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# Spatial models of essential fish habitat (South Inshore and Offshore marine plan areas): Assessing EFH value annex

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# Spatial models of essential fish habitat (South Inshore and Offshore marine plan areas)

## Assessing EFH Value Annex

## MMO Project No: 1044

Marine Management Organisation

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## List of acronyms

| | |
|---|---|
| EFH | Essential Fish Habitat |
| EUNIS | European Nature Information System |
| ICES | Institute of Estuarine and Costal Studies (University of Hull) |
| IFCA | Inshore Fisheries and Conservation Authorities |
| IHLS | International Herring Larval Survey |
| MCZ | Marine Conservation Zone |
| MMO | Marine Management Organisation |

# 1. Introduction

In order for the MMO to develop effective marine plans, understanding the 'value'[1] of environmental assets and ecosystem services provided by the marine environment is of primary importance.

Allocating a relative 'value' to areas in the marine environment is of particular relevance to marine planning. Identifying the location of most valuable marine areas allows management of the marine space to be prioritised, thus facilitating provision of a greater-than-usual degree of risk aversion in management of activities in such areas. This approach is also known as hotspot approach (e.g., Myers *et al*., 2000; Derous *et al*., 2007).

When the 'value' of marine habitats is discussed, in most of cases it's their importance for human use that is taken into account. Their socio-economic value is considered, i.e. the value of the goods and services provided by marine ecosystems, with attempts being made to attach a monetary value to them (e.g., Bockstael *et al*., 1995; King *et al*., 1995; Edwards and Abivardi, 1998; De Groot *et al*., 2002; Turpie *et al*., 2003).

An intrinsic 'value' can also be associated with marine habitats, due to their support to the functioning of the marine ecosystem. This 'value' can be assessed against a set of ecological criteria (hence it will be named from here on ecological value) and it makes no reference to anthropogenic use. Marine biodiversity has been used to characterise the ecosystem qualities that define this 'value', hence to identify hotspots of ecological value (Derous *et al*. (2007) called it 'marine biological value').

When considering Essential Fish Habitats (EFH), their ecological value is evident in that these habitats provide suitable conditions where critical life stages can survive (eggs and larvae in spawning habitats and juveniles in nursery habitats) or where adults can find available food for their growth (adult foraging grounds). In doing so, these aquatic habitats contribute to the growth and viability of fish populations hence providing support to the functioning of the ecosystem also via the links to other ecosystem components through the marine food webs. The socio-economic value of EFH, in turn, can be related to the benefits that are gained by the human society from the use of the resources (goods) that these habitats provide or from the services that they provide to the ecosystem for its functioning. These goods and services are associated not only to the fish component characterising EFH (for example, fishery and larval supply, respectively), but also to the other components (abiotic and biotic) of the habitat (for example, clean water/sediments and primary production, respectively).

This Annex reports on the assessment of the relative importance of marine areas within the South Inshore and South Offshore plan areas based on the 'value' of EFH identified in the project. Both the ecological and socio-economic values were taken into account to allocate a non monetary value to the EFH. Where possible,

[1] In order to distinguish the monetary (or economic) value from the term value used in its wider meaning as synonym of importance, 'value' is used within inverted commas in the latter case, unless an adjective specifying the nature of the value (e.g., ecological value, socio-economic value) is given.

environmental economic methods to assign a monetary value were also identified and data requirements for their application to the EFH were outlined.

In order to provide an objective evaluation of the value of EFH, a common framework was used to define the assessment methods, i.e. the ecosystem services framework, outlined in the following section.

## 2. Ecosystem Services Framework

Marine and coastal ecosystems are important to society in a number of ways, mainly through the multiple direct and indirect uses for services to society provided by coastal areas. It is well known in the environmental sciences that the coastal zone is subject to many and varied changes resulting from human activities as well as natural processes (Aubry and Elliott, 2006). As the human population is increasing and diversifying their use of the marine and coastal environment, marine life, habitats and landscapes are affected. Therefore the development of environmental policies that consider all members of the user community is increasingly necessary (Atkins *et al*., 2011). The use of the concept of ecosystem services allows the dynamic nature of the environment and all its aspects to be translated into a series of functions. By assessing any ecological processes using the services provided by them, any benefits or losses to the ecosystem when development or exploitation takes place can be understood by all stakeholders involved (Beaumont *et al*., 2007), and appropriate planning can be developed to manage future activities in the area.

Ecosystem services are defined by the Millennium Ecosystem Assessment as the outputs of ecosystems from which society derives benefits (MEA, 2005). This is further enforced in a guideline identified by Boyd and Banzhaf (2007) and Fisher and Turner (2008), who propose that ecosystem services are the aspects of ecosystems, actively or passively used, to produce human well-being. For this definition, three important characteristics are identified:

**1. Services are not goods/benefits**
For example, recreation is not a service provided by ecosystems, but a good/benefit of which ecosystems provide important inputs. A good/benefit is something that has an explicit impact on changes in human well-being, e.g. more food, better hiking or walking, less flooding.

**2. Ecosystem services and therefore goods/benefits are ecological in nature**
Aesthetic values, cultural contentment and recreation are not ecosystem services, but rather the goods/benefits that arise from the environment and subsequent processes, that lead to direct changes in human welfare.

**3. Ecosystem services do not have to be utilized directly**
If human welfare is affected by ecological processes or functions at some point, they are services (Fisher and Turner, 2008). For example, carbon sequestration is an ecosystem service because there are net human benefits derived from this process (e.g. climate regulation). Likewise, pollination is an ecosystem service as we indirectly use the ecological process to gain certain food benefits, so pollination would be classified as the service, and the direct food gained as the benefit (Fisher and Turner, 2008).

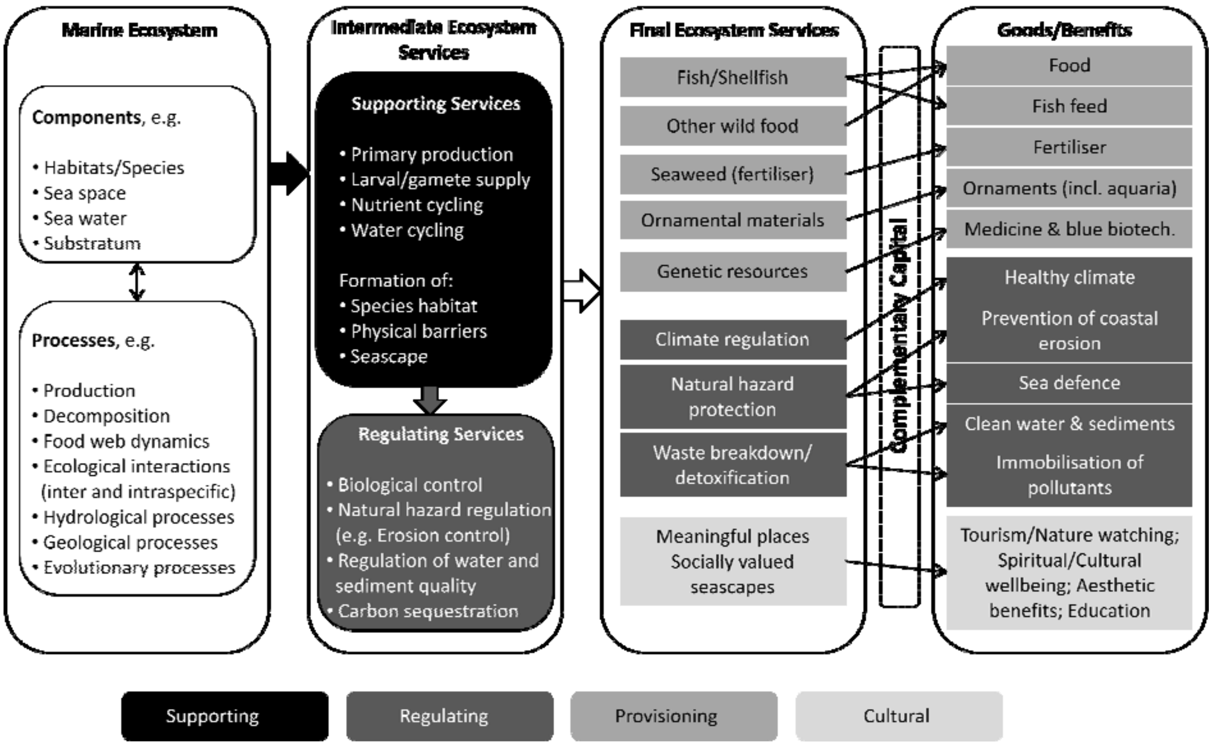
A framework that classifies ecosystem services and interprets how they interact in the marine environment is provided by the UK National Ecosystem Assessment. Figure 1 shows this framework, which has been adapted further by the UK Valuing Nature Network initiative (NERC funded) to specify components of the marine ecosystem that provide ecosystem services, and illustrate the flow of services from the environment to the good or benefit society will gain (Potts *et al*., 2013).

This framework identifies ecosystem services as either supporting, regulating, provisioning or cultural, and shows how marine ecosystems comprise of a range of fundamental components (e.g. habitats, species, substratum) and processes (e.g. production, food web dynamics) which lead to the provision and delivery of intermediate supporting services (e.g. primary production, nutrient cycling) and regulatory services (e.g. biological control, carbon sequestration).

The intermediate services are processes, and do not have a direct influence on human welfare, however, they provide the basis for final ecosystem services which are the end result of this process, providing direct use and benefits to society such as resources for consumption (e.g. fisheries, seaweed for fertilizer), important coastal processes which help sustain human populations (e.g. hazard protection, waste breakdown), and the production and development of natural areas providing socially and culturally valuable benefits (e.g. recreation, aestheticism).

Through both intermediate and final services, as well as the input of complimentary capital (e.g. labour, fishing vessels, time, energy, machinery), society can obtain goods/benefits from marine ecosystems in the form of food, raw materials, sea defences, tourism, etc. and can be broadly defined as something of anthropocentric instrumental value, of both personal use (direct/indirect) or non-personal use (altruistic/existence value) (Potts *et al*., 2013).

**Figure 1: Schematic showing the intermediate and final ecosystem services and the goods/benefits provided by marine systems. Adapted from VNN report (Potts *et al*., 2013).**



# 3. Assessment of Value of EFH

The method for assessing the relative importance of EFH is presented in this section, with examples of application of this method to the outputs of this project and caveats and limitations highlighted.

## 3.1 Ecological value

For highly mobile species, like fish, the localisation of critical areas for a species' foraging, nursing or spawning (i.e., EFH) is considered important for the purpose of ecological valuation (Connor *et al*., 2002; Roff and Evans, 2002; Derous *et al*., 2007). In addition, a holistic approach (considering different components of a system) is called for ecosystem management as opposed to the reductionist view of single-species management (Simberloff, 1998). The occurrence and importance of different EFH in a marine area can therefore be used as a criterion to quantify the ecological value of that area.

The 18 EFH spatial outputs obtained in the project were taken into account for this assessment, including EFH for 10 species, namely plaice (adult foraging grounds, nursery and spawning grounds), sole (nursery and spawning grounds), lemon sole (nursery and spawning grounds), dab (nursery and spawning grounds), red gurnard (nursery and spawning grounds), common dragonet (nursery and spawning grounds), solenette (nursery and spawning grounds), thickback sole (nursery grounds), thornback ray (nursery grounds), herring (spawning grounds).

In order to identify the most important marine areas acting as EFH for each species, the information obtained from the EFH spatial outputs and the associated confidence maps was used. The EFH predicted with higher confidence were selected for each species following the criteria below:

- Adult foraging grounds were identified from the outputs obtained from species habitat models (M1), as those habitats where adult occurrence is predicted (alone or together with juveniles) with the highest relative confidence level (highest confidence class associated with adult foraging habitat predictions, as identified in the confidence maps).

- Nursery grounds were identified from the outputs obtained from models on the probability of occurrence of juveniles of the species (M2), as those habitats where juveniles occurrence is predicted with a probability >50% and with the highest relative confidence level (highest confidence class associated with nursery habitat predictions, as identified in the confidence maps).

- Spawning grounds were identified from the outputs obtained from models on the probability of occurrence of eggs (plaice) or larvae (herring) of the species (M2), as those habitats where eggs/larvae occurrence is predicted with a probability >50% and with the highest relative confidence level (highest confidence class associated with spawning habitat predictions, as identified in the confidence maps).

Based on the above criteria, the presence of the most important EFH for each species (EFH hotspots) was identified within the 5 x 5km grid covering the study area.

The overall ecological value of marine zones within the study area was assessed by estimating the frequency of presence of the EFH hotspots in each grid cell. This frequency was calculated considering the 18 EFH altogether to identify hotspots of overall ecological value, but also by distinguishing EFH by their function, in order to identify areas more valuable either as adult foraging grounds, nursery areas or spawning grounds.

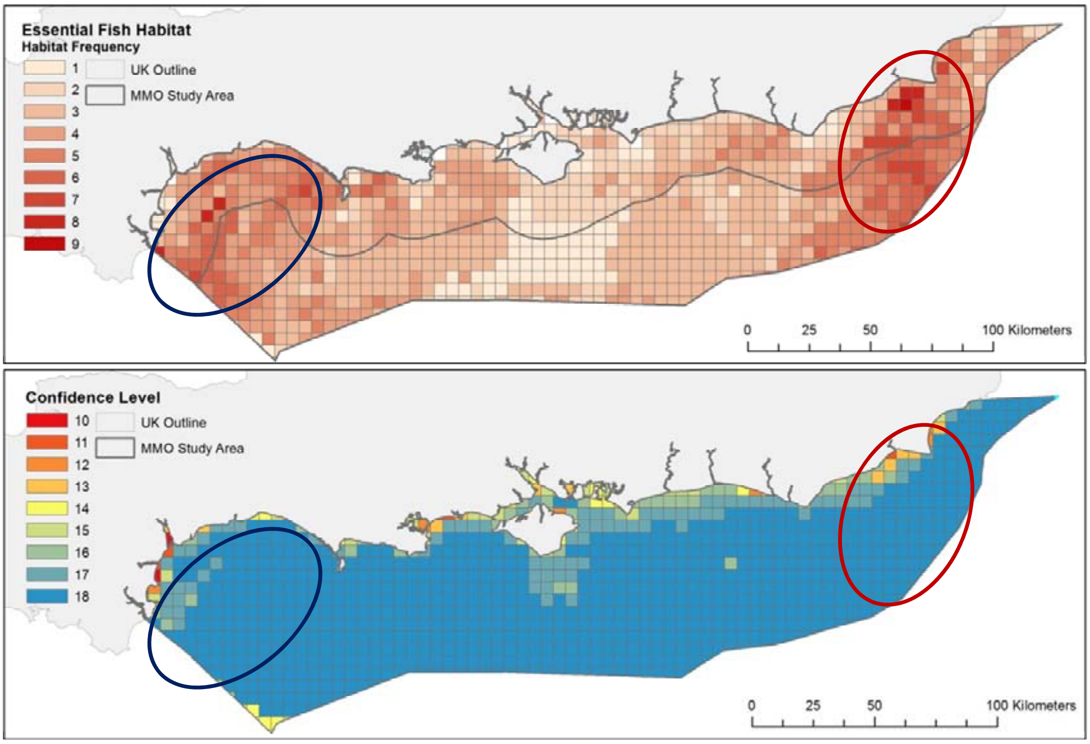
A limitation in the estimates of ecological value was identified in that, in some areas, low 'values' could be determined by limitations in predictive models (i.e., absence of valid predictions) rather than by an actual absence of certain EFH. This would occur in areas where the general environmental ranges are similar to those associated with the EFH hotspots, but the confidence on the model prediction is null (hence the area is not identified as an EFH hotspot). The lowest (0) confidence in these areas is due to the fact that values for certain environmental variables fall outside the range of validity of the model (i.e. the range of variability defined within the calibration dataset). This is ascribed to the limited spatial distribution of the survey data used as input to the EFH models (as highlighted, for example, in the marine area in front of the Isle of Wight).

In order to account for these limitations, a measure of confidence was associated with the estimate of ecological value. For each EFH, the grid cells were identified where the problem described above occurred and marked as invalid. When combining the information across EFH (overall or divided by EFH type), the frequency of valid cases was calculated as an estimate of the relative confidence associated with the estimate of ecological value in a grid cell. The resulting confidence value has a maximum in the number of EFH combined (18 when considering all the EFH, 7 for adult foraging habitats, 9 for nursery habitats and 2 for spawning habitats), indicating that all the data on presence or absence of EFH hotspots are valid. The confidence in the ecological value estimate decreases with the increase of invalid predictions associated with a grid cell, with a theoretical confidence minimum of 0, indicating that the predictions of all the EFH models considered are invalid in that grid cell.

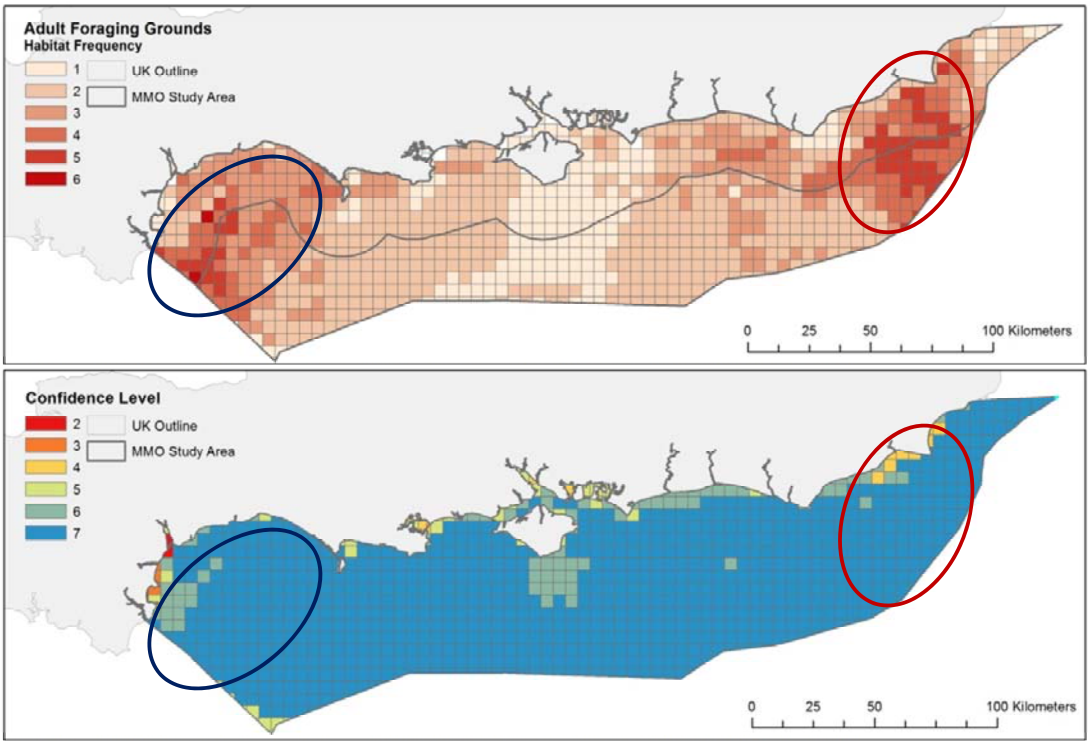
The resulting hotspot maps showing the relative ecological value of marine areas along the South Coast and the associated confidence level are shown in Figure 2A (as overall ecological value) and Figure 2B to 2C (ecological value by EFH function).

**Figure 2: Relative ecological value of marine areas (habitat frequency) and associated confidence (frequency of valid EFH predictions). Relative importance of marine areas is given as (A) overall ecological value (all 18 EFH), (B) 'value' as adult foraging grounds (7 species), (C) 'value' as nursery grounds (9 species), and (D) 'value' as spawning grounds (2 species). Circles indicate the general location of the main hotspots of overall ecological value.**

(A)




(B)

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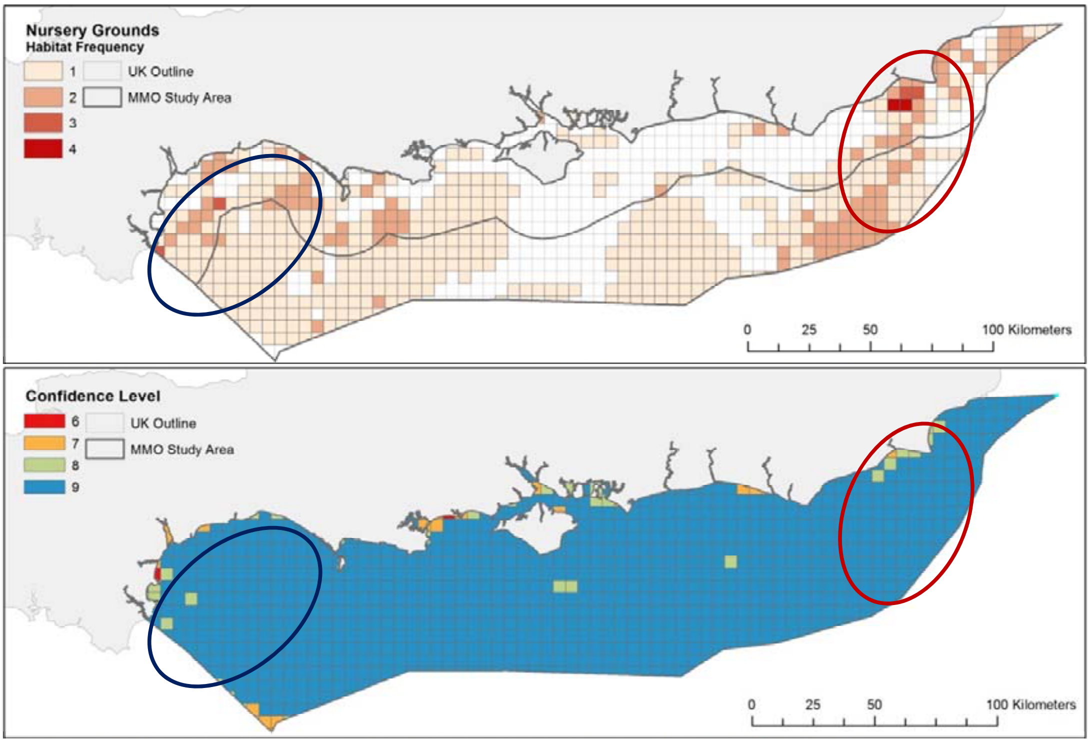
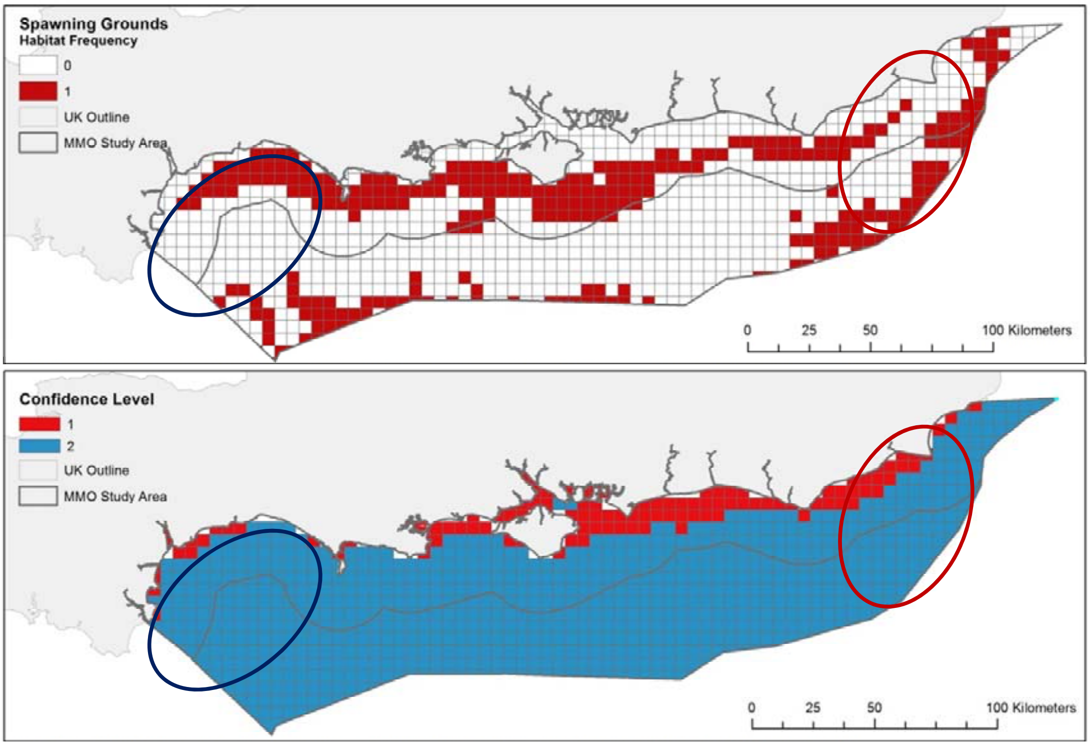
(C)




(D)

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Areas of higher ecological value (overall) are located in the eastern and western sides of the study area, in front of the coasts of Devon and of East Sussex and Kent, respectively. A higher confidence is associated particularly to the eastern hotspot areas, whereas part of the western hotspots, as well as some areas of lower ecological value (in front of the Isle of Wight and inshore areas), show a lower confidence in these estimates. This lower confidence is likely the result of gaps in the model predictions hence higher caution should be placed when considering the ecological value of these areas.

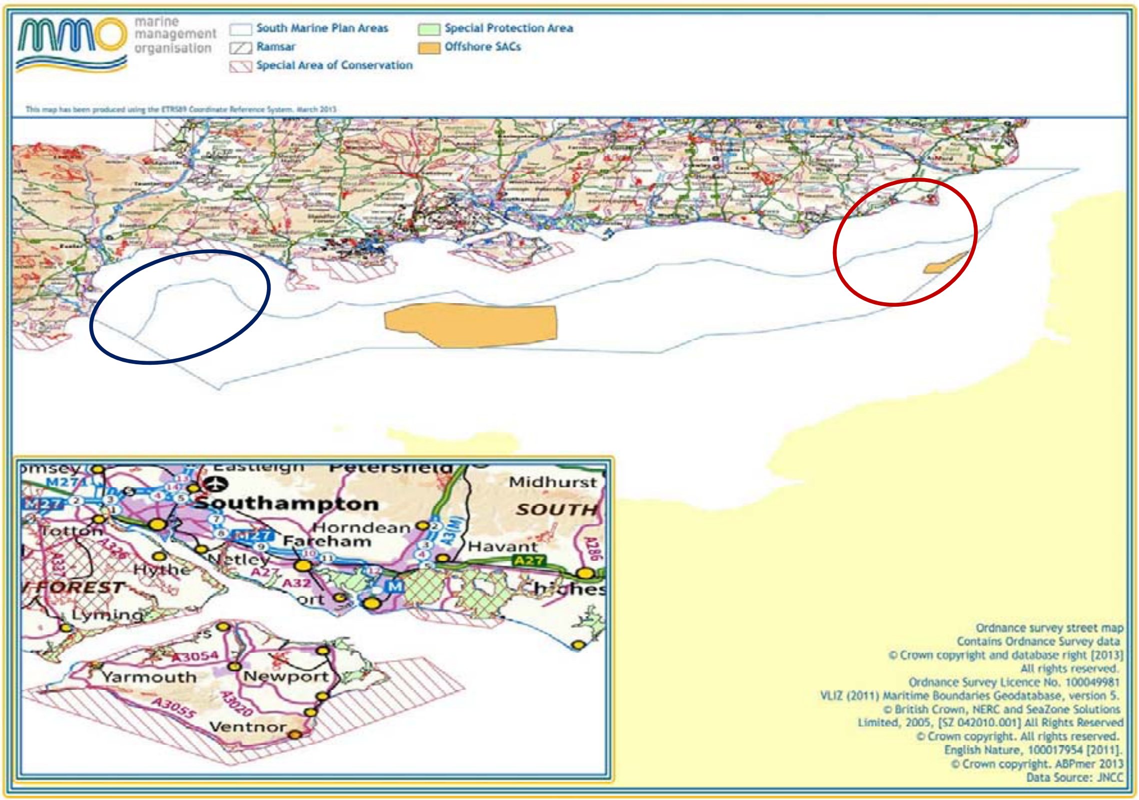
The hotspots of ecological value observed in front of the coasts of Devon are mostly ascribed to the higher frequency of adult foraging grounds (including most of the species except for red gurnard), and, in places, also to fish nursery hotspots (particularly for red gurnard, thickback sole, sole and plaice). Relatively valuable areas are identified also in the inshore waters around Portland, due to the frequency of adult foraging habitats (mostly for thickback sole and red gurnard) and to the presence of potential spawning grounds for herring.

In the eastern side of the study area, hotspots of ecological value are observed inshore, although relatively valuable areas occur also offshore from Dungeness. The presence of adult foraging grounds for most of the species considered in the study (with the exception of red gurnard) highly contribute to the ecological value of both these areas, with also nursery grounds occurring frequently in places, particularly inshore (particularly for plaice, red gurnard, thickback sole and thornback ray). The presence of potential herring spawning grounds also contributes to the ecological value of the areas offshore.

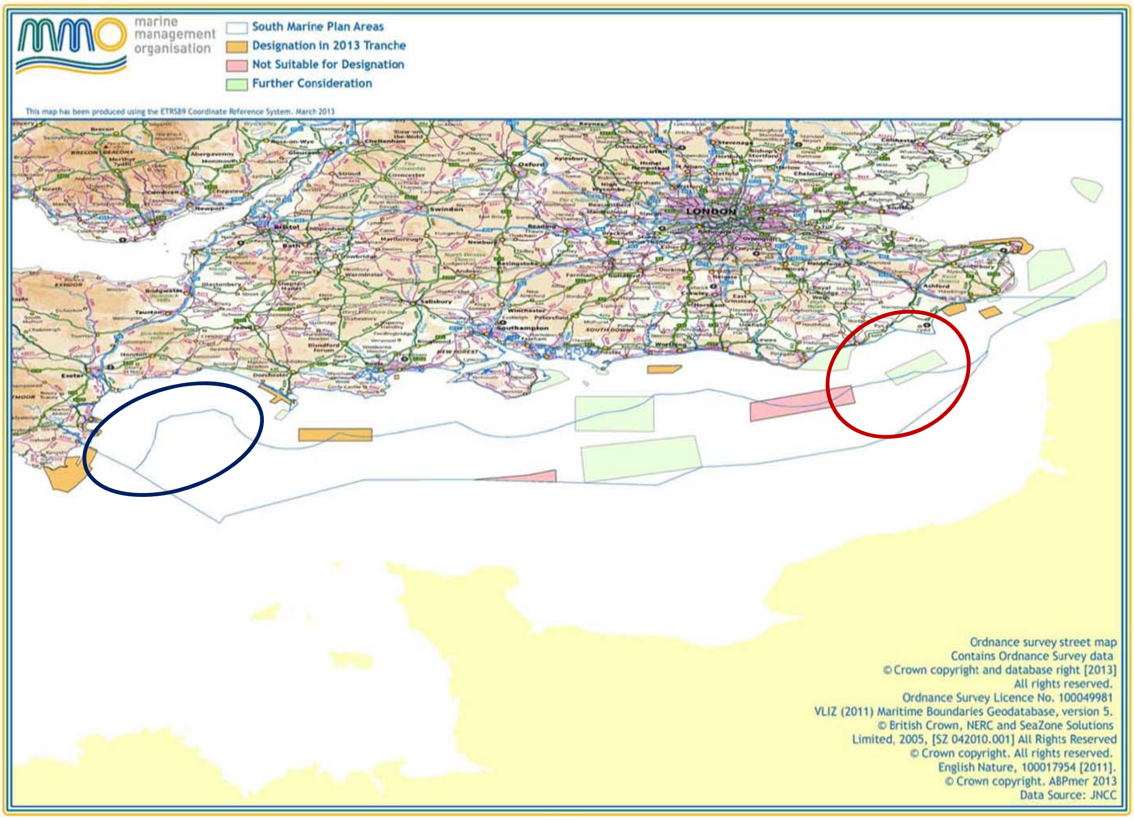
It is of note that these hotspots of ecological value partly overlap with areas identified as important for conservation, like in the Bassurelle Sandbank SAC offshore from Dungeness (Figure 3A). In addition, although they are not included in any of the recommended marine conservation zones (MCZs) in the South marine plan areas that have been proposed for designation in the first tranche of sites, they overlap with recommended MCZs (rMCZ), which are currently considered for designation (Figure 3B).

**Figure 3: Location of (A) internationally-designated sites and (B) recommended marine conservation cones in the South marine plan areas (source: MMO project 1039, MMO, 2013). Circles indicate the location of the main hotspots of overall ecological value as identified in Figure 2.**

(A)



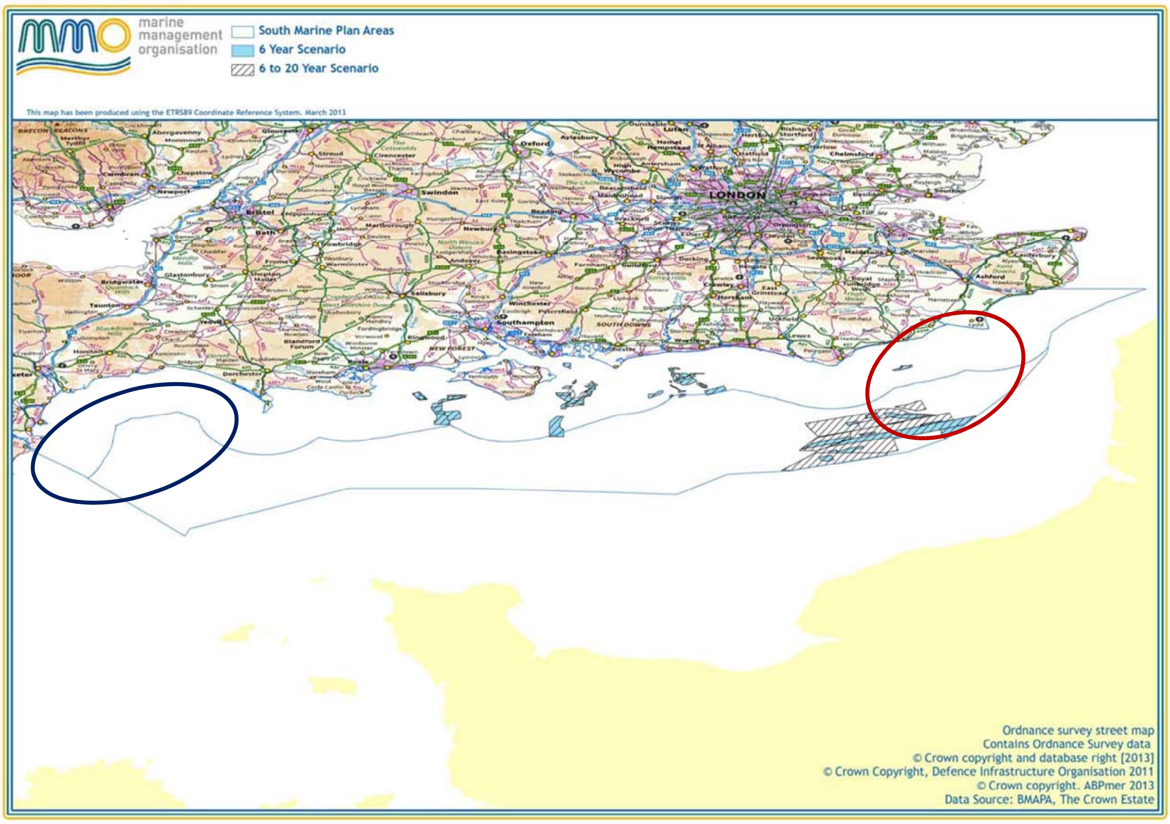

(B)



These hotspot areas can be considered as warning systems for marine managers who are planning new activities at sea, and can help to indicate conflicts between human uses and an area's high 'value' during spatial planning. For example, the ecological hotspots located offshore from Dungeness are included in areas currently used for marine aggregate extraction or where these activities are likely to increase in the next future (MMO, 2013; Figure 4). In particular, the co-occurrence with herring spawning grounds constitutes an important management issue for the MMO, and it is often a condition on licences and an issue for integrating these activities with other industry sectors (e.g., fishery).

It is of note that this specific issue is not restricted to the hotspot area above, but might occur also in the inshore areas around the Isle of Wight, where also a significant amount of future dredging activity (MMO, 2013) would co-exist with the presence of herring spawning grounds. The ability of identifying herring spawning habitats with high confidence is therefore important to inform marine planning in the South marine plan areas hence it is acknowledged the need of improving these EFH models by using larval abundance rather than presence-absence (see Section 3.10 of the Final Report).

**Figure 4: Future trends for marine aggregate extraction in the South marine plan areas (source: MMO project 1039, MMO, 2013). Circles indicate the approximate location of the main hotspots of overall ecological value as identified in Figure 2.**



### 3.1.1 Limitations and caveats

Although spatial predictions with higher confidence have been taken into account to identify most important EFH for each species before combining them into the final index of ecological value, still some limitations are associated with these predictions due to the general moderate-low confidence (on average) associated with the EFH outputs (see details on output confidence assessment in Final Report of the project).

The ecological value as calculated from the EFH outputs takes into account a limited number of demersal fish species (see limitations of the EFH data and outputs in Final Report of the project) therefore it is likely that the extent and ecological value of marine areas as EFH in the study area is underestimated.

A lower confidence in the ecological value assessment is attached to some areas, due to the limitations in the spatial coverage of the data originating the EFH models. As a result, the ecological importance of these areas might be underestimated.

There is room for improving the above assessment (and the associated confidence) by integrating the dataset used for the model calibration with additional fish survey data in order to cover a wider range of environmental variability and of species. This might result also in the increase of occurrence of species life stages in the dataset. This would allow the modelling of fish abundance data rather than presence-absence, thus improving the information provided by the EFH identification.

## 3.2 Ecosystem service provision

A ‘value’ can be also attached to EFH based on the ecosystem services they provide. The framework given by Potts *et al*. (2013) is of particular use for this purpose. These authors defined a relationship between the provision of ecosystem services and the features of marine areas by scoring the relative importance of marine features in providing a set of intermediate ecosystem services and goods/benefits. EUNIS habitats were among the features assessed in this study.

The assessment provided by Potts *et al*. (2013) was used to estimate the relative ‘value’ of ecosystem services provision in the South marine plan areas, hence to associate it to the identified hotspot areas of high ecological value (based on EFH). EUNIS habitats were used as a reference.

The EUNIS seabed habitat map obtained during the EUSeaMap project and provided by JNCC was processed to identify the EUNIS habitats occurring in the study area. The 5 x 5km grid used as spatial reference in this EFH project was applied to the map in GIS environment and, for each grid cell, the dominant EUNIS habitat was identified (based on the area of the habitat polygons included in the cell). These habitats were then matched with those considered in Potts *et al*. (2013) in order to allow association with the ‘value’ for ecosystem services provision defined in that paper. In some cases a perfect match was not achieved, due to the different habitat classification levels used in the two studies (EUNIS level 3 or 4 in EUSeaMap, EUNIS level 2, 3, 4 and higher in Potts *et al*. (2013)). For example, EUNIS habitat A4.11 was identified in the study area from EUSeaMap, while habitats A4.1 or A4.131 were considered in Potts *et al*. (2013). In cases like this one, the habitat matching was carried out by using the correspondent lower habitat level available in Potts *et al*. (2013), based on the assumption that the ecosystem services provided by a habitat defined at a lower level reflect the provision of the features included in that habitat (in the example above, A4.11 was matched with A4.1[2]). As a result, the 21 EUNIS habitats identified in the study area based on the EUSeaMap were matched into 14 of the habitat features considered by Potts *et al*. (2013) and their importance in terms of ecosystem services provision was identified (Table 1 and 2).

**Table 1: Relative importance of EUNIS habitats occurring in the study area in providing goods/benefits. The relative importance is scored as 3-significant, 2-moderate, 1-low, 0- absent or negligible (blank cells are not assessed). Data on the importance of single ecosystem services are derived from Potts *et al*. (2013). Goods/benefits for which data are not available for their assessment in the selected habitats are not shown. The overall importance of each habitat in providing significant and moderate goods/benefits is indicated.**

| Goods/Benefits (G/B) | | from Provisioning services | | from Regulating services | | | | | from Cultural services | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EUNIS habitats in the study area (EUSeaMap) | EUNIS habitats in Potts *et al.* (2013) | Food | Fish feed | Healthy climate | Prevention of coastal erosion | Sea defence | Clean water and sediments | Immobilisation of pollutants | Tourism / Nature watching | Spiritual / Cultural wellbeing | Education | G/B of significant and moderate import. (relative freq.) |
| A3.1 | A3.1 | 3 | | | 2 | 2 | | | 2 | 1 | 1 | 0.50 |
| A3.2 | A3.2 | 3 | | | 2 | 2 | | | 2 | 1 | 1 | 0.50 |
| A3.31 | A3.3 | | | | 2 | 2 | | | 2 | 1 | 1 | 0.60 |
| A4.11 or A4.13 | A4.1 | 3 | | | 1 | 1 | | | 2 | 1 | 1 | 0.17 |
| A4.12 | A4.12 | 1 | | | | | | 1 | 2 | 1 | 1 | 0.20 |
| A4.2, A4.27 | A4.2 | 3 | | | 1 | 1 | | | 2 | 1 | 1 | 0.17 |
| A4.31, A4.33 | A4.3 | 3 | | | 1 | 1 | | | 2 | 1 | 1 | 0.17 |
| A5.14, A5.15 | A5.1 | 2 | 3 | | 1 | 1 | 2 | 1 | | 1 | 1 | 0.25 |
| A5.13 | A5.12, A5.13 | 2 | 3 | | | | 2 | | 1 | 1 | 1 | 0.33 |
| A5.23 or A5.24, A5.25 or A5.26, A5.27 | A5.2 | 2 | 3 | | 1 | 1 | 2 | 1 | | 1 | 1 | 0.25 |
| A5.33 or A5.34, A5.35 or A5.36 | A5.3 | 2 | 3 | | 1 | 1 | 2 | 2 | | 1 | 1 | 0.38 |
| A5.37 | A5.371 | 2 | | | 1 | 1 | 2 | 2 | | 1 | 1 | 0.43 |
| A5.44, A5.45 | A5.4 | 2 | 3 | | 1 | 1 | 2 | 2 | | 1 | 1 | 0.38 |
| A5.43 | A5.43, A2.41, A2.42 | 1 | | 1 | | | 2 | 2 | 1 | 1 | 1 | 0.29 |

[2] Besides the alphanumerical code identifying the EUNIS habitat level, the habitat description was also taken into account to refine the matching. It is of note that some broad scale habitats were also defined in the EUSeaMap (e.g., high energy deep circalittoral seabed), but a clear correspondence with habitats in Potts *et al*. (2013) could not be identified, hence their importance in ecosystem services provision could not be defined.

**Table 2: Relative importance of EUNIS habitats occurring in the study area in providing intermediate ecosystem services. The relative importance is scored as 3-significant, 2-moderate, 1-low, 0- absent or negligible (blank cells are not assessed). Data on the importance of single ecosystem services are derived from Potts *et al*. (2013). Intermediate services for which data are not available for their assessment in the selected habitats are not shown. The overall importance of each habitat in providing significant and moderate intermediate ecosystem services is indicated.**

| Intermediate services (IS) | | Supporting services | | | | | Regulating services | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EUNIS habitats in the study area (EUSeaMap) | EUNIS habitats in Potts *et al*. (2013) | Primary production | Larval / Gamete supply | Nutrient cycling | Formation of species habitat | Formation of physical barriers | Biological control | Natural hazard regulation | Regulation of water & sediment quality | Carbon sequestration | | IS of significant and moderate import. (relative freq.) |
| A3.1 | A3.1 | 2 | 2 | | 3 | 3 | | 2 | | | | 1.00 |
| A3.2 | A3.2 | 2 | 2 | | 3 | 3 | | 2 | | | | 1.00 |
| A3.31 | A3.3 | 2 | 2 | | 3 | 3 | | 2 | | | | 1.00 |
| A4.11 or A4.13 | A4.1 | 1 | 2 | | 2 | 1 | | 1 | | | | 0.40 |
| A4.12 | A4.12 | | 2 | | 2 | | 1 | | | | | 0.67 |
| A4.2, A4.27 | A4.2 | 1 | 2 | | 2 | 1 | | 1 | | | | 0.40 |
| A4.31, A4.33 | A4.3 | 1 | 2 | | 2 | 1 | | 1 | | | | 0.40 |
| A5.14, A5.15 | A5.1 | 1 | 2 | 2 | 2 | | | 1 | 0 | | | 0.50 |
| A5.13 | A5.12, A5.13 | 1 | 2 | 2 | 2 | | | | 2 | | | 0.80 |
| A5.23 or A5.24, A5.25 or A5.26, A5.27 | A5.2 | 1 | 2 | 2 | 2 | | | 1 | 0 | | | 0.50 |
| A5.33 or A5.34, A5.35 or A5.36 | A5.3 | 1 | 2 | 2 | 2 | | | 1 | 0 | | | 0.50 |
| A5.37 | A5.371 | 1 | 2 | 2 | 2 | | | 1 | 1 | | | 0.50 |
| A5.44, A5.45 | A5.4 | 1 | 2 | 2 | 2 | | | 1 | 0 | | | 0.50 |
| A5.43 | A5.43, A2.41, A2.42 | | 1 | 1 | 2 | | | | 2 | 1 | | 0.40 |

In order to obtain an estimate of the overall importance of these habitats in providing ecosystem services, only services of significant and moderate importance were considered (scores 3 and 2 in Table 1 and 2, respectively) and the relative frequency of these services was calculated, distinguishing goods and benefits from intermediate services (Table 1 and 2). As the number of ecosystem services assessed for the different habitats was variable (depending on the information available for the assessment; Potts *et al*., 2013), the relative frequency was calculated as the ratio between the number of services of significant or moderate importance and the total number of services assessed for the specific habitat (Table 1 and 2).

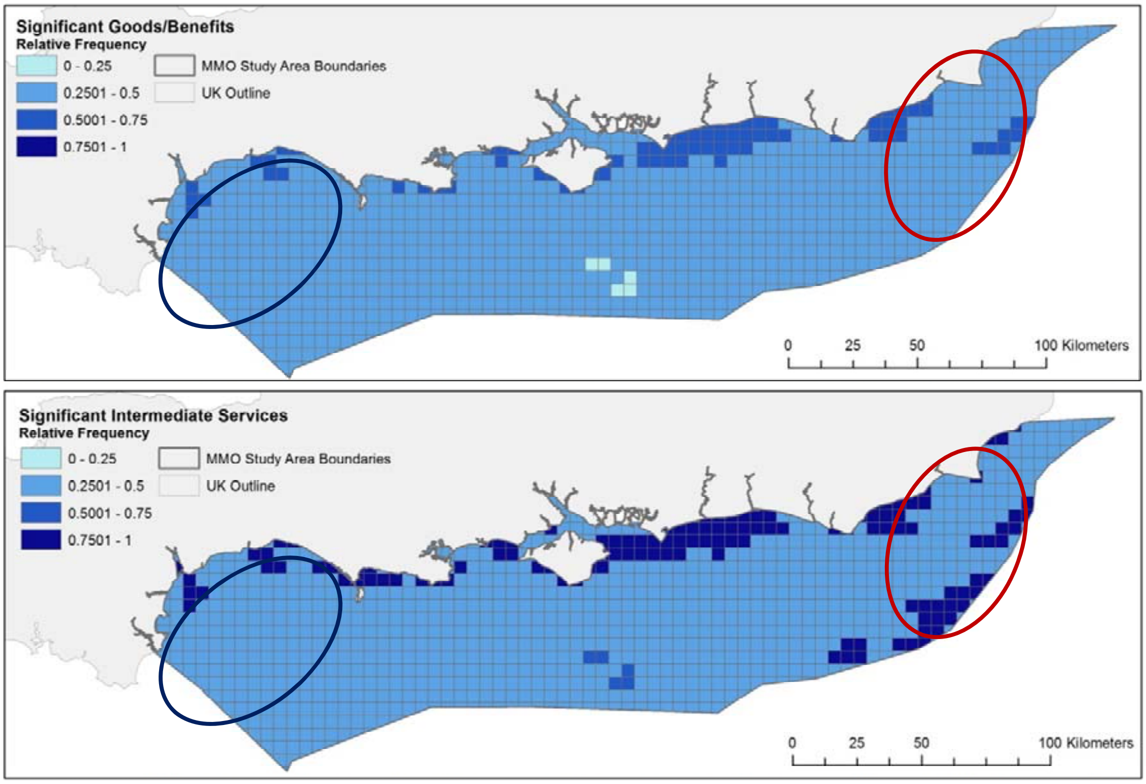
Results showed that, overall, a higher importance in goods/services provision is associated with infralittoral rocky habitats of variable energy (A3.1 to A3.3), and relatively high importance is also associated with muddy and mixed sediment substrata (A5.3 to A5.4) (Table 1). Food and fish feed are the goods and benefits provided with higher importance (significant) by most of the marine habitats included in the study area. Significant contribution to food provision is particularly relevant in infralittoral and circalittoral rocky habitats (A3.1 to A4.3), whereas significant provision of fish feed is more relevant in subtidal sedimentary habitats (A5.1 to A5.43). A moderate provision of fish food, clean water and sediments and immobilisation of pollutants is also observed in these latter habitats, whereas rocky habitats provide moderate good/benefits regarding tourism/nature, but also prevention of coastal erosion and sea defence.

As regards intermediate services, the highest overall importance in these services provision is associated with infralittoral rocky habitats of variable energy (A3.1 to A3.3), and relatively high importance is also associated with subtidal sands and gravel substrata (A5.13) (Table 2). The formation of species habitat is the most important intermediate service provided by the habitats in the study area, with higher 'value' particularly in infralittoral rocky habitats of variable energy (A3.1 to A3.3), whereas a moderate 'value' is associated with the other habitats. Infralittoral rocky habitats significantly provide also formation of physical barriers and are of moderate importance in providing intermediate services like primary production and natural hazard regulation. Larval/gamete supply is moderately important in most of the habitats included study area, as well as nutrient cycling in sedimentary habitats (A5.1 to A5.4), with the exclusion of sheltered muddy gravels (A5.43).

The results of the assessment of the importance of marine habitats in ecosystem services provision were mapped in GIS by using the gridded map of EUNIS habitats (from EUSeaMap) as a reference. This allowed the identification of the spatial distribution of ecosystem services provision in the study area hence the relative 'value' of EFH could be assessed by comparison with the ecological value hotspots obtained in Section 3.1 (their approximate location is indicated in Figure 5).

The importance of ecosystem services provision can be seen as an added 'value' to the relevant ecological hotspots identified in the study area due to their functioning as EFH (Figure 5). The areas occurring in both hotspots supply important ecosystem services, mostly associated to dominant subtidal sedimentary habitats in the western area and in the eastern areas offshore, whereas rocky habitats were more frequent in the eastern area inshore. This added 'value' is associated in particular to the supply of goods and benefits like food, fish feed, clean water and sediments and, secondarily, immobilisation of pollutants, and to the provision of intermediate services like the formation of species habitat, larval and gamete supply, and nutrient cycling. This additional 'value' is particularly evident in the eastern hotspots, due to the larger overlapping with important areas for ecosystem services provision (Figure 5). This overlap is particularly significant offshore, on sedimentary habitats, where ecological hotspots are identified with the highest confidence (Figure 2). As discussed before, these areas are likely to provide important spawning areas for herring, hence the particular relevance of intermediate ecosystem services like larval/gamete supply and formation of species habitat.

**Figure 5: Distribution of the overall importance of marine areas within the South marine plan areas in providing significant and moderate goods/benefits and intermediate services. Circles indicate the approximate location of the main hotspots of overall ecological value as identified in Figure 2.**






A confidence rating has been assigned to the assessment of the importance of ecosystem services provision depending on the type of information used to assess a specific habitat (namely expert opinion, grey or overseas literature and UK-related, peer-reviewed literature) (Potts *et al*., 2013). Although this confidence score was not quantitatively included in the assessment above, it was considered *a posteriori* to judge the general confidence in the assessment of the two hotspot areas highlighted above. The main ecosystem services provided by these areas were taken into account and it was noted that most of the data supporting the assessment of ecosystem services provision in the selected hotspot areas were obtained from UK-related, peer-reviewed literature (hence with a higher level of confidence attached), particularly when considering sedimentary habitats. The only exception was the information on the provision of food that, for sedimentary habitats, was obtained mostly from grey or overseas literature. Therefore a lower confidence should be attached to the assessment of the importance due to good/benefits provision resulting in the eastern offshore hotspot and in the western areas (where sedimentary habitats dominate), compared to the eastern inshore hotspot (where rocky bottom is more frequent).

### 3.2.1 Limitations and caveats

Potts *et al*. (2013) highlighted that the assessment at the level of specific habitat features (EUNIS habitat level 3 or higher) has attached a greater level of confidence than when considering broad-scale habitats (Level 2). However, in most of cases, matching of habitat types in the study area, as identified from the EUSeaMap, was not possible at the feature scale, hence broad-scale habitats were considered for the assessment. In addition, as evident in Table 1 and 2, there is still a paucity of data on ecosystem services associated to habitat features, and this leads to uncertainties in the 'value' assessment. These factors are generally ascribed to gaps/limitations in the data available, hence the assessment could benefit from further research to improve the quality and availability of data on ecosystem services associated with marine habitats.

## 3.3 Economic valuation

As ecosystem services potentially lead to goods/benefits for human welfare, attempts have been made to translate their 'value' into a monetary value, and this approach can then be used to value particular areas. In this section, the main methods available to value ecosystem services are outlined, with details provided in particular for those services that proved to be more important for the identified EFH areas. An example of the application of such methods to EFH in the South areas is also provided.

The economic valuation of ecosystem services requires certain guidelines to be followed, to ensure accurate values which are applicable for policy makers and managers:

- **Spatial explicitness and scale**

Ecosystem service valuation should have a clear spatial scale, as this discourages treating ecological systems at a biome level, and ensures any values obtained can have a wider application for policy makers, on a national or international level (TEEB, 2010). Ecosystem services are also largely context dependent, potentially forming 'socio-ecological mosaics', or a patchwork of landscape units ranging in management issues or biophysical variations, which means the way ecosystem services are produced and used can also vary spatially, therefore spatial context should be given.

- **Marginality**

Economic analysis should be conducted "at the margin", when marginal environmental changes are being assessed. This means the focus of the study should be on relatively small or incremental changes rather than larger state changing impacts in order to obtain an accurate valuation (Turner *et al*., 2010).

- **Double counting**

This is a widely recognised issue in environmental valuation which can cause uncertainty and poor reliability when estimating the value of ecosystem services (Fu *et al*., 2010). Primarily, double counting can be caused when competing ecosystem services are valued separately, but the values are then aggregated; or when an intermediate or final service is valued separately, and then is also indirectly valued through its contribution to the end good/benefit. This may be the result of ambiguous definitions and inconsistency when classifying ecosystem services, a poor understanding of the ecosystems complexities or failure to properly recognise how linked ecosystem services complement each other (Fu *et al*., 2010). To avoid the issue of double counting Fu *et al*. (2010) propose four steps for ecosystem service valuation: (1) identifying the spatial-temporal scales of ecosystem services; (2) establishing consistent classification systems for ecosystem services; (3) valuing only the goods/benefits obtained from ecosystem services; and (4) selecting valuation methods appropriate for the study context.

- **Nonlinearities in benefits**

An underlying assumption when valuing ecosystem services is that the quantity of an ecosystem service varies linearly with other independent variables and characteristics of the environment, such as ecosystem size, change in season, disturbance (anthropogenic or otherwise), and species interactions. However these effects, particularly in dynamic environments, tend to be non-linear (Farnsworth, 1998). Because many different ecosystems typically respond to disturbances in a non-linear fashion, their functioning may appear unaffected by increasing disturbances, until they reach a point when the amount of perturbation will cause a dramatic system-changing response (Morse-Jones *et al*., 2011).

- **Threshold effects**

Ecosystems in general are complex but adaptive systems, and can have varying levels of resilience. The resilience of an ecosystem refers to the amount of disturbance that a system can experience (and adapt to) before it is forced to shift into a different state, which in turn may mean different structures or functions, and a shift in ecosystem services available. The point at which the ecosystem is forced to change is referred to as the threshold effect and knowledge of the system is required to account for when this may occur.

Taking these criteria into consideration, possible valuation techniques are identified, and a suggested approach for the economic valuation of goods/benefits in important EFH is presented

### 3.3.1 Identification of goods/benefits and possible valuation techniques.

The approach to ecosystem goods/benefits evaluation suggested here is to: identify the relevant goods/benefits in relation to the ecological hotspots in the study area; ascertain the appropriate technique for economic valuation subject to data availabilities; and then implement the technique in order to economically value the chosen good/benefit.

The ecosystem services and goods/benefits identified for economic valuation were done so in relation to the ecological hotspots identified in the South marine plan areas (Figure 2). This ensured all economic valuation would be in relation to ecological hotspots, linking the ecological importance with the economic value, and ensuring a spatial scale is defined. The intermediate services and goods/benefits of significant importance relating to the EUNIS habitats found in the ecological hotspots were identified in Section 3.2.

For both areas, at the East end and West side of the study area, significant intermediate services were larval/gamete supply, nutrient cycling and formation of species habitat. The presence of the intermediate services larval/gamete supply and formation of species habitat at significant importance in the ecological hotspot at the East end of the study area was identified as of particular relevance in the light of the presence in this area of potential herring spawning grounds and of the conflicts that might arise due anthropogenic activities occurring or planned in this area, e.g., aggregate extraction, as highlighted in Section 3.1.

Although it is acknowledged that intermediate services have an important role in marine ecosystem, to reduce the possibility of double counting it is suggested that only the goods/benefits be considered for valuation, in agreement with what proposed by Fu *et al*. (2010). The significant goods/benefits associated with the ecological hotspots were identified as food, fish feed, clean water and sediments, and, to a lesser extent, immobilisation of pollutants.

It is important that appropriate methodology is chosen for valuing the goods/benefits. For some marine ecosystem services, market prices reflect their value, but for others use of a market value may not be possible, either if it does not exist or if it is inadequate to value the service (Cooper *et al*., 2013). A range of methods is available to assess the values placed on goods/benefits, including market and non-market approaches, which are useful for those goods/benefits in which a market price is not available or inappropriate for valuation (Cooper *et al*., 2013). These methods are outlined in Table 3, where also the relevance to specific ecosystem services is indicated.

**Table 3: Economic valuation techniques and examples of their relevance to ecosystem services (adapted from Cooper *et al*., 2013). Underlined ecosystem services are relevant to this study.**

| Economic valuation method | Description | Relevance to ecosystem services |
|---|---|---|
| Choice Experiment Method (CEM) | Discrete choice model which assumes the respondent has perfect discrimination capability. Uses experiments to reveal factors that influence choice. | Applicable to all ecosystem services. |
| Contingent Valuation Method (CVM) | Construction of a hypothetical market by direct surveying of a sample of individuals and aggregation to encompass the relevant population. Problems of potential bias. | Applicable to all ecosystem services. |
| Cost-of-Illness (COI) | The benefits of pollution reduction are measured by estimating the possible savings in direct out-of-pocket expenses resulting from illness and opportunity costs. | Applicable to: clean water and sediments; and immobilisation of pollutants. |
| Damage Avoidance Costs (DAC) | The costs that would be incurred if the ecosystem good or service were they not present. | Applicable to: healthy climate; prevention of coastal erosion; sea defence; clean water and sediments; and immobilisation of pollutants. |
| Defensive Expenditure Costs (DEC) | Costs incurred in mitigating the effects of reduced environmental quality. Represents a minimum value for the environmental function. | Applicable to: healthy climate; prevention of coastal erosion; and sea defence. |
| Hedonic Pricing (HP) | Derive an implicit price for an environmental good from analysis of goods for which markets exist and which incorporate particular environmental characteristics. | Applicable to: tourism/nature watching. |
| Market Analysis | Where market prices of outputs (and inputs) are | Applicable to: food; fish feed; |

| Economic valuation method | Description | Relevance to ecosystem services |
|---|---|---|
| (MA) | available. Marginal productivity net of human effort/cost. Could approximate with market price of close substitute. May require shadow pricing where prices do not reflect social valuations. | ornamentals; medicine; healthy climate; prevention of coastal erosion; and sea defence. |
| Net Factor Income (NFI) | Estimates changes in producer surplus by subtracting the costs of other inputs in production from total revenue and ascribes the remaining surplus as the value of the environmental input. | Applicable to: food, fish feed, medicines, clean water and sediments; and immobilisation of pollutants. |
| Production Function Analysis (PFA) | An ecosystem good or service treated as one input into the production of other goods: based on ecological linkages and market analysis. | Applicable to: food; fish feed; ornamentals; medicine; healthy climate; prevention of coastal erosion; and sea defence. |
| Productivity Gains and Losses (PGL) | Change in net return from marketed goods: a form of (dose-response) market analysis. | Applicable to: healthy climate; prevention of coastal erosion; and sea defence. |
| Replacement / Substitution Costs (R/SC) | Potential expenditures incurred in replacing the function that is lost; for instance by the use of substitute facilities or 'shadow projects'. | Applicable to all provisioning and regulating services but with limited role for cultural services. |
| Restoration Costs (RC) | Costs of returning the degraded ecosystem to its original state. A total value approach; important ecological, temporal and cultural dimensions. | Applicable to: healthy climate; prevention of coastal erosion; sea defence; clean water and sediments; and immobilisation of pollutants. |
| Shadow Price of Carbon (SPC) | A price that reflects the social cost of carbon consistent with the damage experienced under an emissions scenario such that e.g. a specific policy goal can be achieved (the precautionary principle might support a further adjustment to the price). | Applicable to: healthy climate. |
| Social Cost of Carbon (SCC) | Damage costs of an incremental unit of carbon (or equivalent amount of other greenhouse gas emissions) imposed over the whole of its time in the atmosphere. | Applicable to: healthy climate. |
| Travel Cost Method (TCM) | Cost incurred in reaching a recreation site as a proxy for the value of recreation. Expenses differ between sites (or for the same site over time) with different environmental attributes. | Applicable to: tourism/nature watching. |

There are several possible economic valuation methods available for the most important goods/benefits associated to the ecological hotspots identified in the study area. Therefore each of these goods/benefits is presented here with details on the possible methods for its valuation, including the advantages and disadvantages of using each method, and identifying the main data requirements (Table 4-6). This information can be used to address future studies on economic valuation of EFH in South marine plan areas and elsewhere.

**Table 4: Valuation techniques for the ecosystem good/benefit food (adapted from www.seafish.org, accessed 22.09.13).**

| Technique | Data Required | Approach/Formula | Advantages | Disadvantages | Recommendation |
|---|---|---|---|---|---|
| Proportional area technique (*Market Analysis*) | • Landings statistical data per ICES rectangle | [Proposed area / total ICES rectangle area] * total ICES rectangle landings | • Standardised data relatively easy to access<br>• Quick to undertake | • Likely to be very inaccurate as assumes even distribution of value across ICES rectangle | **Avoid where possible** |
| Effort as a proxy for landed value (*Market Analysis*) | • Landings statistical data per ICES rectangle<br>• Effort data (VMS, surveillance or Fishermap, etc.) | [Effort in proposed area / effort in total ICES rectangle area] * total ICES rectangle landings | • Data moderately easy to access<br>• Allows comparison of landed value of different areas of ICES rectangles | • Constrained by accuracy and coverage of effort data (e.g., VMS only for >15 m vessels) | **Recommended** |
| Effort as a proxy for financial performance (*Market Analysis*) | • Seafish Cost & Earnings data<br>• Effort data (VMS, surveillance or Fishermap, etc.) | To value Proposed Area alone: Effort in Proposed Area * Seafish Cost Earnings<br><br>To value Proposed Area relative to wider ICES Rectangle:<br>[Effort in Proposed Area * Seafish Cost Earnings] / [Effort in Total ICES Rectangle Area * Seafish Cost Earnings] | • Data moderately easy to access<br>• Allows comparison of profitability/GVA of different areas of ICES rectangles | • Based on 'Average' profit/GVA data | **Recommended** |
| Consultation approach (*Choice Experiment or Contingent Valuation*) | • Interviews/surveys/ focus group/meeting transcripts | Collation and analysis of communications from proposed area stakeholders | • Methodology is easy to explain | • Resource intensive and likely to be costly.<br>• Subject to usual survey/response bias<br>• Non-standardised data set | **If time permits may be useful** |
| Resource valuation (*Production Function Analysis*) | • ICES stock assessments<br>• Local / national stock assessments | Determine biomass of resource on a species/stock basis and define exploitable levels to determine overall value of the resource | • Useful for assessing benefits of any intervention to stocks | • Data intensive and therefore likely to be costly. | **If time permits may be useful** |
| Direct method (*Market Analysis*) | • Direct haul data<br>• CCTV/ fully documented fishery<br>• On-board observer reports | Use of direct value of landings, although average trip prices and costs may have to be assumed | • No need for use of proxy estimated | • Resource intensive<br>• May be based on average trip prices and costs | **Recommended if data available** |

**Table 5: Valuation techniques for the good/benefit fish feed (sources: De Groot *et al*., 2002; Birol *et al*., 2006; Cooper *et al*., 2013).**

| Technique | Data Required | Approach/Formula | Advantages | Disadvantages | Recommendation |
|---|---|---|---|---|---|
| Market Analysis | • Landings £ value data of fish species for non-human consumption<br>• Human effort/cost data | Use the direct value of the landings, or approximate the value of landings with the market price of a close substitute if species specific landing data is not available. | • Data moderately easy to access/collate<br>• Quick to undertake | • Requires shadow pricing where prices do not reflect social valuations, relying on assumptions. | **Recommended if data available** |
| Net Factor Income | • Landings £ value data of non-commercial fish species.<br>• Human effort/cost data<br>• Information on any inputs for the system. | Specify the functional relationship between the inputs and outputs. Estimate how a change in the input will effect a change in the output. Changes in producer surplus can be estimated by subtracting costs of other inputs in production and assuming remaining surplus is value of the input in question. | • Straightforward methodology<br>• Data requirements are limited and readily available | • Limited to only valuing resources used as inputs for marketed goods.<br>• Inferred value of whole ecosystem may be under/overstated. | **Recommended where information on the entire ecosystem is available** |
| Production Function Analysis | • Landings £ value data of fish species for non-human consumption<br>• Human effort/cost data<br>• Information on any inputs for the system | Based on ecological linkages and Market Analysis. Determine the physical effects of changes in an ecosystem service on an economic activity. Then the impact of an environmental change can be valued, in terms of the corresponding change in market output of the relevant activity. | • Data moderately easy to access/ collate | • Limited to only valuing resources used as inputs for marketed goods. | **Recommended if there is sufficient knowledge of inputs and associated ecological linkages.** |
| Choice Experiment Method | • 'Willingness to pay' values from Interviews/surveys/ focus groups | Collation and analysis of value bids from proposed area stakeholders/local residents | • Methodology is easy to explain | • Assumes respondent has perfect discrimination capability.<br>• Resource intensive so likely to be costly.<br>• Data collection can be time intensive | **If time permits may be useful** |
| Contingent Valuation | • 'Willingness to pay' values from Interviews/surveys/ focus groups | Collation and analysis of value bids from proposed area stakeholders | • Methodology is easy to explain | • Resource intensive so likely to be costly.<br>• Subject to usual survey/response bias<br>• Data collection can be time intensive | **If time permits may be useful** |

**Table 6: Valuation techniques for the good/benefits clean water and sediments & Immobilisation of pollutants (the same techniques are applied to both goods/benefits) (sources: De Groot *et al*., 2002; Birol *et al*., 2006; Cooper *et al*., 2013).**

| Technique | Data Required | Approach/Formula | Advantages | Disadvantages | Recommendation |
|---|---|---|---|---|---|
| Cost-of-Illness | • Potential costs of avoiding illness e.g. medical bills, loss of earnings.<br>• What local residents/ stakeholders are willing to pay to avoid illness, or willing to accept in compensation. | Estimate any possible savings from potential illness avoidance, and use to measure the benefits of clean water/sediments (e.g. pollution reduction). | • Can provide useful estimates when valuing this ecosystem service. | • Uses 'costs' as a measure of 'benefit', implying the ratio of costs to benefit in avoiding an illness is always equal to 1. | **Only use as an estimate or guide for valuation where possible.** |
| Damage Avoidance Costs | • What local residents/ stakeholders are willing to pay to avoid damage, or willing to accept in compensation. | Estimate the value of clean water/ sediment based on the cost of avoiding the damage through collation and analysis of communications from proposed area stakeholders | • Cost-based methods are useful when the funds for a full valuation study are not available. | • Based on willingness to pay, and is therefore subject to usual survey/response bias | **Only use as an estimate or guide for valuation where possible** |
| Net Factor Income | • Estimated costs of all inputs | Specify the functional relationship between the inputs and outputs. Estimate how a change in the input will effect a change in the output. Changes in producer surplus can be estimated by subtracting costs of other inputs in production and assuming remaining surplus is value of the input in question. | • Straightforward methodology<br>• Data requirements are limited and readily available | • Limited to only valuing resources used as inputs for marketed goods.<br>• Inferred value of whole ecosystem may be under/overstated. | **Recommended where information on the entire ecosystem is available** |
| Restoration Costs | • What local residents/ stakeholders are willing to pay to return a degraded ecosystem to its original state. | Collation and analysis of communications from proposed area stakeholders | • Important ecological, temporal and cultural dimensions.<br>• Can provide useful estimates for the value of water treatment, etc. | • Based on willingness to pay, and is therefore subject to usual survey/response bias | **Can be useful for valuing polluted water systems.** |

### 3.3.2 An example of economic valuation application.

Market Analysis was used to assess economic value of the good/benefit food provided by the ecological hotspots in the study area (see second method indicated in Table 4). This method was chosen, as it was appropriate for the data collated for the study area (Table 7).

**Table 7: Data layers used to obtain valuation information in the analysis.**

| Data theme | Data layer (Source) | Description |
|---|---|---|
| Fishing Activity | 2002-2012, Marine Management Organisation (MMO), English Channel, UK landing data | Landing data (weight and value) from the ICES rectangles, by gear type, in the South Coast Plan Areas for 2002-2012 for all species recorded<br>A limitation of this dataset is that it does not show data for Non-UK vessels that fish in UK waters and land outside the UK. In addition, the 2012 data are preliminary (not yet published by the MMO). |
| Fishing Activity | 2005-2010, Natural England (NE), MCZ project Stakmap Commercial Fishing | Monthly UK Fishing activity by gear. This feature class contains interview data that has been summarised onto a grid of 3/4 of a nautical mile longitude and 3/8 of a nautical mile latitude. This data represents the activities of vessels under 15 metres in length using:<br>Gear definitions:<br>Mobile demersal gears: beam trawls, demersal otter trawls, unspecified bottom trawls, Danish, Scottish and pair seines. Beach seining has been included in the mid water trawls analysis, on the basis that it does not have heavy gear interacting with the benthos and only occurs in littoral environments.<br>Dredges: towed dredges and all powered and hydraulic/suction dredges.<br>Mobile pelagic gear: midwater (pair) trawls, purse seines and ring nets (which are considered to be a form of purse seining rather than a static netting practice, beach seining.<br>Nets: drift nets, moored gill nets, tangle and trammel nets, and fixed nets.<br>Lines: drift lines, moored static lines and lines deployed from a boat (trolling, handlining, rod fishing and gurdy lining).<br>Pots: inkwell, parlour, whelk and unspecified pots. it also includes cuttlefish and fish traps.<br>This data is presented as a series of monthly totals of vessel numbers per grid cell. |
| Fishing Activity | 2007-2009, Centre for Environment, Fisheries and Aquaculture Science (Cefas), UK National Inshore Fishing Activities Data Layer | Fishing effort within 6 nm of the English and Welsh coast. Derived from boarding data provided by Sea Fisheries Committees (now Inshore Fisheries Conservation Authorities, IFCAs) and the Marine Management Organisation (MMO).<br>Fishing activities presented by type of fishing gear (Dredging; Trawling; Netting; Potting; Lining; and Commercial Angling), vessel length and vessel power.<br>Data from 2007 and 2009 and gridded onto a 0.05 deg. in longitude and 0.025 deg. in latitude cells (approx. 5.5 by 5 km).<br>ARC-GIS layer showing Inshore Fishing Effort as determined from fishing vessel sightings<br>Data from sightings are also available, but data on boardings should be preferred due to the improvements in the accuracy of the data as a result of the capture method.<br>A confidence layer is associated to these data. This should be always considered when using these data (it has been suggested that these data should not be used in isolation where the confidence shown in the confidence layer is low). |

As the assessment is carried out by using ICES rectangles as a spatial reference (Table 4), an example to demonstrate the technique is given considering ICES rectangle 30F0 which highly overlaps with the ecological hotspot on the East side of the study area. Also four species were only considered (Dab, Lemon Sole, Plaice and Sole) showing important EFH in this ecological hotspot. However the method application could be applied to any area and species, where appropriate data were available.

The economic values of the studied fish species were calculated from fish landings data according to gear. Data were available for most species between the years of 2002 and 2011, but not all species had data for all years, i.e. some species only had data for 2 or 3 years. Therefore there may be some under-valuing of the contribution of a certain species or gear type to the wider commercial fishery where total landings are taken. To help prevent this, the mean yearly landing was calculated, which takes into account the number of years observed (Table 8).

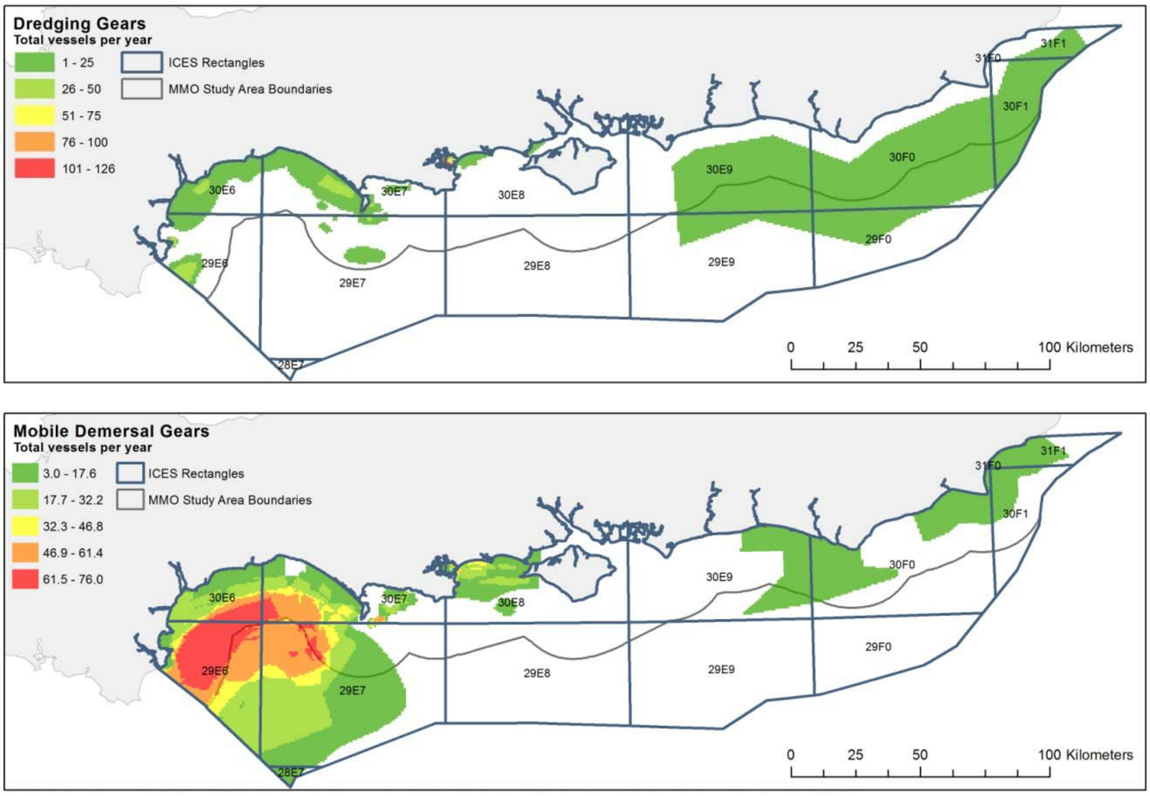
**Table 8: Landings values (£) by gear type for selected fish species in ICES rectangle 30F0.**

| Fish species | Gear type | Total landings 2002- 2011 (£) | Mean yearly landing (£) |
|---|---|---|---|
| Dab | Trawls | 50,247 | 5,025 |
| | Gill nets & entangling nets | 32,451 | 3,245 |
| | Seine nets | 6,028 | 1,507 |
| | Traps | 292 | 42 |
| | Harvesting machines | 213 | 30 |
| | Hooks & lines | 33 | 6 |
| | **Grand total** | **89,264** | **9,854** |
| Lemon Sole | Gill nets and entangling nets | 118,528 | 11,853 |
| | Trawls | 1,086,309 | 108,631 |
| | Seine nets | 42,328 | 8,466 |
| | Harvesting machines | 3,887 | 389 |
| | Traps | 1,186 | 198 |
| | Hooks and lines | 17 | 6 |
| | **Grand total** | **1,252,255** | **129,541** |
| Plaice | Gill nets and entangling nets | 2,005,448 | 200,545 |
| | Trawls | 2,572,829 | 257,283 |
| | Traps | 15,760 | 2,251 |
| | Harvesting machines | 13,244 | 1,324 |
| | Seine nets | 10,837 | 2,167 |
| | Hooks and lines | 1,133 | 189 |
| | **Grand total** | **4,619,250** | **463,760** |
| Sole | Gill nets and entangling nets | 12,670,753 | 1,267,075 |
| | Trawls | 8,684,118 | 868,412 |
| | Harvesting machines | 87,384 | 8,738 |
| | Hooks and lines | 27,202 | 4,534 |
| | Seine nets | 177 | 177 |
| | **Grand total** | **21,469,635** | **2,148,936** |

The average distribution of fishing effort (by gear) in the ICES rectangle was derived from available data layers. In particular, for this valuation exercise, data obtained from the NE data layers (Table 6) were considered due to the higher temporal overlap of these data (2005 to 2010) with the landing dataset (2002 to 2011). The resulting distribution of fishing effort in the study area (with ICES rectangles highlighted) is shown in Figure 6. Only a portion of the ICES rectangle 30F0 was identified as where fishing effort occurred.

These analyses have been used to estimate the relative value of the regional commercial fishery depending on the area where EFH occur. Within the ICES rectangle, only a portion was identified as EFH for the species considered. In particular, for assessing the economic value of direct provision of food, only adult foraging grounds were taken into account.

**Figure 6: Fishing effort plotted as mean annual total number of vessels, per gear type. With ICES rectangles.**

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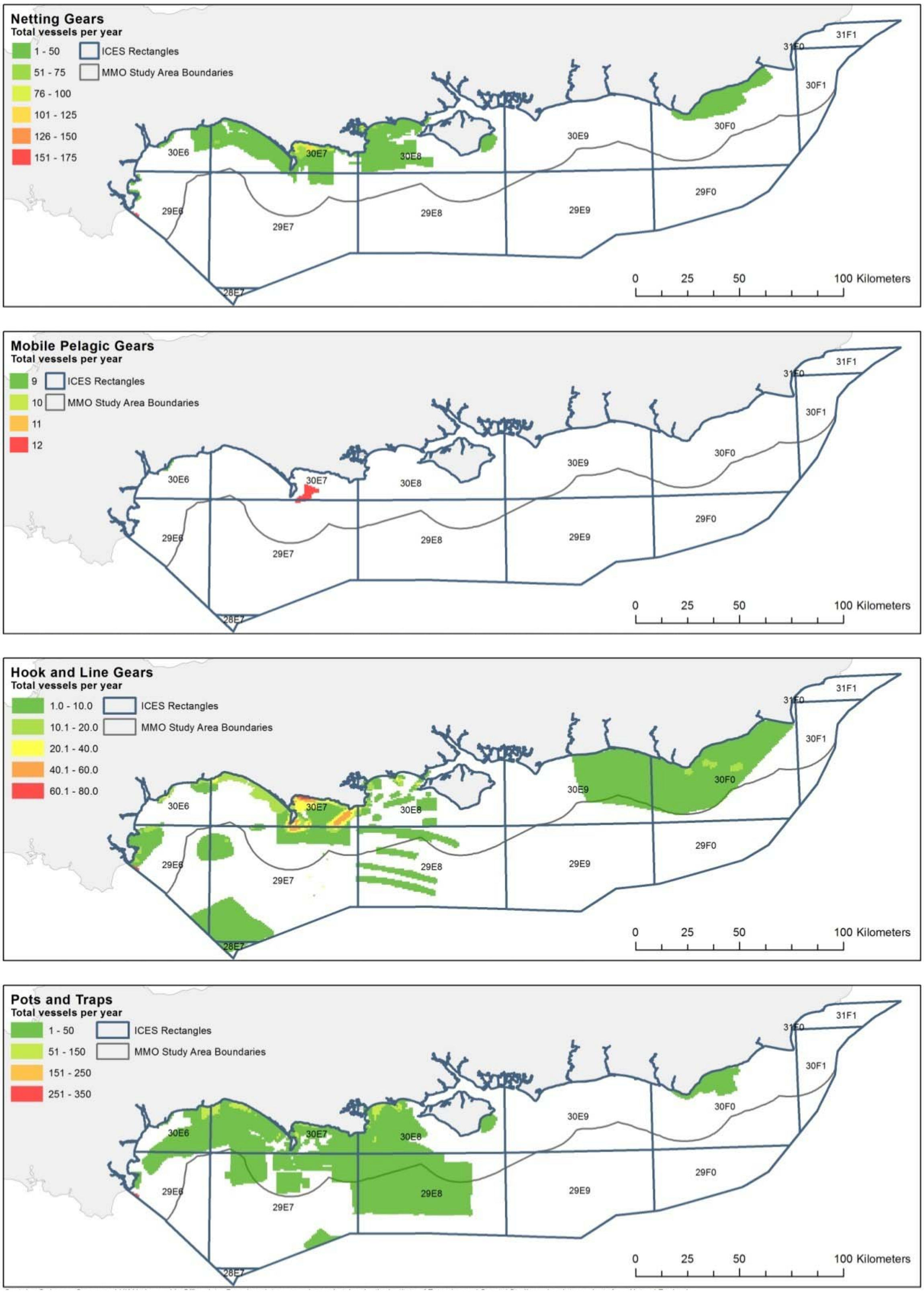


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For each species, the dominant fishing methods used to generate landings were identified (based on the MMO landing data, Table 8), and the corresponding fishing effort by gear data was used to determine the proportional level of fishing effort accounted for by the species EFH in the ICES rectangle 30F0 (based on spatial overlapping between adult foraging grounds and fishing areas). Where more than one gear type significantly contributed to fishing effort, value of the landings were calculated separately for each gear type, then were combined for that species.

The formula suggested in Table 4 for Market Analysis using effort as a proxy for landed value was modified in order to take into account the availability of data by gear and the resulting formula was applied to the data:

$$L_{EFH} = \sum_{g_i} \left( L_{g_i} \cdot \frac{e_{g_{iEFH}}}{E_{g_i}} \right)$$

where: $\mathrm{L_{g_i}}$ = Landings within the ICES rectangle for gear $\mathrm{g_i}$;

$\mathrm{E_{g_i}}$ = Total effort in the ICES rectangle for gear $\mathrm{g_i}$;

$\mathrm{e_{g_{iEFH}}}$ = Effort in the EFH (within ICES rectangle) by gear $\mathrm{g_i}$.

The calculation of the effort for the ICES rectangle and within the EFH should take into account not only the area covered by the effort but also the intensity of the effort. However, it is of note that a relatively homogeneous distribution of lower effort intensity values was observed in the fishing grounds within the selected rectangle (as identified from fishing effort maps in Figure 6). Therefore, the proportional fishing effort associated to the EFH ($e_{giEFH}/E_{gi}$) in this specific example was assumed to be equivalent to the proportion of area subject to fishery (by a specified gear) overlapping with the EFH in the ICES rectangle.

The resulting estimates of the direct economic contribution of the species predicted adult foraging grounds to the regional commercial fisheries depending on these EFH are summarised in Table 9. Although the analysis was focused on the direct contribution of adult fish habitats to marine fisheries, it is of note that, in most of cases, these EFH also included areas of nursery value to fish species (see Figures in Section 3 of Final Report). The approximate proportion of adult habitats where also nursery grounds occur for a species was therefore estimated in the selected ICES rectangle, and the correspondent value was calculated as a proportion of the value associated to adult foraging habitats. The results from the economic analysis for the ecosystem good/benefit food show that the EFH for Sole contribute the highest economic value to the fishery (Table 9).

**Table 9: Results from Market Analysis of the good/benefit food. '-' indicates absence of overlap between the EFH and fishery areas.**

| Fishery | Dominant gear type(s) | Adult foraging habitat | | Nursery grounds | |
|---|---|---|---|---|---|
| | | % of total area subject to gear type | Potential annual contribution (£) | % of adult foraging area | Potential annual contribution within adult foraging area (£) |
| **Dab** | Trawling | 80 | 4,020 | 30 | 1,206 |
| | Netting | 40 | 1,900 | 45 | 855 |
| | **Total** | | **5,920** | | **2,060** |
| **Lemon Sole** | Trawling | 25 | 27,160 | - | - |
| | Netting | - | - | - | - |
| | **Total** | | **27,160** | - | - |
| **Plaice** | Trawling | 60 | 154,370 | 20 | 30,875 |
| | Netting | 40 | 80,220 | 45 | 36,099 |
| | **Total** | | **234,590** | | **66,974** |
| **Sole** | Trawling | 85 | 721,150 | 40 | 288,460 |
| | Netting | 70 | 886,950 | 45 | 354,780 |
| | **Total** | | **1,608,100** | | **643,240** |

### 3.3.3 Limitations and caveats

The results from the Market Analysis are subject to some limitations and caveats. Primarily, the valuation is conducted based on areas of overlapping between EFH and fishing areas, and does not consider the transferability of economic value associated to the EFH in adjacent (non overlapping) fishing areas, due to fish movements and connectivity between habitats (see Section 3.4). Therefore, the estimates provided in the example are likely to be underestimates of the actual contribution of EFH to the regional commercial fishery.

In the example analysis, discrepancies were identified between the fishing gear used to characterise fishing effort data and those used for the fish landing data (due to different gear categories used in the two datasets), and so these calculations were modified according to the data to match the gear categories hence allow estimation of economic value of fisheries dependent on EFH. The fishing gear data available from the fishing effort data layers were used as proxy to estimate the probable fishing effort for the landing data. It is acknowledged that this method involves assumptions, i.e. that the gear types from both data sets yield a similar level of fishing effort. To decrease assumption, further data collation is needed. Subsequent results should be treated as estimations, which will require further study.

The MMO landing data used in this study only include landings in the UK. Therefore, the additional landings from the EFH that may be attributed to non-UK vessels are not accounted for. This means that the economic value of the landings from the EFH have most likely been undervalued, and further landings data from other sources is required to conduct a more accurate economic evaluation.

When considering the value of commercial fisheries in a specific area, shellfish are classically included as a key aspect of that fishery, and shellfish species have been identified as of important commercial value in the English Channel (MMO, 2012). Within the ICES rectangle study area used in the assessment here, over 30% of the total economic value earned from the fishery is specifically just from shellfish. However, shell fisheries have not been considered, as they were outside the scope of the current project. This is acknowledged as a potential gap in the report, and could be considered as a separate project at an appropriate scale using suitable data.

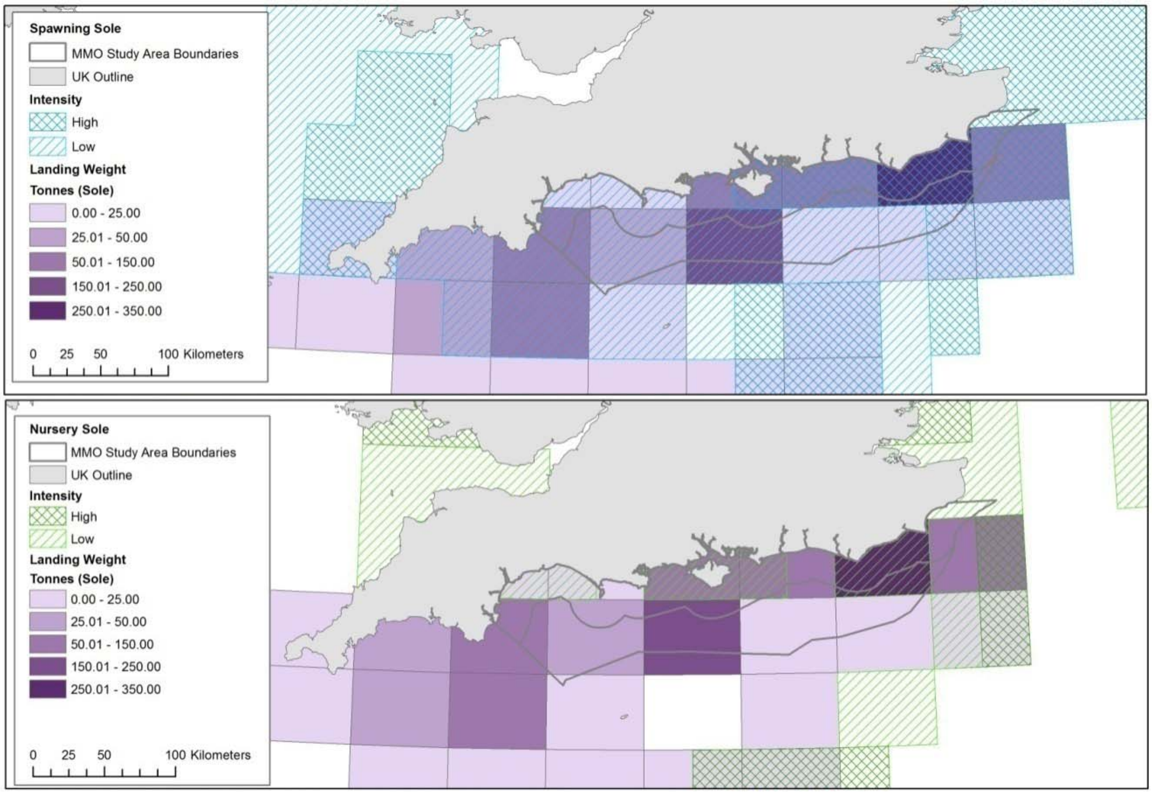
## 3.4 Transferability of EFH value

By providing the environment required by fish populations throughout different stages of the species life cycle, an EFH provides support to a sustainable fishery and reflect a healthy ecosystem. An important aspect that characterises the contribution of EFH to the fishery stocks is associated with their connectivity with adult habitats, i.e. the exchange of individuals among geographically separated sub-populations of marine organisms (Cowen *et al*., 2002). In fact, although EFH can be identified by particular environmental conditions reflecting the ecological requirements of a species life stage, hence showing a spatial distribution limited to where these conditions occur, the mobility of these life stages (e.g. through larval dispersal, or juvenile fish movements) determines the exchange of individuals with other areas where adult occur. This role of EFH as source habitats for adult populations is of particular importance to maintain viable stocks hence to contribute to the sustainability of their exploitation.

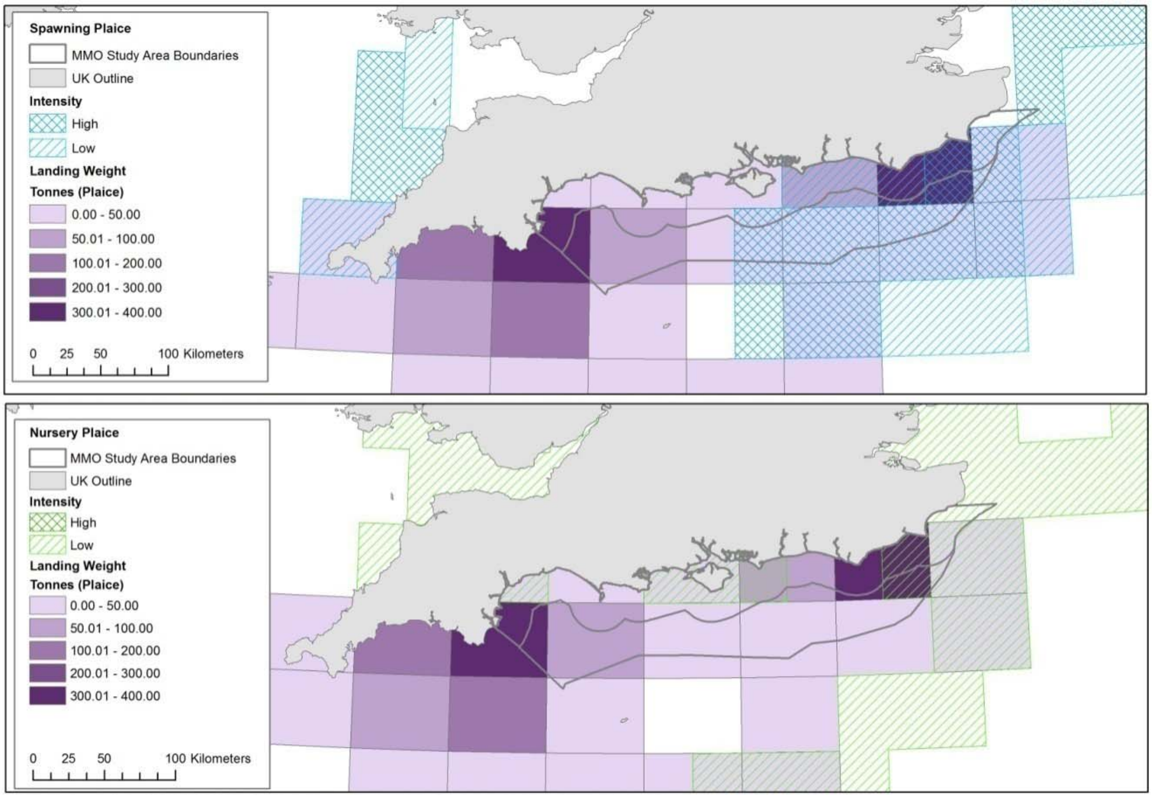
A mismatch can be observed between the distribution of EFH and the distribution of fishery catches in the marine area. An example is given in Figure 7 for sole and plaice, considering the distribution of broad scale nursery and spawning habitats of these species, as obtained from Ellis *et al*. 2012, and their mean landing weight, as calculated for each ICES rectangle over the period 2002-2011 using the MMO landing data used in the previous section. It is clear from this example how areas that are important as nursery or spawning grounds (e.g. in the Eastern English Channel) can be of minor importance when considering landing data and *vice versa*. Nevertheless, these EFH might contribute significantly to the catches in other areas by functioning as a source of new individuals that can move and recruit to adult stocks (sink sub-populations) in these areas, hence contributing to the fishery in there. For example, it is estimated that 87% of the Western Channel recruits to the plaice stock originate from outside of the area (i.e. North Sea and Eastern English Channel; MMO, 2012). Through this connectivity, the value of an EFH is therefore transferred to other areas, hence assessing the value of EFH by considering solely the area where these habitats occur, clearly leads to an undervaluation of the actual contribution of EFH to the regional fishery.

**Figure 7: Distribution of catches (landing weight, mean 2002-2011) of (A) sole and (B) plaice over their nursery and spawning habitats (distinguished by high and low intensity; Ellis *et al*., 2012). Landing data are shown only for the ICES rectangles within the Channel.**

(A)




(B)



Habitat connectivity should therefore be integrated in the economic valuation of EFH based on landings in order to link source EFH to sink sub-populations. In order to do this, spatial patterns of connectivity should be identified by using the available empirical research / evidence on the subject.

The patterns of connectivity among sub-populations of marine organisms are the result of the interaction between biological factors (e.g., life history characteristics, larval behaviour) and physical processes of advection and diffusion (Cowen *et al*., 2002). For example, vertically-stratified flows can interact with vertical migrations of the individuals in the water column, thus affecting the extent of larval dispersal from source spawning grounds. In addition, the quantitative contribution to sink sub-populations would depend also on the mortality larvae and juveniles are subject to along their transit, induced by starvation or predation, or by the encounter of unfavourable environmental conditions (Cowen *et al*., 2002).

Taking into account all these elements, the type of evidence that can be used to identify these spatial patterns includes the following:

- Pelagic duration of the larval dispersive stage coupled with predictive models of advection/diffusion of particles (passive or behaviourally active, if possible) accounting also for the hydrodynamic circulation in the area

- Genetic differentiation among sub-populations of marine fish

- Tagging studies

- Recruitment models (survival and/or mortality) to estimate the adult equivalent for eggs, larvae, and juvenile fish to that can be used in value assessment.

With particular regard to the fish species considered in this project, the available evidence that can inform the characterisation of connectivity between EFH in the study area (and between the study area and adjacent marine areas) is reported in Table 10.

**Table 10: Evidence and information on spatial connectivity of EFH for species included in this study.**

| Fish species | Evidence on spatial connectivity | Source |
|---|---|---|
| **Herring** | • **General information**<br>An exchange of juvenile herring from the Downs spawning areas in the Channel to extensive nursery grounds off the German and Danish coasts is suggested. 1-year old herring then move offshore to feed in the central North Sea, where these stocks are are exploited together. When maturity is reached (at 2-3 years of age), a seasonal (autumn) southerly migration to the Eastern Channel is reported. The Channel serves only as a breeding ground for the Downs herring stock when it migrates from the North Sea to spawn in autumn. | In Pawson *et al*., 1995; Dickey-Collas *et al*., 2010 |

| | | |
|---|---|---|
| | • **Transport models of Downs herring larvae**<br>A 10-layered, finite-volume advection-dispersion model with real-time meteorological and freshwater runoff drivers investigated the interannual differences in the transport of Downs herring larvae in the southern North Sea. Simulations were carried out for the winters of 1989 and 1996 to 2003. Meteorological forcing transport Downs herring larvae to the nursery grounds in the eastern North Sea with large interannual differences. Diel vertical movement is relatively unimportant in the transport of larvae in the hydrographically mixed southern North Sea.<br><br>• **Genetic evidence**<br>Genetic evidence generally indicates that Downs spawning herring are not reproductively isolated from other spawning groups.<br><br>• **Tagging studies**<br>Tagging studies suggest that the interchange between Central North Sea population (Bank herring) and Downs population is negligible. In autumn, the Downs-spawning herring migrate south and appear in the Channel during November. After spawning, spent Downs fish return to the central North Sea, where they feed during the summer. | Dickey-Collas *et al*., 2009<br><br>In Pawson *et al*., 1995<br><br>In Pawson *et al*., 1995 |
| **Plaice** | • **Hydrographic studies**<br>The spawning peak coincides with predominant easterly-moving current system, such that most of larvae produced in the Channel are carried with the currents to the North Sea. Data suggest that young-of-the-year plaice in the Easterscheldt were spawned in the Eastern Channel.<br>Plaice spawned in the Western English Channel most probably are retained within the system (due to weaker currents) and replenish the population in the region.<br><br>• **Tagging studies**<br>There is considerable interchange of individuals between the North Sea and Eastern Channel, whereas limited interchange of individuals occurs between Eastern and Western Channel (ICES divisions VIId and VIIe). Very limited exchange occurs between the Channel and the Celtic and Irish Seas.<br>It was estimated that:<br>• Eastern Channel nursery grounds supplied 34% of recruits in the Western Channel and 0.3% of recruits to the North Sea<br>• 38% of recruits to the Eastern Channel and 53% of recruits to the Western Channel came from the North Sea<br>• Approx. 20% of the adult plaice spawning in the Eastern Channel have migrated there from the Western Channel, but few adult plaice spawning in the Western Channel have been recaptured in the Eastern Channel<br>• 20–30% of the adult individuals caught in winter in the Eastern Channel originated from the North Sea<br>• Retention rate of spawning plaice tagged in the Eastern Channel is 28%, while 62% of spawning fish tagged were recaptured in the North Sea.<br><br>• **Eggs dispersion observations**<br>Plaice eggs may travel for several kilometres in a few days; a dispersion of up to 45km in 3 days of drift from spawning areas has been reported in the Southern Bight (with higher dispersion in | In Pawson *et al*., 1995<br><br>In Pawson *et al*., 1995; Kell *et al*., 2004; Burt *et al*., 2007 (Cefas 'Tagfish' database); MMO, 2012<br><br>Simpson, 1959 |

| | | |
|---|---|---|
| | stormy conditions) | |
| **Sole** | • **Larval movement**<br>There have been no studies of sole larval movement in the Channel but, on the basis of current movements, a proportion of larvae hatching in the Eastern Channel may move east and recruit to nurseries in the southern North Sea.<br><br>• **Tagging studies**<br>Sole undertake their most extensive migrations as maturing juveniles, whereas their movements appear to be relatively restricted once fully mature.<br>Some exchange of juveniles occurring during the recruitment period has been reported between the Eastern and Western Channel (where two distinct stocks are identified). Recaptures from eastern Channel releases suggested that there was a permanent emigration of up to 30% of 3- and 4-year old sole to the Western Channel and around 10% to the southern North Sea. There was no evidence of a significant immigration to the Eastern Channel by sole tagged in the southern North Sea or from the Western Channel, suggesting that sole nurseries in the Eastern Channel act as a source of recruitment also for stocks in adjacent regions. Juvenile sole may recruit into to the English coast of the Western Channel also from the French Coast.<br>Distribution of tag returns suggests that adult sole make short seasonal migrations between deeper offshore areas and the shallower spawning grounds, with a return movement in the autumn. It is unlikely that a significant proportion of adult sole migrate from the Channel to adjacent seas, because sole appear to continue to use the spawning ground to which they first recruit. Sole appear to move predominantly south through the Dover Strait in December, and it has been suggested that a proportion (~5%) of the population, which feeds and spawns in the southern North Sea, moves into the Eastern Channel for the winter. | In Pawson *et al*., 1995<br><br>In Pawson *et al*., 1995; Burt *et al*., 2007 (Cefas ‘Tagfish’ database); MMO, 2012 |
| **Lemon Sole** | • **Tagging studies in Western Channel**<br>Over a thousand ripe, running and spent lemon sole were tagged off south Devon during April and May 1970. By the end of 1972, only 4 fish had been recaptured away from the tagging area; 3 in the Celtic Sea and caught within one year of release; and one from the Eastern Channel in the second quarter of 1972. All recaptures of lemon sole in 1973 and 1974 were from or adjacent to the release area.<br>The returns from these tagging experiments suggest that most adult lemon sole remain in the western Channel throughout the year and undertake no extensive migration. | In Pawson *et al*., 1995; Burt *et al*., 2007; |
| **Thornback ray** | • **Tagging studies in Western and Eastern Channel**<br>A total of 614 thornback rays, mostly juveniles, were tagged and released in 1930-1935 off Plymouth in the western Channel; 203 recaptures were reported within 4 years of release. Juvenile rays tended to remain on the same grounds throughout the year. One individual was recaptured on the same grounds on six occasions in a period of 14 months. Thornback rays which were becoming mature appeared to range more widely than juveniles, but no rays were recaptured more than 50 nautical miles from the release position.<br>Returns from the releases of 237 juvenile thornback rays in the eastern Channel, during spring and summer 1975, produced few recaptures from areas which were not adjacent to the tagging site. The results suggest that immature thornback rays do not make extensive migrations. Insufficient numbers of adults have been tagged to determine the extent of their movements. | In Pawson *et al*., 1995; Burt *et al*., 2007 (Cefas ‘Tagfish’ database) |

Most of the above information highlights the relevance of accounting for the connectivity between EFH and fishing grounds within the study area and with areas outside it (particularly the southern North Sea) when valuing these ecologically-important habitats.

To be able to integrate this information into economic evaluation of EFH, quantitative estimates of connectivity are needed that characterise not only the additional input into regional fisheries (e.g., percentage contribution of recruits from other areas into fishing stocks), but that quantify also the output (in terms of fish recruits) from source EFH. With this regard, it is acknowledged the limitation of the current EFH models, in that a quantitative characterisation of EFH is needed for this purpose. Identifying EFH based on abundance catch data (e.g. fish density), in fact, would allow to quantify the importance of the source spawning, nursery or adult foraging habitat, in terms of the amount of fish eggs/larvae, juveniles or adults, respectively, that could potentially contribute to the fisheries in adjacent areas. The link between the contribution of EFH in terms of number of individuals at early stage that eventually recruit to adult stocks in other areas and the resulting gain to fishery in these areas can be established by calculating the equivalent adult value (with the method defined in Turpenny, 1988). This method uses life history information obtained from the scientific literature for individual species of fish to estimate the equivalent number of adult fishes that would be added to the population (adult equivalent curves for herring, sole, plaice, dab, cod and whiting are given in Turpenny, 1988).

Although Table 10 reports on the main evidence of fish movements (hence connectivity) for species that were considered in this project for EFH assessment, tagging studies have been conducted in the Channel area also for other species like cod, whiting, sea bass, mackerel, spurdog (Pawson *et al*., 1995; Burt *et al*., 2007). In turn, little or no tagging data are available on movements/migrations in this area of other species like dab, anglerfish, red gurnard, pollack (Pawson *et al*., 1995; Burt *et al*., 2007).

## 3.5 Recommendations

The key issues that should be taken into consideration when conducting an economic valuation of EFH are as follows:

Correct identification of the ecosystem services and goods/benefits associated with the EFH in consideration, in order to understand the connections between the services and goods/benefits in association with a working framework. This ensures accurate valuation, minimising double counting. The EUNIS habitat classification and the framework provided by Potts *et al*. (2013) has been used as the key to apply ecosystems services to EFH, although some limitations have been highlighted, mostly related to the need for further research to improve the quality and availability of data on ecosystem services associated with marine habitats.

Application of a confidence limit to the valuation technique applied to EFH and their contribution to fishery. Although this was not conducted in the present study, as it was primarily presented as an example of methodology use, the economic valuation of EFH needs to be improved by attaching a confidence value. It is of note that, although no spatial confidence was estimated for the fishing effort data used in the valuation example, a confidence layer was associated to boarding data on fishing effort (from IFCAs), hence this confidence could also be taken into account if applying the valuation method to these latter data layers (in this case landing data for 2007 to 2009 should only be considered for comparability with effort data). In addition, confidence estimate should take also the temporal (inter-annual) variability in fish movement and subsequently landings and effort. In order to do so, the valuation approach could be applied separately to data for each year, and the mean monetary value could be calculated from the results, with an associated estimate of variability (e.g., coefficient of variation) attached to the mean value.

Increase data sets to include non-UK and larger vessels, as well as data regarding shell-fisheries, in order to broaden the applicability of the method and gain a more accurate economic value. Although the addition of data on shell-fisheries was not included in this analysis as it was outside the current scope of this study, shell-fisheries are recognised as an intrinsic part of a dynamic marine ecosystem, and contribute economically to the commercial fishery in the current study area. It is recommended that a project based on the ecological and economic valuation of shellfish in the current study area be considered, in order to create a more holistic valuation representation of the area.

Integrate connectivity between EFH and fishing grounds. It is suggested that a quantitative review of the available data that could be used to estimate connectivity is carried out and that quantitative data are extracted that, integrated into the described economic valuation approach, would allow a more accurate assessment of the economic value of EFH. Further research (e.g. tagging studies) would also allow filling the gaps in the knowledge of the extent and importance of movements of certain fish species in the study area and elsewhere (as highlighted also by the above mentioned review).

## 4. References

Atkins, J.P., Burdon, D., Elliott, M., Gregory, A. (2011). Management of the marine environment: integrating ecosystem services and societal benefits with the DPSIR framework in a systems approach. *Marine Pollution Bulletin*, 62: 215- 226.

Aubry, A., Elliott, M. (2006). The use of environmental integrative indicators to assess seabed disturbance in estuaries and coasts: Application to the Humber Estuary, UK. *Marine Pollution Bulletin*, 53: 175- 185.

Beaumont, N.J., Austen, M.C., Atkins, J.P., Burdon, D., Degraer, S., Dentinho, T.P., Derous, S., Holm, P., Horton, T., van Ierland, E., Marboe, A.H., Starkey, D.J., Townsend, M., Zarzycki, T. (2007). Identification, definition and quantification of goods and services provided by marine biodiversity: implications for the ecosystem approach. *Marine Pollution Bulletin*, 54: 253-265.

Birol, E., Karousakis, K., Koundouri, P. (2006). Using economic valuation techniques to inform water resources management: A survey and critical appraisal of available techniques and an application. Science of the Total Environment, 365: 105–122

Bockstael N., Costanza R., Strand I., Boynton W., Bell K., Wainger L. (1995). Ecological economic modeling and valuation of ecosystems. Ecol. Econ., 14: 143-159.

Boyd, J., Banzhaf, S. (2007). What are ecosystem services? *Ecological economics*. 63: 616- 626.

Burt, G., Goldsmith, D., and Armstrong, M. (2007). Science Series Technical Report No 135, A summary of demersal fish tagging data maintained and published by Cefas Cefas Lowestoft, 135: 40pp. Available online at http://www.cefas.defra.gov.uk/publications/techrep/tech135.pdf

Connor D.W., Breen J., Champion A., Gilliland P. M., Huggett D., Johnston C., Laffoley D. d'A., Lieberknecht L., Lumb C., Ramsay K., Shardlow M. (2002). Rationale and criteria for the identification of nationally important marine nature conservation features and areas in the UK. Version 02.11, Peterborough, JNCC (on behalf of the statutory nature conservation agencies and Wildlife and Countryside Link) for the Defra Working Group on the Review of Marine Nature Conservation.

Cooper, K., Burdon, D., Atkind, J.p., Weiss, L., Somerfield, P., Elliott, M., Turner, K., Ware, S., Vivian, C. (2013). Can the benefits of physical seabed restoration justify the costs? An assessment of a disused aggregate extraction site off the Thames Estuary, UK. *Marine Pollution Bulletin*. IN PRESS

De Groot R. S., Wilson M.A., Boumans R.M. J. (2002). A typology for the classification, description and valuation of ecosystem functions, goods and services. Ecol. Econ., 41: 393-408.

Derous S., T. Agardy, H. Hillewaert, K. Hostens, G. Jamieson, L. Lieberknecht, J. Mees, I. Moulaert, S. Olenin, D. Paelinckx, M. Rabaut, E. Rachor, J. Roff, E.W.M.

Stienen, J.T. van der Wal, V. Van Lancker, E. Verfaillie, M. Vincx, J.M. Weslawski and S. Degraer. (2007). A concept for biological valuation in the marine environment. Oceanologia, 49: 99-128.

Dickey-Collas, M., Bolle, L. J., van Beek, J. K. L., Erftemeijer, P. L. A. (2009). Variability in transport of fish eggs and larvae. II. The effects of hydrodynamics on the transport of Downs herring larvae. Marine Ecology Progress Series, 390: 183–194.

Dickey-Collas, M., Nash, R. D. M., Brunel, T., van Damme, C. J. G., Marshall, C. T., Payne, M. R., Corten, A., Geffen, A. J., Peck, M. A., Hatfield, E. M. C., Hintzen, N. T., Enberg, K., Kell, L. T., and Simmonds, E. J. (2010). Lessons learned from stock collapse and recovery of North Sea herring: a review. – ICES Journal of Marine Science, 67: 1875–1886.

Edwards P. J., Abivardi C. (1998). The value of biodiversity: where ecology and economy blend. Biol. Conserv., 83: 239‑246.

Farnsworth, E.J. (1998). Issues of spatial, taxonomic and temporal scale in delineating links between mangrove diversity and ecosystem function. *Global Ecology and Biogeography Letters,* 7*:* 15–25*.*

Fisher, B., Turner, R.K. (2008). Ecosystem services: classification for valuation. *Biological conservation*, 141: 1167- 1169.

Fu, B-J., Su, C-H., Wei, Y-P., Willet, I.R., Lu, Y-H, Liu, G-H. (2011). Double counting in ecosystem services valuation: causes and countermeasures. *Ecological research*, 26: 1-14.

Kell, L.T., Scott, R., Hunter, E. (2004). Implications for current management advice for North Sea plaice: Part I. Migration between the North Sea and English Channel Journal of Sea Research, 51: 287-299.

King O.H. (1995). Estimating the value of marine resources: a marine recreation case, Ocean Coast. Manage., 27: 129‑141.

Millennium Ecosystem Assessment (2005). Ecosystems and human well-being: wetlands and water. World Resources Institute, Washington DC, Island Press.

MMO (2012). Evaluating the distribution, trends and value of inshore and offshore fisheries in England. A report produced for the Marine Management Organisation. pp761. MMO Project No: 1011. ISBN: 978-1-909452-04-6.

Morse-Jones, S., Luisetti, T., Turner, R.K., Fisher, B. (2011). Ecosystem valuation: some principles and a partial application. *Environmetrics*: 5: 675- 685.

Myers N., Mittermeier R.A., Mittermeier C.G., da Fonseca G.A. B., Kent J. (2000). Biodiversity hotspots for conservation priorities. Nature, 403 (6772), 853–858.

Nunes P.A. L.D., van den Bergh J.C. J.M. (2001). Economic valuation of biodiversity: sense or nonsense? Ecol. Econ., 39: 203‑222.

Potts, T., Burdon, D., Jackson, E., Atkins, J., Saunders, J., Hastings, E., Langmead, O. (2013). Do marine protected areas deliver flows of ecosystem services to support human welfare? Marine Policy. Available online 22 August 2013. http://dx.doi.org/10.1016/j.marpol.2013.08.011

Roff J.C., Evans S. (2002). Frameworks for marine conservation – non-hierarchical approaches and distinctive areas, Aquat. Conserv., 12: 635–648.

Simberloff D. (1998). Flagships, umbrellas, and keystones: is single-species management pass´e in the landscape era?, Biol. Conserv., 83: 247–257.

Simpson (1959). The spawning of the plaice (Pleuronectes platessa) in the North Sea. Fishery Invest., Lond., Vol. 22 (No. 7) (1959), p. 111 Ser. 2

TEEB (2010). The economics of ecosystems and biodiversity: mainstreaming the economics of nature: a synthesis of the approach, conclusions and recommendations of TEEB. (The Economics of Ecosystems and Biodiversity study)

Turner, R. K., Morse-Jones, S., Fisher, B. (2010). Ecosystem valuation. *Annals of the New York Academy of Sciences*, 1185: 79–101

Turnpenny, A.W.H. (1988). Fish impingement at estuarine power stations and its significance to commercial fishing. Journal of Fish Biology, 33 (Supplement sA): 103–110.

Turpie J. K., Heydenrych B. J., Lamberth S. J. (2003). Economic value of terrestrial and marine biodiversity in the Cape Floristic Region: implications for defining effective and socially optimal conservation strategies. Biol. Conserv., 112: 233‑251.