seagrass beds	BSH that provide this function	UK SeaMap MB0102 Marine Institute	Relatively low as seagrass beds are unlikely to be long term accreting environments and vegetative storage is low.		Based on response to pressures, relationship between pressures and service should be linear (based on increases or decreases in extent).	

Table 5. Clean water and sediments

Contributing factors	Spatially defined	Available datasets	Contribution	Relative Contribution	Response / sensitivity to pressures	Marginal Change
Coastal water column	Water column in proximity to coast	UKHO and others	Relative area contributing to waste breakdown through dispersal and bacterial action in mixed, well oxygenated waters.		Change in water column processes as a result of pressure	Based on response to pressure.
Saltmarsh	BSH that provide this function	PSEG Environment Agency UK SeaMap	Relative area contributing to waste sequestration though sediment accumulation. In 54 ha of Saltmarsh in the Humber Estuary, 90 tonnes of Zn, 46 tonnes of Pb, 16 tonnes of As (arsenic) and 19 tonnes of Cu have been recorded (Andrews et al. 2008).		Change in saltmarsh function to breakdown waste products as a result of pressure.	Based on response to pressure.
Coastal coarse sediment and rock habitats	BSH that provide this function	PSEG EA UK SeaMap	Relative area contributing to waste breakdown through dispersal and bacterial action in mixed, well oxygenated waters.		Change in habitat function to breakdown waste products as a result of pressure.	Based on response to pressure. Habitat and species present are proxy indicators of the dominant process, rather than contributing to service provision.
Coastal mud habitats or muddy sands	BSH that provide this function	PSEG EA UK SeaMap	Relative area contributing to sequestration and bacterial breakdown through sediment accumulation and bioturbation.		Change in habitat function to breakdown waste products as a result of pressure.	Based on response to pressure.

Table 6. Nutrient Cycling

Contributing factors	Spatially defined	Available datasets	Contribution	Relative Contribution	Response / sensitivity to pressures	Marginal Change
Coastal water column	Water column in proximity to coast	UKHO and others	Relative area contributing to nutrient cycling through dispersal and bacterial action in mixed, well oxygenated waters.	High	Change in water column processes as a result of pressure	Based on response to pressure.
Habitats dominated by secondary producers	BSH / functional groups that provide this function	UK SeaMap MESH	Relative contribution made by each BSH / functional group that provides this function (i.e. quantification of secondary productivity). Derived by literature review.		Change in function of the habitat in response to pressure. Derived by literature review.	Based on response to pressure.
Habitats dominated by vegetation	BSH / functional groups that provide this function	UK SeaMap MB0102 EA	Primary production and subsequent decomposition of plant matter. Derived by literature review.		Change in function of the habitat in response to pressure. Derived by literature review.	Based on response to pressure. Changes in extent of macro-vegetation and associated habitats through land claim and development will directly reduce delivery of the service (linear).
Soft Sediments	BSH / functional groups that provide this function	UK SeaMap	Nitrification and denitrification processing of bacteria facilitated by macro-invertebrate bioturbation. Derived by literature review.		Change in function of the habitat in response to pressure. Derived by literature review (MORE).	Based on response to pressure.

Table 7. Tourism and Recreation

Contributing factors	Spatially defined	Available datasets	Contribution	Relative Contribution	Response / sensitivity to pressures	Marginal Change
Nature watching	Habitats that provide this function – based on expert opinion AONB, NNR, SSSIs, National Trust properties and RSPB reserves	Bryden (2010) Taylor (SNH) et al. (2010) RSPB (2010)	Relative value of each BSH / functional group that provides this function. The latest annual report for the National Trust (in references) identified visitor numbers to coastal properties with >50,000 visits.		Where areas are designated sites these will be subject to management for conservation value. However, broadscale management measures may indirectly support sites especially as birds may migrate or otherwise have large habitat ranges.	Based on response to pressure.
Recreational Activities	Habitats that provide this function – based on expert opinion	Visit Britain Cefas	Relative value of each BSH / functional group that provides this function.		Sea angling value underpinned by the health of trophy fish stocks, marine management measures may directly contribute to the delivery of this ecosystem service. Other services are largely provided by abiotic habitat and management measures may not affect their delivery.	Based on response to pressure.
Scuba diving	No national data collected for this activity. Some dive areas are relatively well known – ABPmer have created case studies for previous reports that can be referred.	There is a lack of reliable data at a national level – some local studies exist.	Relative value of each BSH that provides this function.		Lyme bay shows change in diver numbers following habitat protection.	Based on response to pressure.
Other	World Heritage Site-Dorset and East Devon Coast (Jurassic Coast).	Visit Britain	Relative value of each BSH that provides this function. A number of sites will have a 'unique' reason for visiting. Era Ltd (2009) produced an economic impact study of the World Heritage Site.		Service largely provided by abiotic habitat and marine management measures will not affect the delivery of this service.	Based on response to pressure.

Table 8. Assumptions on changes in fish and shellfish (capture fisheries) landings values (percentage of baseline value)				
Year	**World Markets**	**Nature @ Work**	**National Security**	**Local Stewardship**
2015	100%	90%	100%	90%
2030	85%	120%	90%	105%
2060	35%	150%	90%	120%

Table 9 Percentage Increase in aquaculture production from existing farms

	Year	1. Estimated percentage change in GVA (compared to baseline)	2. Value (£m) GVA	3. % capacity increase	4. Assumed increased value (£m) from increased capacity	5. Assumed new value (£m) from new farms
Baseline	0		147		147	
World Markets	2015	150%	221	20%	176	44
	2030	180%	265	20%	212	53
	2060	225%	331	30%	275	56
Nature@work	2015	125%	184	20%	176	7
	2030	144%	211	10%	194	17
	2060	165%	243	15%	223	20
National Security	2015	162%	198	20%	176	22
	2030	202%	238	10%	194	44
	2060	130%	298	30%	252	45
Local Stewardship	2015	150%	191	10%	162	29
	2030	172%	220	10%	178	42
	2060	162%	253	30%	231	21

Table 10. Assumptions on changes in carbon sequestration (percentage of baseline value)

Year	World Markets	Nature @ Work	National Security	Local Stewardship
2015	100%	100%	90%	100%
2030	95%	100%	95%	100%
2060	85%	100%	90%	100%