Article

Mapping Ecosystem Services for Marine Planning: A UK Case Study

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Abstract: This study presents an ecosystem-services-mapping tool that calculates the monetary value of several ecosystem services (ES) provided from an area comprising both MPAs (Marine Protected Areas) and non-managed areas. Findings in the UK South West Marine Management Organisation (MMO) Plan Area show that different MPAs yield high value estimates and that activities are grouped in certain areas, with the Severn Estuary and surrounding Site(s) of Special Scientific Interest (SSSI) attracting the most recreational anglers, despite having lower water quality. This can be explained by increased nutrient levels, which enhance biological activity and yet do not cause oxygen depletion. The yearly value of the ecosystem service of carbon sequestration and storage in the area is estimated between £16 and £62 thousand. Proximity to large urban areas and shallow waters appear to be the most appealing factors for anglers, while proximity with France can be associated with the high fishing effort in the southwest of the study area. We show that the use of a tool integrating a willingness-to-pay function with high spatial resolution layers and associated monetary values can be used for short-term marine spatial planning and management.

Keywords: ecosystem services mapping; value transfer; GIS tool; decision-making tool; carbon sequestration; fishing effort; South West of England

1. Introduction

There has been considerable scientific and policy interest in ecosystem services assessment and valuation since the publication of the Millennium Ecosystem Assessment (MEA, [1]). Economic valuation seeks to quantify the ways in which ecosystem services provide benefits to humans and expresses these values in monetary units that can be compared with other sources of value to society [2]. Growing literature has been devoted to the valuation of marine resources and ecosystems, both in terms of use and non-use values. More recently, a focus on the geographic representation of such monetary values has emerged to serve the purposes of European Union's (EU) policies such as the Biodiversity Strategy 2020 or by the development of ecosystem services-mapping models such as InVEST (https://naturalcapitalproject.stanford.edu/) and ARIES (http://aries.integratedmodelling.org/). International networking initiatives such as the Ecosystem Services Partnership (ESP) or the Intergovernmental Science-Platform on Biodiversity and Ecosystem Services (IPBES) assist this research focus and aim to bring together research from scientists working on the impact and quality of different ecosystem services. The end-purpose of such ecosystem service mapping efforts is to estimate the economic value of different ecosystem services [3]. Such endeavours are also meant to inform Natural Capital accounts in the UK, in an attempt to combine environmental and monetary indicators for different ecosystem "assets" [4]. Assigning economic values to components of an ecosystem is difficult due to

complex interactions between natural environment and humans. This can be attributed to lack of data underpinning marine ecosystem services, leading to the use of coarse estimates to fill gaps in areas lacking spatially-explicit information. This frequently leads to locational uncertainty of marine and coastal areas that provide ecosystem services and welfare benefits ([5], pp. 114–115). Survey data are rarely collected over the spatial extent of interest, scale is often inconsistent across different features and, while local data (e.g., on valuation of recreational services) can be rich, it may not be possible to scale these up to match natural features. Consequently, the development of maps for services provided by the marine and coastal ecosystems has frequently been overlooked or even avoided.

The geographic approach to the distribution of benefits and value in marine and coastal environments is integral to the identification of hotspots where a combination of uses (e.g., recreational, fisheries etc.) shows high economic benefits. The accumulation of such benefits, e.g., within an MPA, can inform decision-makers both on the value of a specific MPA and on the most desirable and profitable attributes of it, as well as how to manage the benefits provided, minimising the risk of overexploitation. Additionally, there is growing demand for energy production in inshore areas, with plans to create lagoons to harness the power of tidal energy. High tourist visitation rates, combined with high fishing activity, planned energy production, and MPA designations makes the Southwest an ideal case study area for mapping ecosystem services flows and use. By revealing the potential for various trade-offs in the area, it is possible to aid marine planning and decision-making.

In our study, economic approaches are combined with biophysical and fisheries data to map ecosystem services in the MMO-designated inshore and offshore Marine Plan Area in the southwest of England. In particular, the MMO South West Marine Plan Area was chosen for this study as it is still under development, thus there exists the potential for the analysis to benefit policy and resource management. Our aim was to scope out current data availability on fisheries and biophysical variables, along with the various species and habitat management measures in place in the area, and to use them to identify the aggregation and distribution of economic values across MPAs in the inshore and offshore South West area.

2. Literature Review

Important pieces of policy work, such as the EU Biodiversity Strategy to 2020 [3], stress the need for both biophysical mapping and valuation of ecosystem services to be undertaken. Action 5 of the Biodiversity Strategy required the mapping and assessment of ecosystem services in biophysical terms (by 2014), and in economic terms, so that the resulting values can be integrated into national accounting systems (by 2020) for each European Union Member State [6]. In a recent paper, Grêt-Regamey et al. [7] reviewed 68 ecosystem services-based tools and listed them according to their functions. According to Grêt-Regamey et al., models such as ARIES and InVEST allow for multiple approaches to decision-making, e.g., driven by conservation, cost-effectiveness, maximising ES benefits, etc. Such models, launched in recent years, have been developed for several mapping initiatives targeting ecosystem services at the global (e.g., Ecosystem Services Partnership (http://www.es-partnership.org)), regional (e.g., in China, [8]), and cross-regional level (e.g., in Vietnam, [9]). Ecosystem services assessments also underpinned mapping efforts, such as the National Ecosystem Assessment follow-on in the UK (UKNEA) in 2014 [10].

Although there is a plethora of terrestrial studies on mapping physical aspects of the natural environment, either at the global or the national (UK) level, spatial representations of ecosystem service assessments and related values in the marine environment have only recently started to increase. A recent example of a large-scale study in the marine environment is the Natural Capital/InVEST project ([11,12]) and its various applications worldwide (e.g., UK and Belize), while a regional example is the STELLA model application in the Kenting coastal zone in Taiwan [13].

Verutes and Rosenthal [12] used the InVEST model to assess potential revenues from the final ecosystem services of fish catches, and revenues from coastal tourism, as well as the avoided costs provided by coastal protection in Belize. The study included stakeholder engagement to support

trade-off decisions between the extent and the revenues provided by the different ecosystem services mapped along the coast. The InVEST model uses information on the extent and quality of different ecosystem services in the area, and values are assigned based on estimates provided by the literature.

Other examples of studies that use decision-support tools include Adame et al. [14], where the cost of restoration for mangroves in a lagoon in Mexico is used as a proxy for the economic costs for changes in ecosystem services provided by mangroves incorporated in the MARXAN tool, while Plantier-Santos et al. [15] present the Web-based tool of GecoServ to value and account for different ecosystem services in the Gulf of Mexico, using economic estimates from the literature for different ecosystem services. Chang et al. [13] use a system dynamic model, built as a decision support system to facilitate integrated coastal zone management in Taiwan. The system dynamic STELLA model allowed for the creation of four subsystems (socio-economic, environmental, biological, and management) to facilitate decision-making for the provision and quality of ecosystem services such as reef fish and clean waters. Focusing on ecosystem services provided by coral reefs, estimated to be the most economically valuable in the US Virgin Islands, Yee et al. [16] attempt to link biophysical attributes of reefs with provisioning of ecosystem services to assess how their economic values are impacted.

A wide range of economic valuation methods have been used to place monetary values on selected marine or coastal areas. These include: i) stated preferences methods such as the contingent valuation methods (CVM) [17] and choice experiments (CE) ([18,19]); and ii) revealed preference (RP) methods such as the travel cost method (TCM) ([20–22]) and hedonic pricing ([23,24]).

In the UK, a growing number of economic valuation studies have focused on the marine and coastal environment. The UKNEA-FO [10] records 25 primary valuation studies published up to May 2013. For example, Ruiz-Frau et al. [25] reported a total annual expenditure for non-extractive uses of marine biodiversity in Wales (excluding recreational angling, commercial fishing and aggregate extraction, but including diving, kayaking, wildlife viewing, and seabird watching) between £21.8 and £33 million in 2008, a figure found to be slightly higher than the total fisheries landing value in the country in 2003.

Few studies were conducted in the southwest of England to estimate values for sea angling and/or diving experience. Using the CVM, Lawrence [26] found that the southwest angling population fished for approximately 14 days per year, and that their WTP varied mainly according to exploitation of different species. At low catch levels, the number of fish caught was particularly important to anglers, but this importance declined with increasing catch numbers. Rees et al. [27] estimated the aggregated value of all sea angling activities in Lyme Bay in southwest England to be £13.7 million per year. They also highlighted the nature of sea angling as a diverse activity, well-spread across various income levels, making it difficult to describe preferences of the average angler. For example, anglers who travelled long distances were usually wealthy and enjoyed the marine and costal environment through boat angling, while local anglers (living by the seaside) had varying expenditures and enjoyed angling from piers. Rees et al. also identified specific sites that were more appealing to visitors and attributed specific expenditure and business turnover to these sites. Similarly, Chae et al. [28] used the TCM to estimate recreational benefits from the Lundy Marine Conservation Zone (MCZ). They found that recreational benefits from visiting the Lundy MCZ varied from £359 to £574 per trip for different visitors. Additionally, respondents in the survey were willing to travel more times within a year to visit the MCZ, with their total WTP for extra trips in the range of £144 to £212 per group of visitors, depending on measure of travel cost used. The use of revealed (TCM) and stated (CVM and CE) methods has allowed for capturing some but not all economic values. All methods though have difficulties disentangling use from non-use estimates and especially cultural values, which refer to sets of beliefs and norms respondents have. Although such values are considered to be a large component of the total economic value of the environment, and especially in the coastal and marine environment (e.g., [29]), their elusiveness makes them not suitable for the present analysis.

As the literature has been producing tools that either focus on the existence and use of biophysical data or on depicting economic values in a spatial format, a tool in an open-source programming

language that can incorporate both is missing, for the marine environment. An attempt to link biophysical data on coastal and marine ecosystems and ecosystem services with their related economic values (both market and non-market) for ecosystem services in a mapping environment is presented in the next section.

3. Methods

3.1. Study Area

Given the mixture of recreational commercial activities taking place in the South West of the UK and the existence of several areas of pristine beauty and ecological importance, this study used the MMO's South West Inshore and Offshore Marine Plan Area MPAs as a case study (Figure 1). The UK is divided into marine planning regions with the MMO as the plan authority who prepares the marine plans for each area. A marine plan also provides guidance on activities to promote or avoid for some locations, highlighting trade-offs between activities and resource use. According to the MMO, 10 marine plan areas in the UK have been demarcated for a long-term (20 years) marine plan with a review of activities every three years. According to the MMO, a marine plan: i) sets out priorities and directions for future development within the plan area; ii) informs sustainable use of marine resources; and iii) helps marine users understand the best locations for their activities, including where new developments may be appropriate.
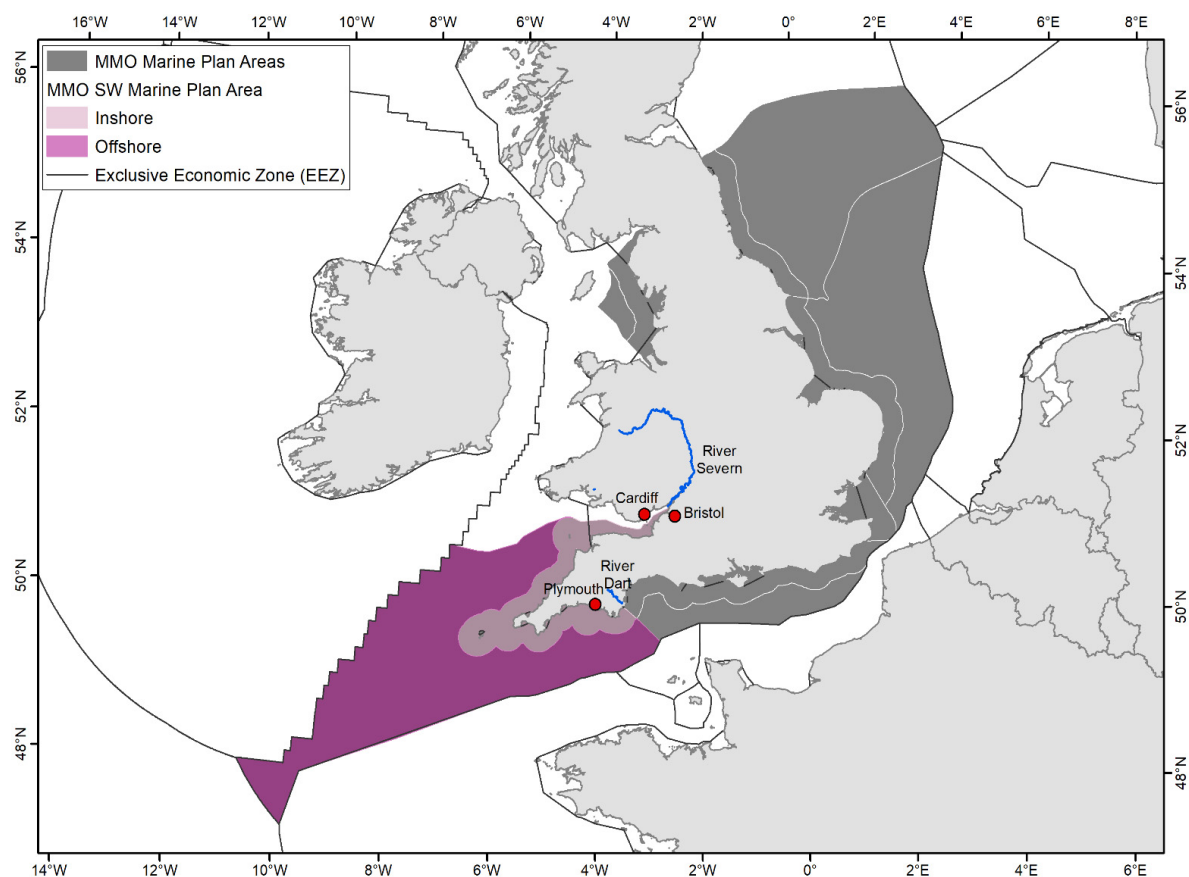
Figure 1. Location of the South West Inshore and Offshore Marine Plan Area forming the case study area.

The South West inshore area covers approximately 2000 km of coastline stretching from the River Severn at the Welsh border to the mouth of the River Dart in Devon, covering 16,000 km^2 of sea. According to the MMO [30], the South West Offshore area extends from 12 nautical miles off the coast to the seaward limit of the exclusive economic zone (EEZ), a total of approximately 68,000 km^2 of sea.

There are three large population centres within the vicinity of the designated south west plan area: Plymouth, Bristol, and Gloucester. The plan area is diverse in terms of marine and coastal ecosystems, boasting important saltmarshes, mudflats and deep-sea habitats. The coastline is the most exposed of all of England's coastlines and the area includes 27 Natura 2000 sites and 33 proposed or designated MCZs. There are two national parks and eight areas of outstanding natural beauty. Recreational activities such as surfing, boating, yachting, recreational sports fishing, sailing, racing, scuba diving, and fishing take place within the designated area. Other activities include aggregate extraction over a 7 km^2 (in 2011) area, along with tidal stream and tidal lagoon agreements for proposed energy generation. Whales, basking sharks, and bird life present some of the main tourist attractions. The area also has 9 Special Areas of Conservation (SACs), 3 Special Protected Areas (SPAs), 2 Ramsar sites, 118 SSSIs, and 19 designated and proposed MCZs. In addition, the area has various heritage assets, including 13 wrecks and World Heritage Sites. Finally, the Southwest is characterised by numerous beaches, with good or excellent status recorded in 91% of its 126 bathing sites. Ten of these beaches are designated as "blue flag" beaches. The South West areas also host fish nurseries for salmon and other migratory fish, especially in the Severn Estuary. For a list of all areas with some type of protected status considered in this analysis, see Table 1.

3.2. Data Layers

Data sets on the distribution of ecosystem services and biodiversity in the case study area were collated and used to generate maps showing the distribution of ecosystem services and of some elements of economic value. Overall, seven different data layers were used for this case study (Table 1). These include MCZs/SSSI, recreational use by sea anglers, UK 2000 seabird nesting sites, protected wrecks, saltmarshes, fishing activity data, and bio-chemical (Figure 2). Data used here are presented in sequence based on their quality. Biophysical data are considered to be of the highest quality given their sources, while the economic ones, as they are based on secondary data, are given higher uncertainty.

Publicly-available data on designated or proposed MCZ and SSSI areas were obtained through the UK Government website (Table 1). These data are generally published by government departments and agencies, public bodies, and local authorities.

Table 1. Available input layers in South West MMO.

Layer Name	Date	Description	Source
MCZ	2016	Polygon layers	Defra (https://data.gov.uk/)
SSSI	2016	Polygon layers	Defra (https://data.gov.uk/)
Sea anglers	2012	Sea anglers survey	Armstrong and Hyder [30]
Seabird nesting sites	2010	Point layer	JNCC (http://magic.defra.gov.uk/)
Protected wrecks	2015	Point and polygon layers	Historic England https://historicengland.org.uk/listing/what-is-designation/protected-wreck-sites/
Saltmarsh	2014	Polygon layer	Environment Agency: https://data.gov.uk/dataset/saltmarsh-extents1
VMS data and landings	2013	Polygon layer	CEDER database (hosted at Cefas, data owner MMO- IFISH database)
Biochemical layers (volume beam attenuation coefficient of radiative flux in sea water; mole concentration of dissolved oxygen in sea water; mole concentration of nitrate in sea water; mole concentration of phosphate in sea water; net primary productivity of carbon; concentration of chlorophyll in sea water)	2003–2013	Point layer	Model output from MyOcean http://www.copernicus.eu/projects/myocean
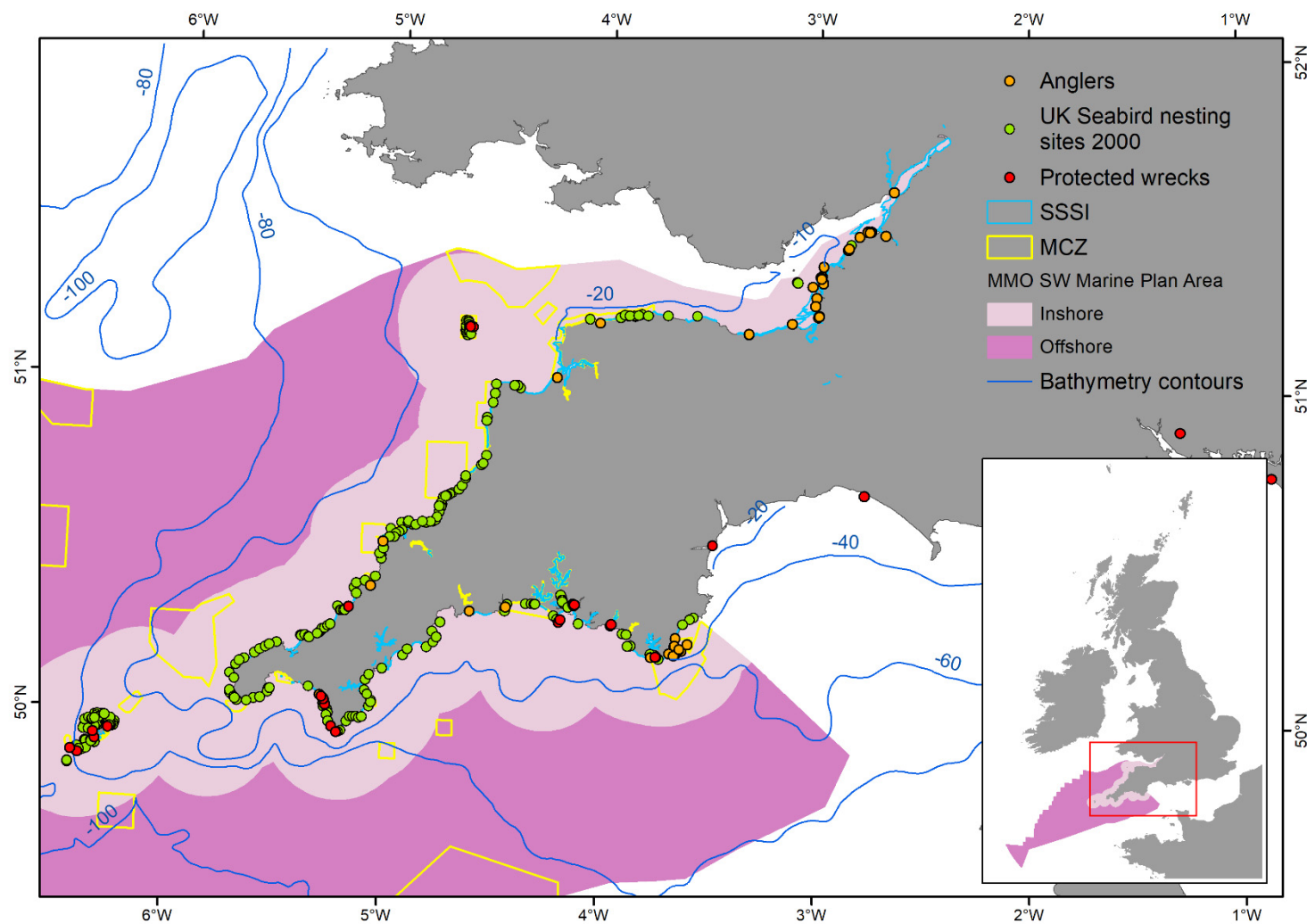
Figure 2. Spatial distribution of the GIS input layers in the SW Marine Plan Area.

The tourism layer consists of sea angling survey data conducted in 2012 by Armstrong and Hyder [30] (Table 1). The sea angling 2012 survey was conducted to explore how many people go sea angling in England, how much they catch, how much is released, and the economic and social value of sea angling [30]. The data includes information on: i) the demographics and activity of those participating in recreational sea angling, as well as visitation rates across Great Britain; ii) estimates of the total catches of the angling charter boat fleet in England, and shore or private boat anglers; and iii) the economic value and social benefits of sea angling in England.

The seabird nesting sites' 2000 data layer contains a census of the entire breeding seabird population of Britain and Ireland and was obtained from the Joint Nature Conservation Centre (JNCC) (Table 1). These data were collected by counting over 8 million breeding seabirds at 3300 coastal colonies, distributed along 40,000 km of the British and Irish coastlines.

The protected wrecks data layer, obtained from Historic England (Table 1), gives the number of wrecks protected under the Protection of Wrecks Act 1973, that are likely to contain the remains of a vessel or its contents, which are of historical, artistic, or archaeological importance.

The saltmarsh data (based on Cefas data) layer provides the extent of saltmarsh in coastal and transitional waters used in flood and coastal risk management and protected under implementation of the Water Framework Directive. The data were interpreted from 10 cm × 10 cm digital aerial imagery. The demarcation of the landward extent is the point at which the uppermost zones give way to terrestrial plants (often at the foot of a seawall). This mark indicates where saltmarsh plants become ≤5% of the predominantly terrestrial community. At the seaward end of the transect, the final demarcation occurs where the saltmarsh vegetation cover has become so sparse that it only attains 5% coverage.

The fishing data layer included landings from UK demersal fishing for 2013, extracted from the fishing activity database (IFISH) (Table 1), which contains details of all UK and non-UK registered fishing vessels landing into the UK. The data include weights and values of landings, ports landed, and gear types used. The fishing activity data layer also included satellite vessel monitoring system (VMS) data for vessels >12 m length, from which information on vessel position and activity could be derived from Jennings and Lee [31]. Fish landings were reported at the ICES rectangle level and VMS data, aggregated per fishing gear type, were processed at a spatial resolution of 0.05 decimal degrees to provide information on the number of hours fished. The VMS data were filtered using criteria where vessel speeds between 1 and 6 knots denoted fishing and vessels located in port were excluded from fishing activity [32].

The biochemical layers included data on: i) volume beam attenuation coefficient of radiative flux in sea water; ii) mole concentration of dissolved oxygen in sea water; iii) mole concentration of nitrate in sea water; iv) mole concentration of phosphate in sea water; v) net primary productivity; and vi) concentration of chlorophyll in sea water. These data are modelled outputs available from MyOcean (Table 1).

3.3. Mapping

To create the value maps, GIS analysis was performed using ArcMap 10.1, integrating biophysical, social, and economic data, summarised in Figure 3. This method was automated in Python 2.7, creating a script toolbox. To avoid double-counting of WTP per location, SSSIs and MCZs were merged, since most of them share the same spatial location. RAMSAR sites and SACs were identical to the SSSIs, hence excluded from the MPA layer. A buffer of 500 m was created around the MPA layer to rule out possible exclusion of sites that may have been visited by sea anglers arising from positional errors. Dummy variables were used to account for their categorical nature as follows: age (6 groups), distance travelled (10 mile intervals), and MPA surface area (log scale). VMS data and fish landings (kg; value - GBP) were aggregated into two groups: a) pelagic and demersal; and b) crustaceans and molluscs.
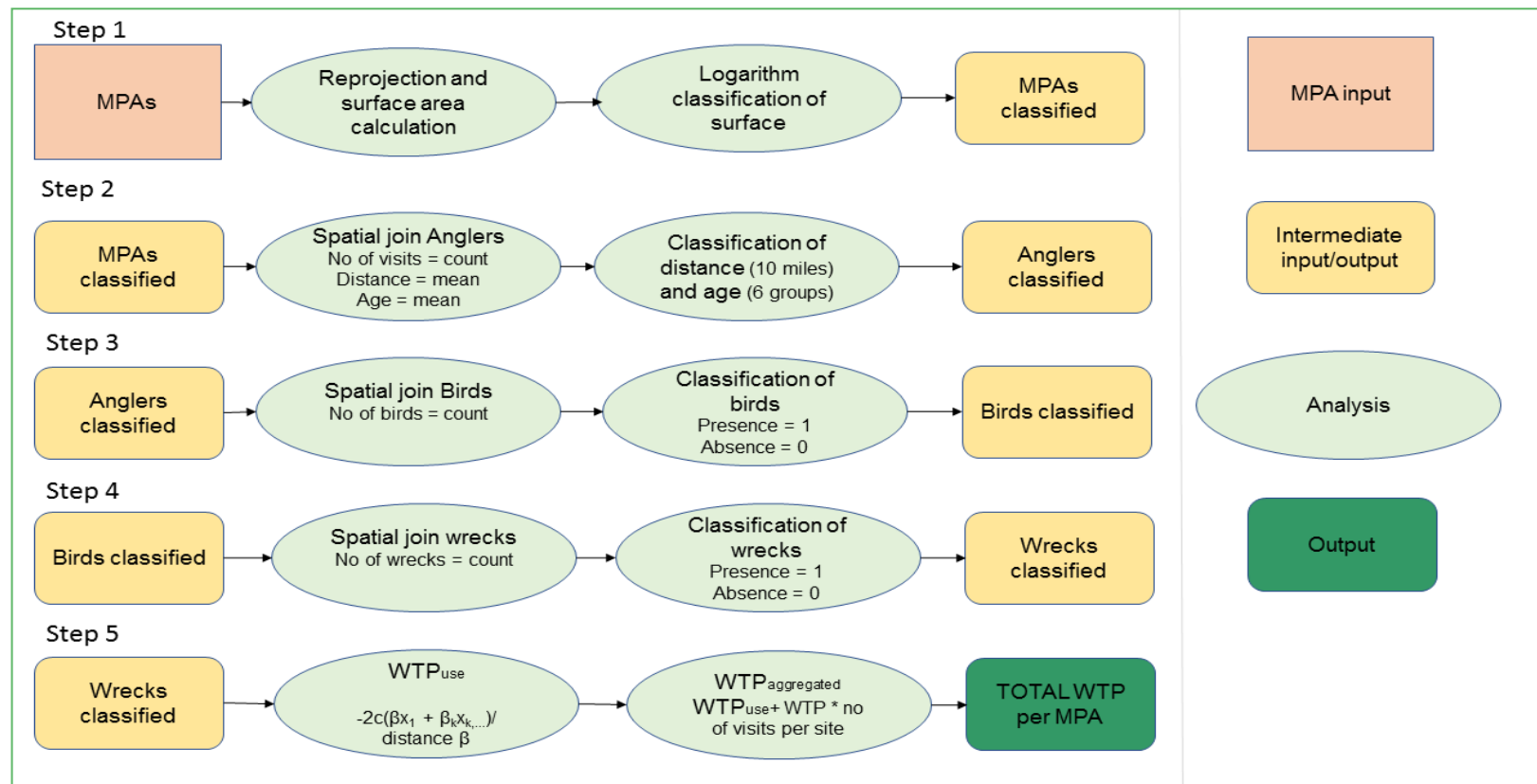
Figure 3. Schematic of GIS methodology, beginning with identifying the geographical location, the input/outputs used, the estimation and measurement of value and the output of the model.

Average, minimum, maximum, and standard deviation values of the biochemical parameters were calculated at the spatial extent of the MPAs. This statistical method was chosen over surface interpolation to avoid data alteration. The focus of the water quality assessment was on those MPAs where WTP could be calculated, thereby facilitating economic and environmental evaluation of the MPAs where data exist. Water quality was assessed using the criteria from the National Report on Eutrophication [33] for chlorophyll-a and dissolved oxygen. Nitrogen phosphate ratio of 16:1 was used from Ekholm [34] to assess water nutrient content. Unique values of light attenuation and net primary productivity per MPA are reported.

4. Economic Estimates for Ecosystem Services

4.1. Carbon Sequestration and Storage

We focus on both the amount of carbon that is captured (sequestered per year) by saltmarshes in the South West MPAs and in their net storage (saltmarsh sediments release some carbon back to the water column and the atmosphere). This way we estimated the value of the flow of carbon (how much carbon per year is sequestered and stored). To do so, we used monetary values that represent either the cost of an extra ton of CO_2 emitted (social cost of carbon) or the cost of policies required to mitigate the damages from the emission of an extra ton of CO_2 (abatement cost). To calculate the benefits from the carbon sequestration and storage provided by saltmarshes in the study area, we use three different estimates for the value of carbon sequestration, accounting for the variability and uncertainty for these estimates in the literature. For the Social Cost of Carbon (SCC), we use the mean estimate of the studies reviewed in Tol [35] and the 2015 value from Nordhaus [36] as the closest to our baseline year of 2012. The SCC estimates represent the cost to future environment and human activities by one extra tonne of carbon emitted. It is worth noting that Nordhaus' model also includes estimates for the Abatement Cost (AC) but we refer to it here as SCC, as this is the way it is described in the study and the accompanying DICE model. We also use one estimate for the yearly AC provided by the BEIS [37] for 2015 (for more details on all values and calculations, see Table 2).

Table 2. Benefit flow values.

	Initial Values	Value, Converted from Tonnes of CO_2 (tCO_2)) to tC	Source	Original Study Information
Social Cost of Carbon	$93.00	$93.00	Tol, 2005 [35]	Mean estimate of all studies, tC
Social Cost of Carbon with Abatement Cost *	$31.20–101.20	$114.50–371.40	Nordhaus, 2017 [36]	tCO_2, 2015
Abatement cost *	£55.00–284.00	£201.85–1042.28	BEIS, 2017 [37]	Central, non-traded values, in 2009 GBP values, tCO_2 equivalent (tCO_2e)

* Most initial prices are reported in terms of tons of CO_2. To transfer them in tonnes of carbon, we multiplied it with 3.67. We did not transfer the prices on a reference base year (e.g., 2012) as the level of prices in the future incorporates changes in consumption. In the analysis, we used the official exchange rate from the Bank of England for the conversion from US dollars to GBP, in 2015 prices.

We created three scenarios for the future of saltmarsh extent, one assuming no change in the extent of saltmarshes, one assuming an annual loss of 1% in their extent, and one assuming a 2% annual loss. These loss rates are the two ends of the range provided by Macleod et al. [38] for the global loss rate of saltmarshes. To demonstrate if such losses have significant impact on carbon sequestration benefits, we use a 50-year time horizon and the HM Treasury [39] guidelines for the discount rate applied, which suggests the use of a declining discount rate. This leads to a 3.5% discount rate for the first 30 years (2015–2044) and then it declines to a 3% for the remainder of the period (2045–2064).

We used the carbon storage rates provided by Beaumont et al. [40] for UK saltmarshes. These range from 120 to 150 g C m^{-2}y^{-1} for the whole of the UK and we choose the most conservative estimate of 120 g C m^{-2}y^{-1}. The area of saltmarshes (Table 2) within MPAs in the South West MMO plan area is 324 hectares, according to the Environment Agency.

4.2. Recreational Angling

To assess the benefits from recreation provided by angling, we use the WTP estimates from Kenter et al. [41] who estimated WTP for multiple angling and diving sites in the UK. These estimates were calculated using both a travel cost TC and a choice experiment method and they allow for a more accurate representation of the true benefits. We also chose to focus on WTP estimates for anglers and not for divers from Kenter et al. [41] given data availability (Table 1).

The inshore SSSIs and MCZs have the widest spatial distribution of the input layers, therefore these areas are the focus of the WTP calculations. The steps used for the creation of the WTP function embedded in the GIS valuation tool include:

- The beta coefficients and estimates from the Kenter's et al. [41] choice experiment study (see Equation (1)). This was done specifically to exploit the marginal values given for specific attributes of the MPAs and associate them with available biophysical data.
- The TC model used by Kenter et al. [41] only takes account of the distance i.e., the cost of travelling an extra mile, by using a fixed estimate of the cost per mile. This approach does not include time costs, i.e., the opportunity cost, which is the cost of performing a specific activity rather than all of the others one could engage in during the same period. Thus, the travel cost estimates used here are an under-representation of the true travel cost for a visitor to an MPA.
- All variables that are statistically significant, but non-existent in the South West MMO data, are included as a fixed value, using the sum of mean estimates for the respective beta coefficients and explanatory variables (WTP$_{normalised}$).
- We assume that the UK-wide coefficients provided by Kenter et al. [41] are representative for the individuals and their preferences in the South West MMO.

The willingness to pay (WTP) from Kenter et al. [41] was modified as follows:
First calculating WTP of anglers who visited MPAs in the study area:

$$\text{WTP}_{use} = \frac{-2c(\beta_1 X_1 + \ldots + \beta_2 X_2)}{\beta_{distance}} \tag{1}$$

Where c = cost of a mile travelled (£0.08), x = presence/absence of a layer in the MPA and β = significant coefficients from Kenter et al. [41]. Then we calculate the aggregate WTP of all anglers as:

$$\text{WTP}_{aggregated} = \text{WTP}_{use} \times \text{number of visits per site} \tag{2}$$

Finally, we calculate WTP based on features non-existent in the study area but still considered a factor to WTP. Adding all significant WTP values (WTP$_{normalised}$) from Kenter et al. [41] to WTP$_{aggregated}$ for the layers which could not be found in the study area accounts for the fact that anglers can be more/less willing to pay to visit MPAs with specific features, but these data were not available during the period of this project. This leads to:

$$\text{WTP} = (\text{WTP}_{use} + \text{WTP}_{normalised}) \times \text{number of visits per site} \tag{3}$$

5. Results

In this section, we present the calculated benefits for all MPAs in the South West MMO Marine Plan area in 2012, for recreational angling, water quality, carbon sequestration, and food provision, from which only water quality is not monetized.

5.1. Recreational Angling

The aggregated WTP calculations show that anglers are the most willing to pay to visit the Severn Estuary and surround SSSIs (MPA number 1, see Figure 4 and for a comprehensive list of all MPAs, see Table 3. This area was the most frequently visited by anglers in 2012 with a total of 33 visits, which is almost a half of the total anglers' sites visits. The total WTP for this area is £5876. The second-most visited MPA by anglers, with 10 visits, is Skerries Bank MCZ with the surrounding SSSIs (Figure 4 and Table 3). The total WTP to visit this area by anglers is £1794. The remaining MPAs exhibit more than three times lower total WTP than these two areas (Table 4). Table 4 shows that the WTP_{use} for almost all MPAs is negative. This is due to the negative beta coefficients of the input layers that were found in this location. To account for the absence of the rest of the layers, the significant WTP values calculated were added to the WTP_{use}, resulting in the total WTP values (Table 4).

5.2. Water Quality

The Severn Estuary MPA exhibits elevated values of nutrients. The N/P ratio is 21, which is much higher than the threshold of 16 (Figure 5). The remaining MPAs of interest have a N/P ratio ~8. The NPP in the Severn Estuary is the second highest with an average 584 mg C/m^3/day (Figure 5). This MPA also exhibits high light attenuation due to low water clarity. However, the decreased water clarity and elevated nutrient content contribute to the lower water quality in this area. Elevated nutrients can lead to excessive plant growth and potential zones of oxygen depletion. Skerries Bank MCZ and surrounding SSSIs (Figure 6, number 2) show the maximum 90th chlorophyll-a percentile being greater than the threshold of 15 μg L^{-1}. Therefore, it can be assumed that there is increased algal growth, but it is not substantial enough to lead to oxygen deficiency since all the MPAs are above the threshold of 4 mg/L.

Table 3. A comprehensive list of all MPAs found in the case study area and taken into account in Table 5.

| MPA Number	MPA Name and Type
1	Aust Cliff (SSSI),Berrow Dunes (SSSI),Blue Anchor to Lilstock Coast (SSSI), Brean Down (SSSI), Bridgwater Bay (SSSI), Clevedon Shore (SSSI), Lower Cliff (SSSI), Lydney Cliff (SSSI), Middle Hope (SSSI), Pennsylvania Fields (SSSI), Portishead Pier to Black Nore (SSSI), Purton Passage (SSSI), River Wye (SSSI), Severn Estuary (Ramsar, SSSI), Shorn Cliff and Caswell Woods (SSSI), Spring Cove Cliffs (SSSI), Upper Severn Estuary (SSSI)
2	Skerries Band and Surrounds (MCZ), Bol Head to Bol Tail (SSSI), Hallsands- Beesands (SSI), Prawle Point and Start Point (SSSI), Salcombe Kingsbridge Estuary (SSSI)
3	Loe Pool (SSSI), Porthleven Cliffs (East) (SSSI), Tremearne Par (SSSI)
4	Wembury Point (SSSI), Yealm Estuary (SSSI), Plymouth Sound Shores and Cliffs (SSSI)
5	Upper Fower and Pont Pill (MCZ), Polruan to Polperro SSSI
6	Whitsand and Looe Bay (MCZ), Eglarooze Cliff (SSI), Rame head & Whitsand Bay (SSSI)
7	Bideford to Foreland Point (MCZ), Taw Torridge Estuary (MCZ), Hartland Point to Tintagel (MCZ), Barricane Beach (SSSI), Boscastle to Widemouth (SSSI), Braunton Burrows (SSSI), Bude Coast (SSSI), Duckpool to Furzey Cove (SSSI), Exmoor Coastal Heaths (SSSI), Fremington Quay Cliffs (SSSI), Hele, Samson's and Combe Martin Bays (SSSI), Hobby to Peppercombe (SSSI), Marsland to Clovelly Coast (SSSI), Mermaid's Pool to Rowden Gut (SSSI), Mill Rock (SSSI), Morte Point (SSSI), Northam Burrows (SSSI), Saunton to Baggy Point Coast (SSSI), Steeple Point to Marsland Mouth (SSSI), Taw-Torridge Estuary (SSSI), Tintagel Cliffs (SSSI), West Exmoor Coast and Woods (SSSI)
8	Newquay and The Gannel (MCZ), Cligga Head (SSSI), Godrevy Head to St Agnes (SSSI), Gwithian to Mexico Towans (SSSI), Hayle Estuary & Carrack Gladden (SSSI), Kelsey Head (SSSI), Penhale Dunes (SSSI), Trevaunance Cove (SSSI)
9	Padstow Bay and Surrounds (MCZ), Bedruthan Steps and Park Head (SSSI), Harbour Cove (SSSI), Pentire Peninsula (SSSI), Rock Dunes (SSSI), Stepper Point (SSSI), Trebetherick Point (SSSI), Trevone Bay (SSSI), Trevose Head and Constantine Bay (SSSI)
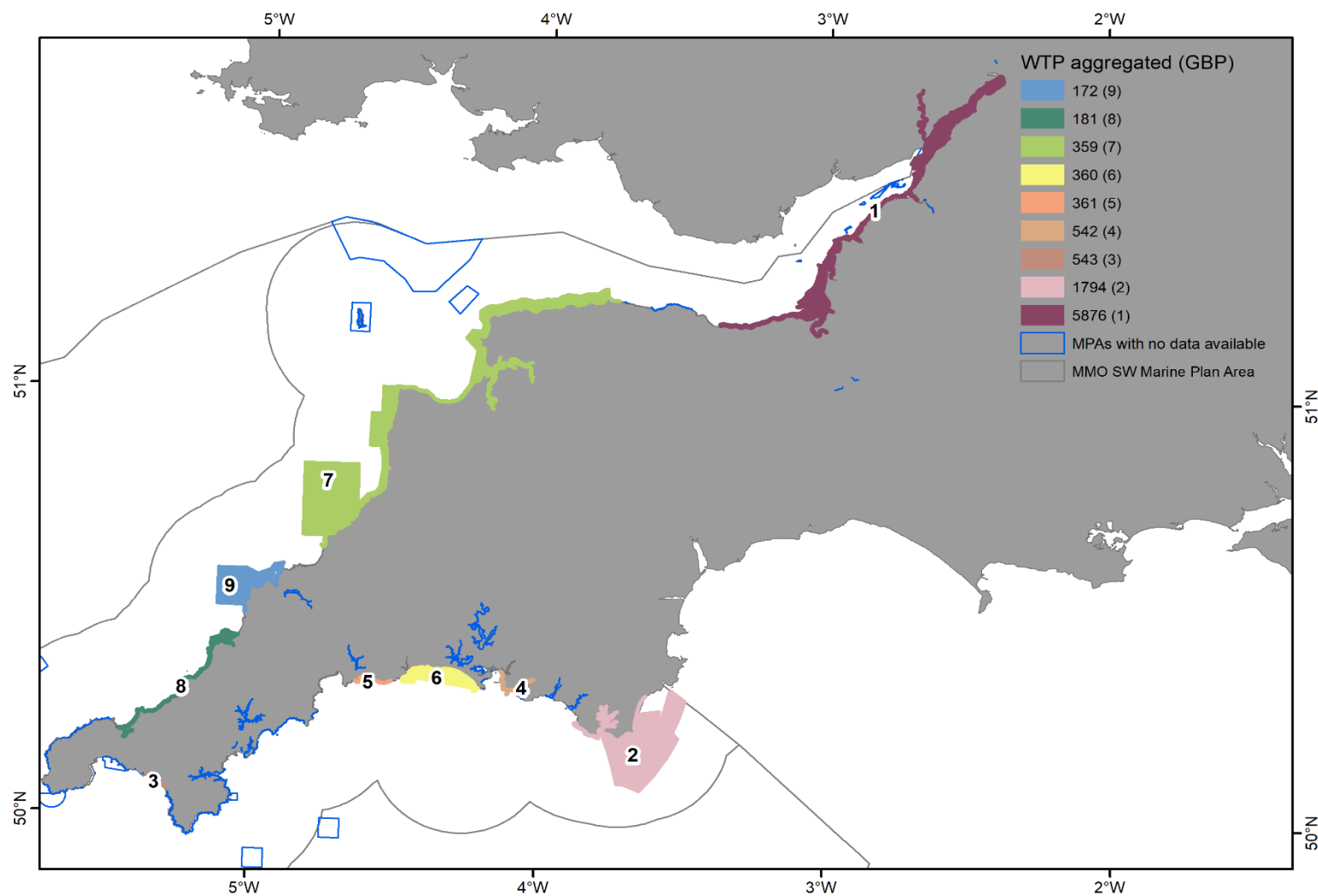
Figure 4. Willingness to pay (WTP) calculated for individual MPAs in the MMO SW Marine Plan Area.

Table 4. Results from WTP calculations for the benefit transfer exercise using Equation (3), in £.

MPA Number	WTPuse	WTPuse Aggregated	WTP Normalised	TOTAL WTP
1	−2.9	−96.4	178.1	5875.6
2	−1.5	−15.3	179.4	1794.4
3	0.1	0.2	181.0	543.1
4	−0.2	−0.6	180.8	542.3
5	−0.6	−1.1	180.4	360.8
6	−0.8	−1.5	180.2	360.4
7	−1.4	−2.8	179.6	359.1
8	−0.4	−0.4	180.6	180.6
9	−8.5	−8.5	172.5	172.5
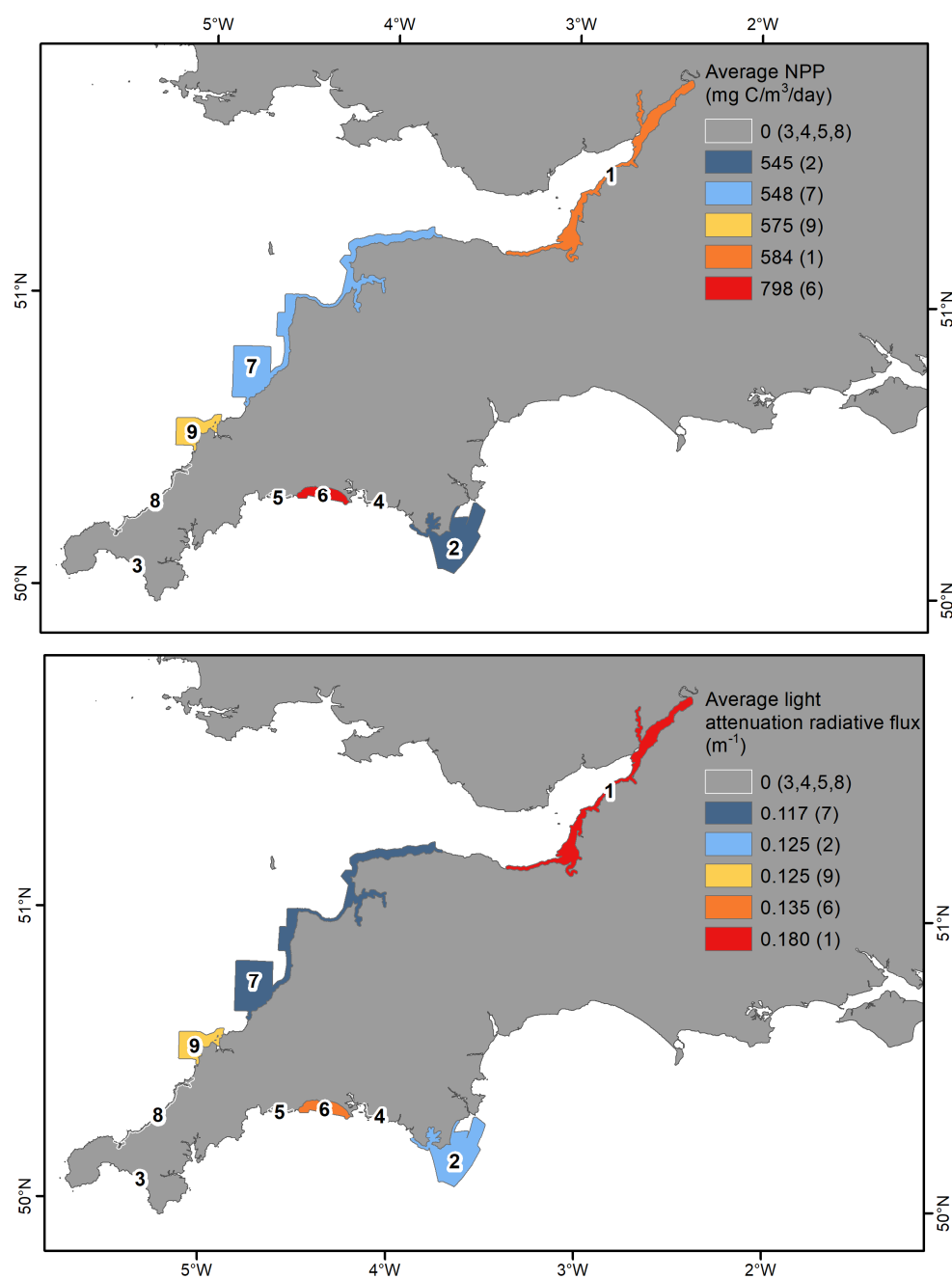
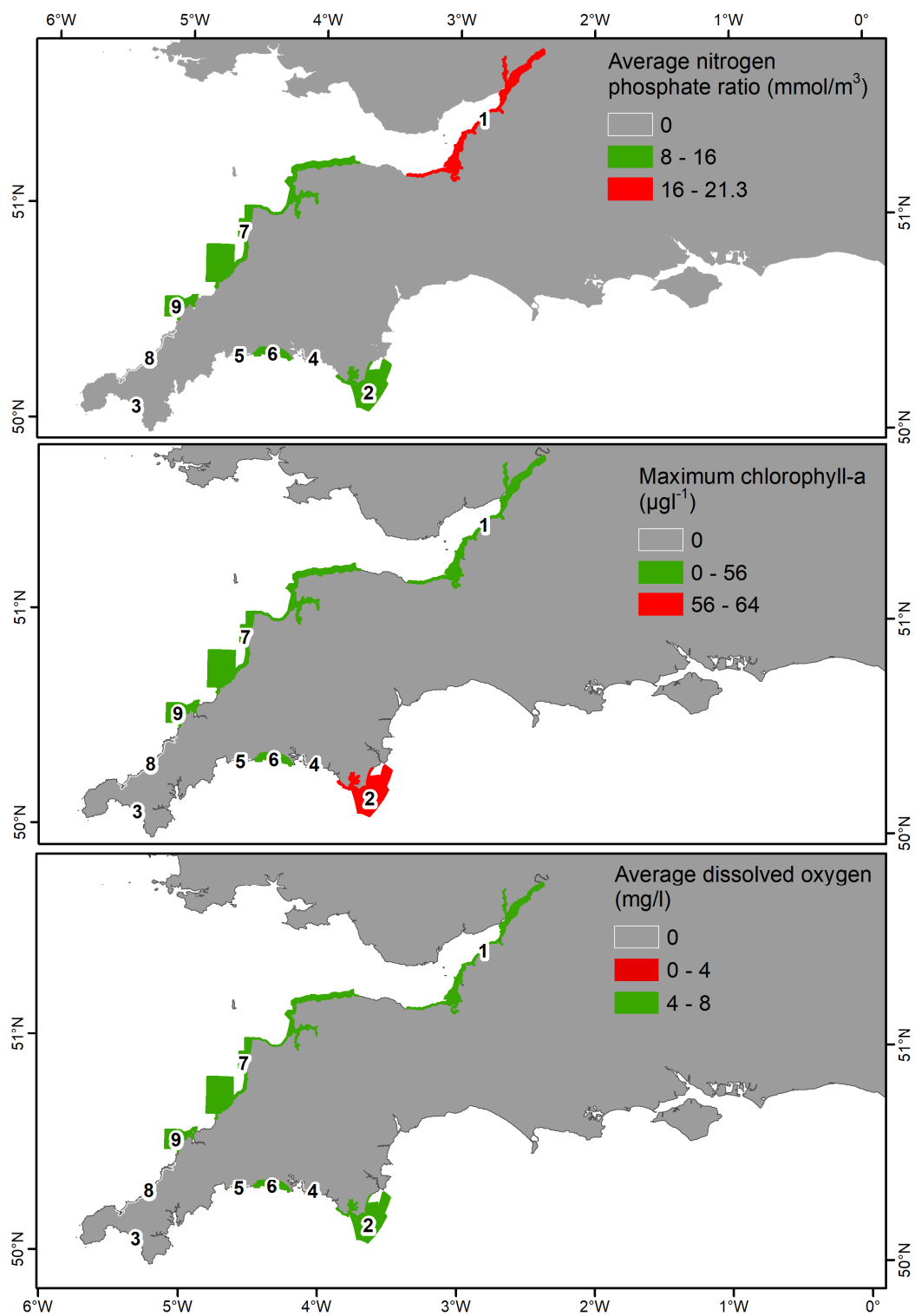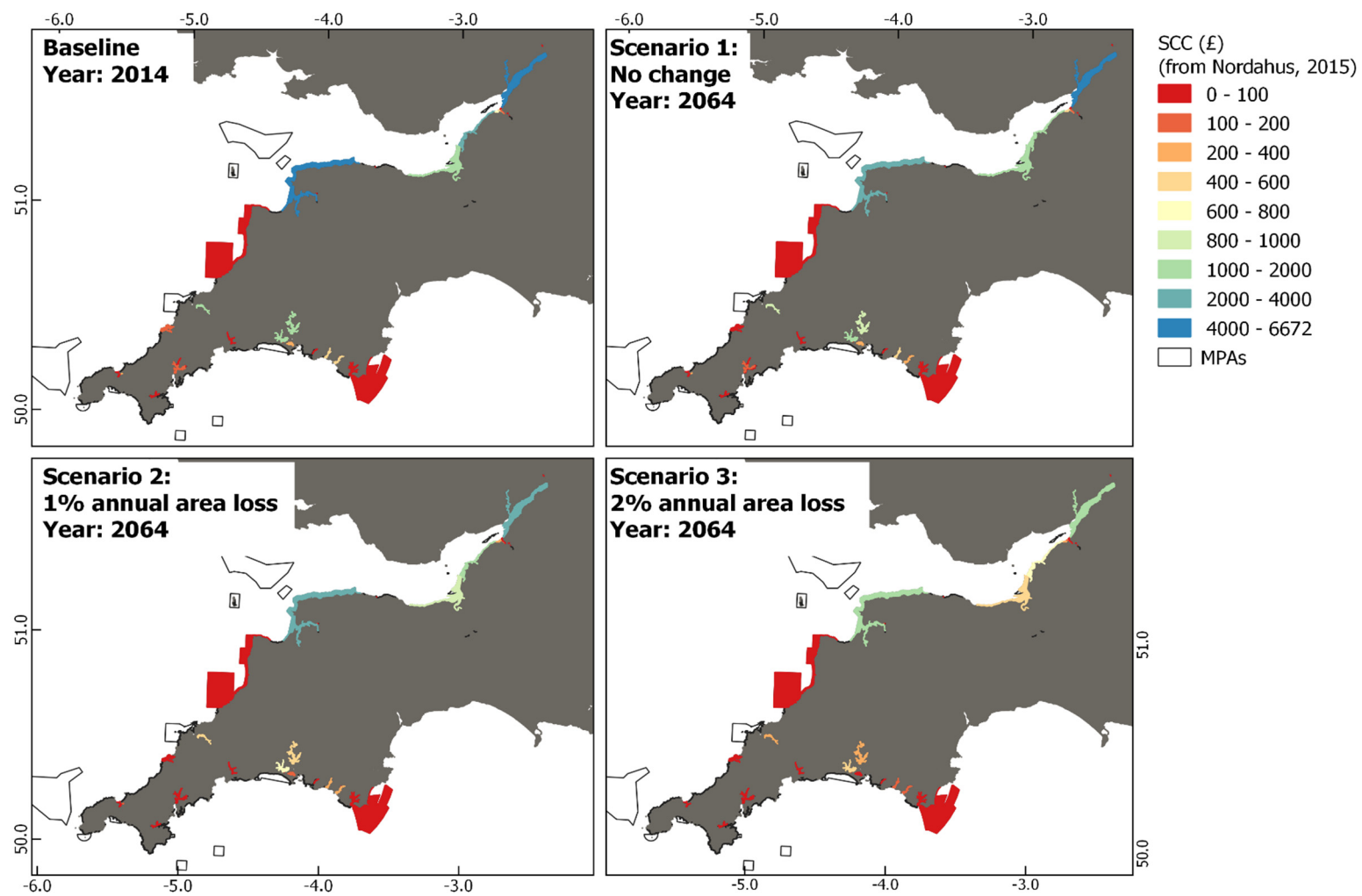**Figure 5.** Levels of N/P, chlorophyll-a, and dissolved oxygen for the targeted MPAs.

Figure 6. NPP and light attenuation radiative flux for the targeted MPAs.

5.3. Carbon Sequestration and Storage Benefits

The results from the benefits provided by saltmarshes found in MPAs in the South West MMO Plan Area, derived from the values described in Table 2, show that for 2015, benefits range between £16 and £61 thousand (Table 5). Overall, using the SCC estimates (Figure 7), the value drops from £1820 to £6672 in the Severn Estuary SSSIs. Figures 8 and 9 show how these combined benefits differ spatially from the baseline in year 2015 and comparing this to the predictions in 2064 using the three scenarios from Table 2. Both SCC and AC methods map Severn Estuary and Bristol Channel as the areas with the highest carbon sequestration and storage benefits in 2015 baseline, thanks to an extensive saltmarsh cover. Therefore, these areas are also expected to undergo the greatest losses in 2064 predictions. A similar pattern is associated in this region for the abatement cost method; however, in Scenario 1 (no area loss), the value of the benefits increases from the baseline in 2014 of £17,462 to £20,568 (Figure 8). In fact, accounting for losses in saltmarsh areas due to anthropogenic and climate change pressures can result in annual losses of 1% to 2% in their extent in the area. Taking into consideration the 1% and 2% annual area losses, however, this value drops to £7490. As such, carbon sequestration and storage play an important role in the north of the South West MMO Plan Area and the loss of saltmarsh area can significantly impact the ecosystem service provision. Aggregated benefits in the end of the 50-year period for the three different estimates of carbon used in this study show losses in benefits that range between 16% and 23% for the 1% annual loss scenario in saltmarsh extent (Scenario 2) when compared to the no-loss scenario and between 29% and 40% in the 2% annual loss scenario in extent (Scenario 3), respectively.

Table 5. The results of the estimations for the value of blue carbon of all saltmarshes are presented below.

	Valuation Method	Value, £	2014 Only	Cumulative for 25 Years	Cumulative for 50 Years
Scenario 1: nothing changes at all	SCC (Tol [35]) SCC (Nordhaus [36]) AC (BEIS [37])	54.0 55.0–284.0 21.0–68.2	£16,446 £23,491 £61,483	£287,493 £546,076 £1,395,527	£419,712 £1,034,642 £3,240,355
Scenario 2: saltmarsh area is lost mostly because of sea-level rise, coastal erosion, and reduced sediment supply (i.e., 1% annual loss of saltmarsh habitat area)	SCC (Tol [35]) SCC (Nordhaus [36]) AC (BEIS [37])	54.0 55.0–284.0 21.0–68.2	£16,446 £23,491 £61,483	£259,166 £485,517 £1,235,749	£350,766 £817,715 £2,493,931
Scenario 3: Continuous population growth claiming saltmarsh areas coupled with climate change (i.e., 2% annual loss of saltmarsh habitat area)	SCC (Tol [35]) SCC (Nordhaus [36]) AC (BEIS [37])	54.0 55.0–284.0 21.0–68.2	£16,446 £23,491 £61,483	£234,649 £433,530 £1,099,669	£298,189 £659,579 £1,958,767

Figure 7. Carbon sequestration and storage values for the SW MMO area using the social cost of carbon by Nordhaus [36].
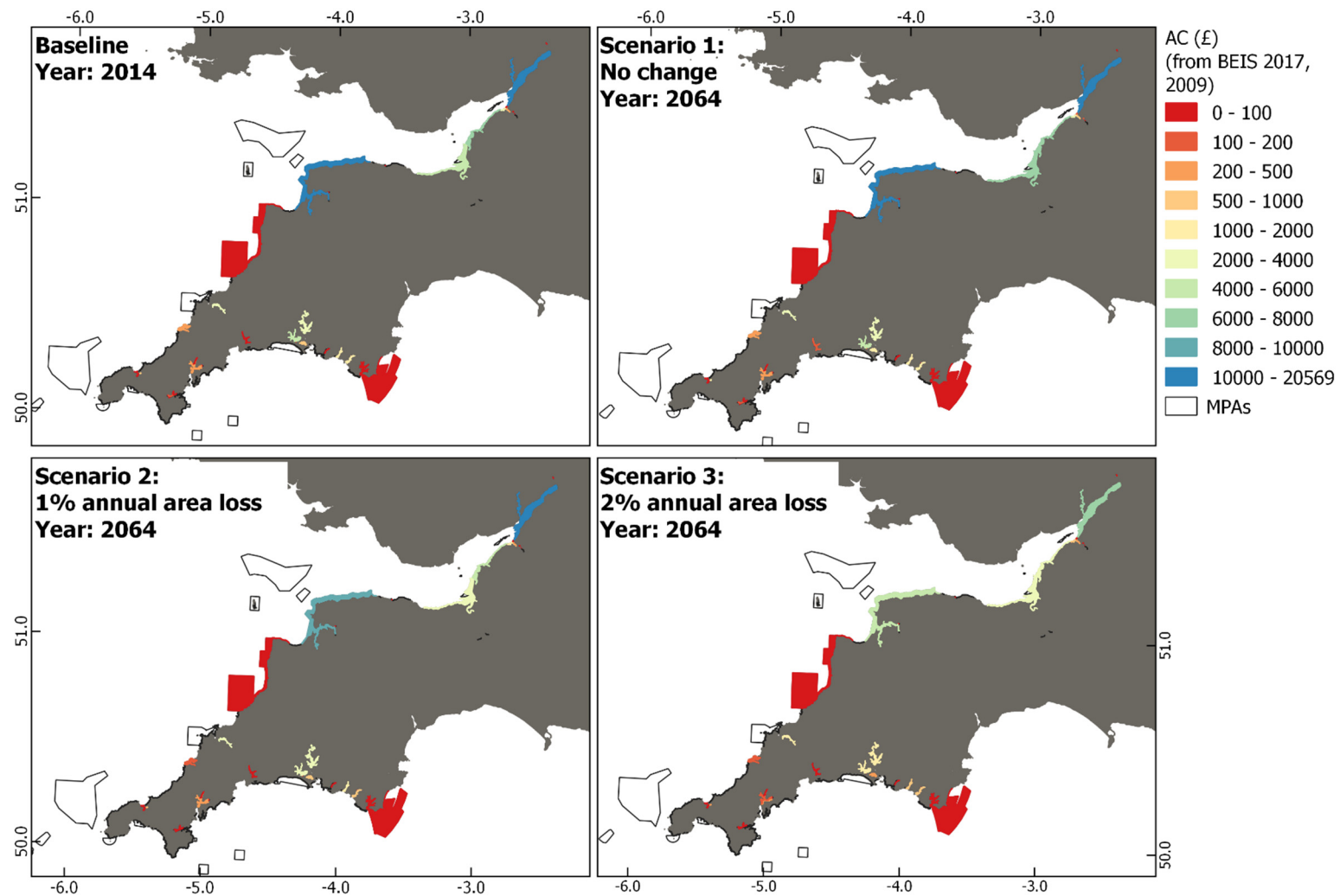
Figure 8. Carbon sequestration and storage values for the SW MMO area using the Abatement Cost (AC) in BEIS [37].

5.4. Food Provision

Landings from the SW MMO plan area are dominated by demersal and pelagic fish, with the highest concentration around the south-eastern tip (Figure 9). Crustaceans and molluscs are caught in abundance south of Plymouth (Figure 9). However, their spatial distribution across the SW Plan Area is located mainly in the inshore and south-east offshore seas. Both groups are fished in the MCZ and SSSI areas, showing no pattern in terms of commercial fishing being strategically targeted outside the MPAs. Naturally, the existence of MPAs in the area reduces fishing effort, with the area south of Plymouth yielding the highest effort estimates. Crustaceans and molluscs are being fished in the shallower waters in the far west side of the SW MMO Plan area, while pelagic and demersal fishing is more evenly distributed.
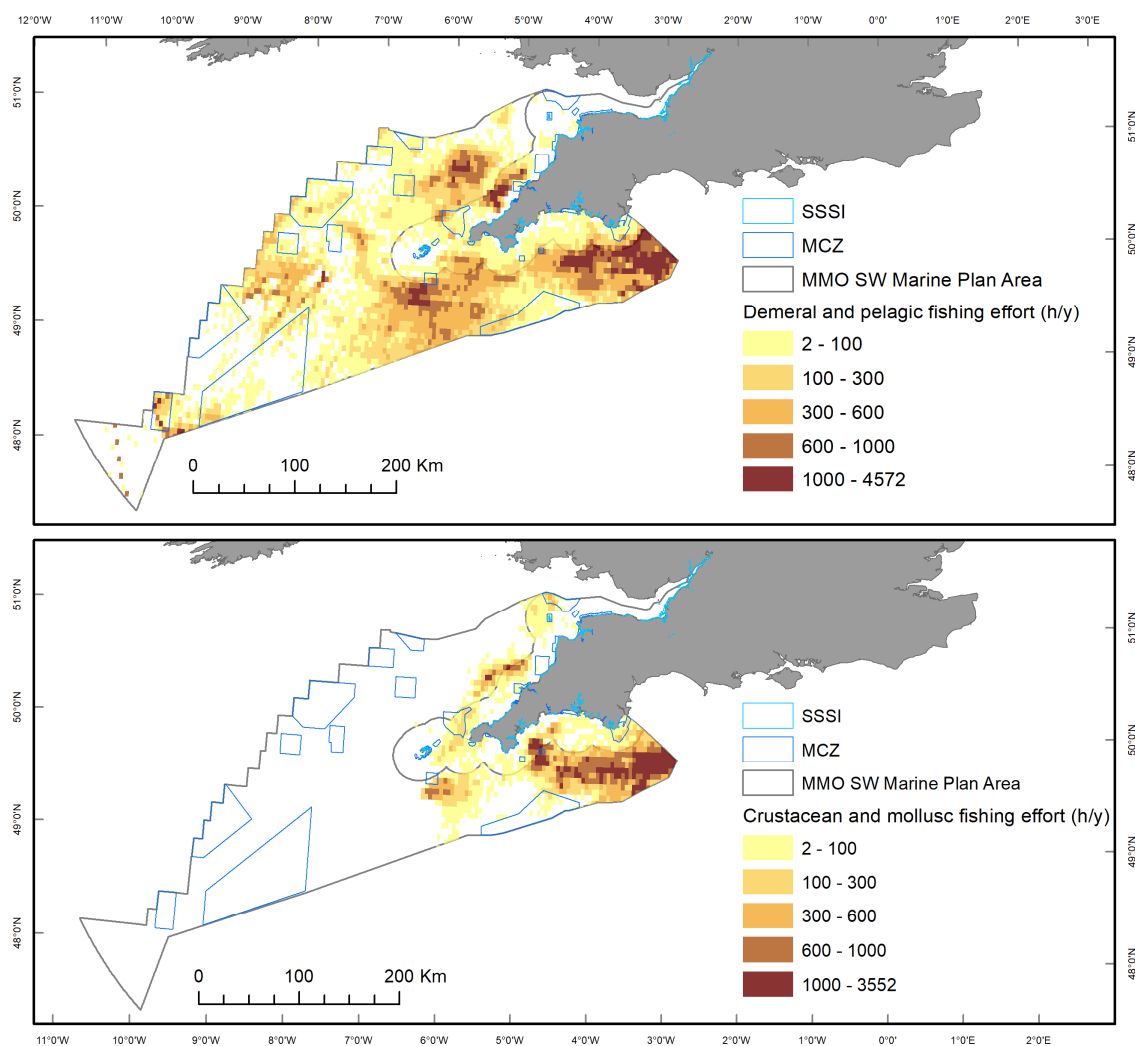
Figure 9. Fishing effort in the SW MMO Marine Plan Area in 2013.

Sea angling differs significantly from the commercial fishing, since it is most concentrated in the Severn Estuary, where no commercial fishing activity occurs and where the waters are considerably shallower (Figure 10). In terms of total landings, demersal and pelagic groups yielded ~£41.5 million and crustaceans and molluscs yielded ~£19 million GBP in 2013. The total landings in 2013 were 30,000 tonnes and 21.5 tonnes for finfish and shellfish, respectively. Between 2011 and 2013, food provisioning had an economic value of £625 m per year.
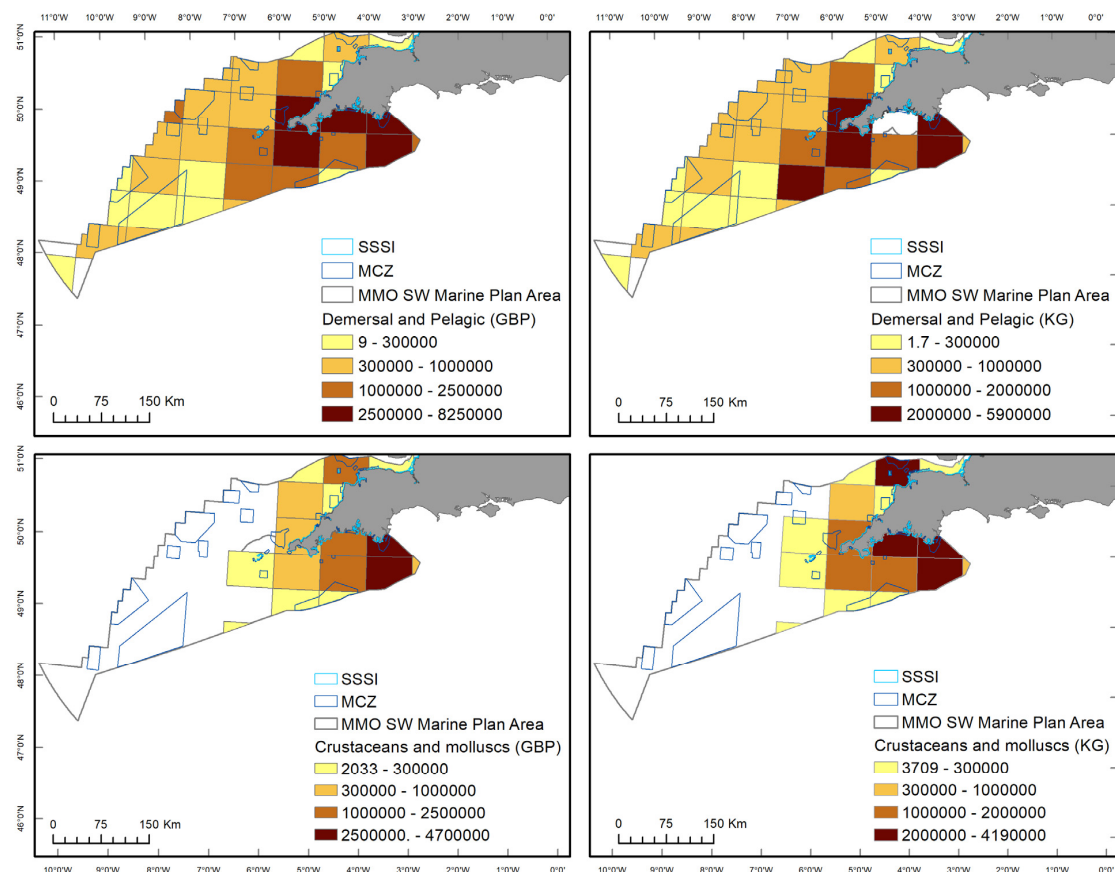
Figure 10. Landings (KG, GBP) in the SW MMO Marine Plan Area.

6. Discussion

Results from the ES mapping tool show that anglers prefer to fish in the Severn Estuary. Underlying reasons might be its accessible location from Wales and middle England as well as multiple smaller SSSIs which are present in this area. As Kenter et al. [41] point out, anglers' willingness to pay decreases with how popular or frequently visited a site is. Higher eutrophication levels might be in favour of sea angling, as increased concentration of nutrients results in more biological activity and food for fish, yet the levels are not high enough to result in oxygen depletion zones. The elevated nutrients do not necessarily have a negative effect on anglers, as they give rise to a higher biological activity and more food for fish in the area. Therefore, even though this area is considered to have a lower water quality, it does not impose a negative effect on anglers.

Recreational angling differs significantly from commercial fishing. As the results depict, almost no commercial fishing (vessels over 12 m long) occurs around the Severn Estuary. According to the MMO, commercial fish stocks are not at MSY levels in the South West area, due to reasons of unsustainable harvesting for most species. As a result, fish populations appear to be shifting towards smaller sized fish. Therefore, providing information to policy-makers on the impact that different management practices have on the population and health of fish stocks is essential. For example, a no-take-zone established on the Great Barrier Reef in Australia has led to rapid increases in fish numbers according to Russ et al. [42]. Goñi et al. [43] found increased effort and landings from areas close to MPAs in the Mediterranean Sea, already under MPA restrictive access scheme for eight years. Similarly, for the Lundy No Take Zone (NTZ), Hoskin et al. [44] found increases in both sizes and abundance of European lobster (Homarus gammarus) within the first five years of implementing the NTZ scheme. Management schemes such as MPAs have varying impact on fish populations depending on the ability of authorities to enforce restrictions; they do not always have positive outcomes to fish populations

though, as Giakoumi et al. [45] demonstrate. For the same NTZ of Lundy, the study found increased injury and disease rates in shell populations due to high population densities resulting from the NTZ scheme. Depending on the management scheme within an MPA, conflicts between fishermen using different gears can occur as they compete over the same number of fish in a more restricted area, as in the case of Lyme bay MPA, but overall minimal impact was found on fishermen's income by the introduction of an MPA in the area [46]. Identifying value of fishing coming from different sources in a spatial context can potentially help solve management issues and conflicts.

The South West MMO Plan Area is second in annual turnover in the UK in tourism (MMO [47], putting a great deal of stress on areas with the highest visitation rates, whether they are on the coast or the inshore area. These stress factors are amplified in the inshore area by the growing demand for energy production, through creation of tidal lagoon plans. As for offshore waters, fishing and transport are the two main activities, and the area is home to some of the most highly exploited fishing grounds in the UK, with rates close to those in the South Inshore and Offshore areas. Much of this can be attributed to the proximity of the continental shelf and deeper waters that are home to high value fish species. High value fish species such as sea bass are under the threat of collapse due to over-exploitation [48]. This is aggravated by the fact that the Southwest possesses the largest commercial fleet in England (managed by three inshore fisheries and conservation authorities), generating 36 million £ in 2014 [47]. Intensive fishing practices and commercial shipping are also disruptive to sensitive species important for the ecological balance (e.g., basking sharks and marine mammals). Intense fishing effort also occurs close to the designated border, where UK and France territorial waters are close, presumably increasing measured fishing effort. There are varying levels of restriction on activities taking place within the numerous MPAs in the South West area, and different levels of management, from no-take to MPAs without designated exploitation status.

This study has used the best data available at the time of the investigation. However, it is worth noting the limitations of the individual data layers: for example, some are delineated by broad polygons, which are unlikely to represent uniform coverage of features across the entire area. Other limitations of the data available include incompleteness and low resolution, which, when combining data layers, may over-emphasise the spatial extent of each activity. Finally, only estimates from carbon sequestration benefits are projected into the future and not benefit estimates from angling or commercial fishing, to account for the uncertainty of these estimates.

To the best of our knowledge, the precise extent of seagrass beds in the SW MMO-plan area is not known. This lack of data does not allow to consider the seagrass meadows contribution to the carbon sequestration service in the area. Therefore, the use of saltmarsh areas only leads to an underrepresentation of the true carbon sequestration benefits value provided by coastal and marine ecosystems. Still, benefits are considerable despite the small extend of saltmarshes (324 hectares) and based on the estimates used, which highlight some uncertainty in the choice of the carbon storage value estimate to be used. The results of the calculations give an indication of the long-term implications of changes in use of carbon-capturing habitats but should only be taken into account for the short term. Nevertheless, such findings should encourage further restoration and protection of carbon-capturing habitats in the SW MMO-plan area. Saltmarshes in that area are more exposed to storm waves and have demonstrated limited growth of saltmarshes towards the sea due to erosion [49].

The ES-mapping tool allows for the portrayal of how economic values "accumulate" within a specific area, given certain human activities (commercial and recreational fishing), for a specific year (2012). The tool was further enhanced to account for changes over time for carbon sequestration and storage benefits in order to show how values change over time. Economic estimates are attempted to be balanced by the use of multiple estimates for the value to account for uncertainty, a common practice in the relevant literature (e.g., [50]). The use of a declining discount rate allows for issues of fairness across time and a negative time preference, meaning that they prefer rewards or benefits in the present rather in the future [51]. The magnitude of potential losses in the extent and the resulting

losses in avoided costs, as defined by the SCC and AC methods, demonstrates the impact of policies that do not consider the whole range of benefits provided by coastal and marine ecosystems.

Using data overlap techniques, as in Kenter et al. [41] allowed us to investigate which attributes are most desirable for anglers in the SW MMO Plan Area. Such answers will help define the characteristics of an "ideal MPA" to visitors. The most "alluring" attributes for anglers might incentivise policy makers to implement specific biodiversity management techniques to preserve or introduce the desired features to MPAs in their region. A similar study conducted for Wales, considering the spatial dispersion of non-extractive recreational uses, found a significant overlap between various recreational groups (divers, kayakers, and wildlife watchers) with total economic values that rival those of commercial fisheries in the same region [25].

Our main result is however the flexibility and the wealth of information that the tool we have created can provide. As illustrated in the Severn Estuary, the ES-mapping tool can combine different layers within a GIS environment. This allows explicit spatial assessment in a multidisciplinary context. However, the spatial resolution at which interpretations can be made will be strongly dependent on the detail and resolution of input data. In other words, it is possible to combine available data to achieve a more holistic assessment of why individuals are willing to pay more for facilities or activities in one location rather than another, but this will be dependent on data quality and quantity. Nevertheless, the tool can be effective for policy makers wishing to run a quick analysis to get a broad overview from available input data.

The visualisation aspect of the ES-mapping tool allows the policy maker to observe which areas of their jurisdiction are adhering to the requirements of various environmental standards, such as those set by the Marine Strategy Framework Directive (MSFD) ([52]), the Water Framework Directive (WFD) ([52]), the Bathing Directive ([53]), and the Habitats Directive (Council Directive 92/43/EEC). The tool can highlight areas that are failing to meet required standards and the nature of the problem (e.g., elevated nutrient levels, overfishing).

Although innovative in its application and geographic presentation the ES-mapping tool is not the only integrated ecosystem services tool that exists. For instance, the Nature Value Explorer (https://www.natuurwaardeverkenner.be/backgroundInfo.jsf) was developed by a team of economists and ecologists in Flanders, Netherlands to value provisions by local ecosystems services. However, ecosystem services are presented in the Nature Value Explorer in a cumulative manner for the entire Flanders' land area, whereas the ES-mapping tool presented in this paper shows higher spatial distribution, depending on ecological, chemical, and anthropological factors within MPAs. Due to data limitations, only carbon sequestration and storage values were shown how they change over time with the ES mapping tool, while the Nature Value Explorer allows for multiple, land-based ecosystem services to vary over time, based on different selected management scenarios.

7. Conclusions

The growing need for mapping and valuing ecosystem services has been mainly focused on terrestrial environments, with few mapping tools and comprehensive initiatives devoted to combining ecosystem services provided by the marine and coastal environments and their values. The European policy context (Biodiversity Strategy to 2020) highlights the need for spatial mapping and valuation of ecosystem services. This study has developed a framework for an effective GIS-based, ES-mapping tool. The tool contains monetary values for different ES, starting with a WTP method developed for the South West MMO Plan Are for recreational angling, values for the final ecosystem services of fish caught (represented through fisheries landings) and clean climate (represented by Blue Carbon sequestration). The level of water quality in the area is also mapped out. Findings show that values for commercial fishing are higher on the western side of the area, south of Plymouth, whereas recreational angling is concentrated in the Severn Estuary, which has the highest WTP value, but elevated nutrient levels. Lower water quality due to elevated nutrient levels is believed to enhance the biological activity in the Severn Estuary without producing oxygen depletion zones. Despite the limited extent

of saltmarshes (0.4%) in the MPAs, and in the absence of data indicating the extent of seagrass beds, the value of carbon sequestration is between £350 thousand and £2.5 million for a 50-year period, assuming a moderate impact from climate change. Overall, this study indicates that MPAs in the South West MMO Plan Area provide very important environmental, financial, and social ecosystem services. The principles of the WTP function are based on estimates found in Kenter et al. [41] but it has been necessary to modify the WTP coefficients due to limited data availability, making downscaling of the Kenter model to the South West MPAs problematic. The strengths of the tool are its convenience and visual aspects. As the WTP tool is automated in a Python environment, the script can easily be modified to incorporate future changes, additional data inputs, etc., and can be shared with other users and re-run repeatedly, while data availability on other ecosystem services available in the area can be incorporated to assist their valuation. This type of tool could be appropriate for multiple purposes, from helping to attain the Biodiversity Strategy target for mapping of ecosystem services by 2020, to contributing to the achievement of the Sustainable Development Goals (e.g., Goal 6.3 to improve water quality and reduce chemical pollution; Goal 6.6 to restore the quality of water-related ecosystems by 2020; Goal 14.2 dictating the sustainable management, protection, enhanced resilience, and restoration of marine and coastal ecosystems; Goal 14.5 using available scientific information to conserve at least 10% of the coastal and marine area). The novelty of this work lies in its application (marine environment) and the tool's ability to use both primary (biophysical) and secondary data (economic) to produce spatially-specific economic estimates for short-term spatial planning to local decision-makers and stakeholders. The emphasis on the short term is due to all types of values changing through time, with economic estimates needing to be discounted and be geographically adjusted and specific [54,55], if different or more targeted estimates become available. As long as suitable high-quality data are available from primary collection (e.g., for economic data) or from rigorous monitoring or survey practices (e.g., for biochemical data), mapping of ecosystem services and their value can be enhanced through the use of GIS, serving as a stepping stone for Natural Capital accounts for specific ecosystem services flows and assets in the marine and coastal environment.

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