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Rewilding the Sea? A Rapid, Low Cost Model for Valuing the Ecosystem Service Benefits of Kelp Forest Recovery Based on Existing Valuations and Benefit Transfers

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Kelp forests and seagrasses are important carbon sinks that are declining globally. Rewilding the sea, through restoring these crucial habitats, their related biodiversity and ecosystem contributions, is a movement and concept, gathering pace in the United Kingdom and globally. Yet understanding of the economic costs and benefits for setting areas of the sea aside—and removing some human impacts from them—is not well understood. The potential benefits and distributional impacts on marine users and wider society is critical to make evidence based decisions. Ensuring that areas of the sea recover, and that the impacts (both positive and negative) are understood, requires targeted research to help guide decisions to optimize the opportunity of recovery, while minimizing any negative impacts on sea users and coastal communities. We approach the problem from an ecosystem services perspective, looking at the opportunity of restoring a kelp bed in Sussex by removing fishing activity from areas historically covered in kelp. Development of an ecosystem services valuation model showed restoring kelp to its highest mapped past extent (96% greater, recorded in 1987) would deliver a range of benefits valued at over £ 3.5 million GBP. The application of an ecosystem services approach enabled the full range of benefits from habitat restoration to be assessed. The results and the gaps identified in site specific data and values for this area, have broader implications in fisheries management and natural resource management tools for restoring marine habitats and ecosystems in the United Kingdom.

Keywords: kelp, fisheries, rewilding, ecosystem services, fisheries management

INTRODUCTION

The Case for Assessing Benefits From Recovery of Marine Ecosystems

Globally, marine and coastal habitats and biodiversity are impacted through over-exploitation, pollution (Laffoley et al., 2019), land-use change and invasive species, leading to losses in productivity and diversity (Smale et al., 2013, 2016; Thurstan et al., 2013; Hynes et al., 2021). Climate change (Smale et al., 2013; Hollowed et al., 2019) and overfishing are the two most significant challenges to the structure and functioning of marine ecosystems (Ling et al., 2009; Pessarrodona and Smale, 2018; Nelson and Burnside, 2019). Loss of biodiversity, and related social and economic impacts are identified on a global scale and have initiated global responses [Convention on Biological Diversity [CBD], 1992, 2010]. The Millennium Ecosystem Assessment provided the first attempt to link ecosystem change and human well-being, identifying the implications of biodiversity loss on degradation of ecosystem services: the benefits people obtain from ecosystems that support human well-being (Millennium Ecosystem Assessment, 2005).

In the marine environment global declines of foundation species (such as seagrasses, corals, kelp and oysters) have been widely documented and their loss often reduces their beneficial ecosystem services, such as carbon sequestration (Ortega et al., 2019), waste detoxification and recreation opportunities (Beaumont et al., 2019) that positively influence human well-being (Oliveira et al., 2015). Kelp forests are in decline in many areas of the world due to both climate and trophic stressors. The decline of kelp globally is linked to climate change and impacts negatively on primary production and carbon storage in the world's oceans and contributes to global biodiversity loss (Reed and Brzezinski, 2009; Wilmers et al., 2012; Schiel and Foster, 2015; Beas-Luna, 2020; Edwards et al., 2020).

Almost three decades on from the initial Convention on biodiversity [Convention on Biological Diversity [CBD], 1992], economic growth paradigms and extractive or polluting activity continue. Presently, Nature-based Solutions (NbS) have been brought into the front line of addressing the biodiversity loss crises, to address climate change through restoration of vegetated habitats and to provide multiple societal benefits (Hynes et al., 2021). Nature-based Solutions are defined as "*actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits*" (IUCN, 2019). International calls for NbS have been made from the United Nations (UN, 2020), European Union (European Commission, 2020), International Union for Conservation of Nature (IUCN, 2019) and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES, 2019).

Ecosystem recovery policies and rewilding of habitats offers an opportunity to move the NbS concept forward and develop both a baseline and trajectory for monitoring improvement and benefits. Coastal habitats (e.g., saltmarsh, seagrass, shellfish reefs, reed beds and mudflats) are however, difficult to include in spatial assessments of marine natural capital as the baseline information on their extent and condition is lacking. Many biotopes (e.g., kelp beds, mussel beds, epiphyte and sponge communities) are significant for water quality (Lv et al., 2019; Timmermann et al., 2019; Jiang et al., 2020; Bayley et al., 2021) and/or climate regulation (Duarte, 2017; Howard et al., 2017). Few global studies, however, quantify the potential range of benefits of recovery of marine coastal habitats and the lack of global valuations presents problems for benefit transfers and modeling. Establishing baselines of past conditions for ongoing comparison and targets, as well as applying biophysical and economic metrics for comparison over time, can reveal society's impact on ES regionally and also demonstrate what is possible to policymakers (Krumhansl et al., 2016; Watson et al., 2020).

In this paper we provide a case study based on restoration of kelp habitat to a past evidenced baseline state, aimed at providing evidence to support resource management decisions. The approach applies a rapid, low-cost ecosystem service model, using existing valuations, to indicate the potential benefits of restoring degraded marine habitat at a coastal location in the eastern English Channel, United Kingdom. Fisheries management options were applied as interventions to reduce pressures to enable recovery of kelp habitats. The model linked potential benefits from habitat restoration to peer-reviewed assessments of contribution of kelp habitat to ecosystem services, including valuations of benefits for: fish resources (including nursery habitats), kelp harvesting, the maintenance of water quality, coastal protection, carbon sequestration as well as tourism and recreation, using a benefit transfer approach.

Natural Capital and Ecosystem Services

We apply a Natural Capital framework to assess contribution of kelp habitat to ecosystem services (Turner and Daily, 2008). The Natural Capital concept seeks to communicate society's dependence on nature (e.g., for climate regulation, flood alleviation or food provision) and also to be used to develop economic theory and practice, to capture the myriad of externalities (causing environmental degradation), which arise from human activity (Gómez-Baggethun and De Groot, 2010; Guerry et al., 2015; Natural Capital Committee, 2017; Tinch et al., 2019). The approach is also aimed at making the benefits we derive from nature visible in economic decision-making (Laurans et al., 2013).

Within the natural capital framework beneficial *flows* from nature are termed "ecosystem services," which stem from the Natural Capital *stocks,* defined as "*the elements of nature that directly or indirectly produce value to people, including ecosystems, species, freshwater, land, minerals, the air and oceans, as well as natural processes and functions*" (Natural Capital Committee, 2017). Stocks, such as kelp and other marine habitats, are identified to supply a public need covering economic, social, environmental, cultural, or spiritual benefits. How the value of these benefits is described can be qualitative or quantitative (including monetary) (Natural Capital Coalition, 2019) and can be used as a tool to highlight (within policy and decision support) the potential benefits of enabling recovery/rewilding (Natural Capital Committee, 2017).

The accepted high-level classification of "functional grouping" divides ecosystem services into four categories: *Provisioning services* (products obtained from ecosystems), *Regulating services* (those benefits obtained from the regulation of ecosystem processes), *Cultural services* (any non-physical benefits that humans obtain from ecosystems) and *Supporting services* (those necessary for the production of all other ecosystem services (Hooper et al., 2019; Tillin et al., 2020).

Ecosystem Service Benefits From Kelp Habitats

Kelps are a group of brown algae (Order *Laminariales*) which are globally important as a foundation species occupying 43% of the world's marine ecoregions and supporting a productivity per unit area rivaling that of tropical rainforests (Reed and Brzezinski, 2009; Duarte, 2017; Smale et al., 2020), enhancing biodiversity and secondary productivity through the formation of biogenic habitat (Schiel and Foster, 2015). The wide-ranging Ecosystem Service benefits of the internationally important kelp forest are summarized in **Table 1** below.

Threats to Kelp

Kelp habitats are threatened by a variety of pressures related to human impacts, which can be direct (harvest, pollution, sedimentation, abrasion or removal from fishing activities and damage or overgrazing by urchins) [Tegner and Dayton, 2000; Werner and Kraan, 2004; Jasper and Hill, 2015; National Oceanic and Atmospheric Administration [NOAA], 2019], or

TABLE 1 | Ecosystem services (ES) provided by Kelp forests globally and their level of contribution to benefit delivery.

Type of Ecosystem service	Types of benefit flows	Level of contribution to benefit delivery
Provisioning services: products/goods people obtain	Commercial, recreational and subsistence harvesting (Kelly, 2005; Borras-Chavez et al., 2012; Vásquez et al., 2014; Vergés et al., 2016)	Not assessed
	Primary productivity (very high compared to other algal communities), including high levels of nutrient uptake, photosynthesis and growth (Kelly, 2005; Smale et al., 2013).	Significant contribution
	Aquaculture/food production/food for intertidal birds (Kelly, 2005)	Not assessed
	Habitat provision for various species of commercially valuable fish (Kelly, 2005) and shellfish (Loomis, 2005) as shelter (Smale et al., 2013).	Moderate contribution
	Materials (alginates) for pharmaceutical and industrial use by the cosmetic and agrochemical industries and for biotech applications (Kelly, 2005).	Significant contribution
	Fertilizer and use in building materials (Kelly, 2005)	Significant contribution
Regulating services: benefits people obtain from the regulation of ecosystem processes.	Water quality maintenance/filtration (Belgrano, 2018)	Not assessed
	Protection of coastlines from storm surges and waves (Loomis, 2005; Smale et al., 2013)	Moderate contribution
	Reduction of shoreline erosion (Loomis, 2005; Smale et al., 2013)	Moderate contribution
	Carbon sequestration (Smale et al., 2013; Duarte et al., 2017; Ortega et al., 2019)	Moderate contribution
	Stabilization of submerged land by trapping sediments (Kelly, 2005; Smale et al., 2013)	Significant contribution
Supporting services: while not providing direct services themselves, supporting services are necessary for the production of all other ecosystem services.	Cycling of nutrients (Belgrano, 2018)	Significant contribution
	Alteration of energy flows and modifying bottom currents (Kelly, 2005).	Not assessed
	Kelp beds provide (nursery and breeding) habitat for species of fish (gadoids and salmon), including protection for juveniles, which are harvested in recreational and commercial fisheries (Kelly, 2005; Loomis, 2005).	Moderate contribution
	Provide additional substrata for sessile macrofauna e.g., sponges, anemones, bryozoans and sea squirts, increasing shelter available, providing habitat for prey species and a forage base. Contribution to diversity is more pronounced in otherwise relatively 2- dimensional environments (Kelly, 2005; Smale et al., 2016).	Moderate contribution
	Kelp is an important food source for a number of species of echinoderm, mollusk and herbivorous fish as well as some bird species (Bradley and Bradley, 1993; Kelly, 2005; Bertocci et al., 2015).	Significant contribution
	Kelp forest particles (detritus) provide important food for filter feeders such as mussels and clams as well as amphipods, crustaceans and sea cucumbers (Loomis, 2005).	Significant contribution
	Biodiversity of kelp forests prevent invasions of non-native species (Loomis, 2005).	Not assessed
Cultural services: non-material benefits people obtain from ecosystems	Tourism and recreation (improving recreational fisheries and water quality for tourism) (Chae et al., 2012; Smale et al., 2013).	Significant contribution
	Foraging habitat for coastal birds and drift kelp in open water provide a valuable roosting site for birds. Many bird species directly depend on kelp detritus, feeding on larvae and invertebrates. Kelp wrack also benefits birds *via* its role in providing organic matter to coastal marine ecosystems (Kelly, 2005).	Significant contribution
	Symbolic of coastal heritage (Belgrano, 2018).	Significant contribution

indirect (e.g., climate change and overfishing) [Ling et al., 2009; Ruckelshaus et al., 2013; Vergés et al., 2016; Arafeh-Dalmau et al., 2019; National Oceanic and Atmospheric Administration [NOAA], 2019]. These threats can be localized or global (Lambert et al., 1992; Krumhansl et al., 2016). The indirect pressures impacting kelps globally such as; ocean warming, predation from urchins, as well as pollution, are thought to be more significant threats to kelp at global scales, while direct local impacts may be more pronounced in individual sites (Connell et al., 2008; Bell et al., 2015; Edwards et al., 2020).

Kelp and seaweed communities are considered at high risk from activities that cause physical removal from substratum, and damage to boulders or reefs such as commercial fishing activity that uses hydraulic dredging and at medium risk from activities that damage fronds, such as otter trawling (Christie et al., 1998; Mannion et al., 2013; Jasper and Hill, 2015). Towed demersal fishing gears also exert pressures on surrounding benthic soft and hard substratum habitats and associated biota (Innes and Pascoe, 2010). Increases in water temperature through ocean warming, are likely to impact native kelp communities. In the North-East Atlantic warm-water kelp species are likely to increase in abundance e.g., *Laminaria ochroleuca*. However, alterations in overall ecosystem functioning may be less pronounced when foundation species share similar traits. Some functions e.g., carbon absorption or food provisioning, for example could be maintained or enhanced (Pessarrodona and Smale, 2018) and planting kelp to mitigate against climate change has also been proposed (Duarte et al., 2017). However, ocean warming as well as coastal eutrophication related to human activity, are identified as pressures reducing the extent of kelp habitats, through conditions favoring growth and survival of turfs over kelps (Filbee-Dexter and Wernberg, 2018).

At a global scale, pressure from grazing by sea urchins has led to extensive kelp loss and even triggered regime shifts to coralline algal-dominated "barrens" (Steneck et al., 2002; Filbee-Dexter and Wernberg, 2018).

When considering flow of ecosystem service benefits from kelp habitats it is important to consider that these require the wider ecosystem to be in condition to support relevant functions and processes. For instance, studies indicate that macroalgal export takes place globally beyond coastal habitats, suggesting that macroalgae may be an important source of allochthonous carbon (Duarte, 2017; Smale et al., 2020). Therefore, contribution to blue carbon assessments require consideration of condition of deeper ocean and shelf sediment habitats and benthic communities (Duarte, 2017; Pessarrodona and Smale, 2018; Macreadie et al., 2019; Ortega et al., 2019; Smale et al., 2020).

VALUATION OF ECOSYSTEM SERVICES

The Role of Valuation in Decision-Making

Economic valuation provides an additional tool to support policy development and assess the long-term sustainability of blue growth and marine management decisions, while raising awareness of the, often invisible, benefits provided by healthy marine ecosystem and the wider importance of our seas to society and in the economy (Austen et al., 2019). Ecosystem Service valuation can improve societal choices through presenting the costs of ecosystem degradation and the benefits of restoration in economic terms (these do not need to be financial). Valuation of goods and services supports both conservation and management policy decision-making regarding natural capital, e.g., the temperate biotopes on the coast (macro algae, sediments, saltmarshes, seagrasses, reed beds and native oyster reefs for example) provided nutrient reductions and avoided climate damages of United Kingdom £1.1 billion from the United Kingdom's Solent European Marine Site (SEMS) for instance (Watson et al., 2020). These could increase to £10 billion if the costs of water-treatment infrastructure and higher Carbon prices were adopted, further strengthening the rational for coastal restoration (Watson et al., 2020). Natural capital frameworks for water quality improvements and climate change mitigation require robust, spatially explicit ecosystem service (ES) data, but for coastal habitats both data and variability of how baselines makes quantifying and valuing "regulatory ES" particularly difficult. Valuations can be: decisive, technical or informative and while valuation is considered an important contribution to decision-making, distributional aspects (who wins and who loses are a result of decisions) are often absent. These distributional impacts which are frequently lacking in economic impact assessments may also be unclear or change over time, but need to be presented, discussed and acknowledged as part of the process (Laurans et al., 2013). A risk exists that without incorporating non-market values into decision-making processes regarding marine policy that these may not be made in the best interest of society (Hynes et al., 2021).

Ecosystem-based management is a principle outlined in the United Kingdom Fisheries White Paper (Defra, 2018). The roll out of this approach notes the importance of incorporating valuation of coastal habitats as a decision support tool (Smale et al., 2016). EU directives have highlighted the importance of increased knowledge concerning the relationship between kelp forests and fisheries to inform fisheries management measures (Araujo et al., 2013).

Economic Valuation of Ecosystem Services Provided by Marine Habitats

In this study a benefit transfer model was developed and applied to the case study area. Valuation generally focuses on those "Use values," which are instrumental to our economies and societies. Use values applied are either direct such as harvested biomass or indirect by providing clean air or water, or recreational opportunities. Nature also has less tangible attributes such as aesthetic services or intrinsic values, which are not necessarily linked to economic production or consumption and yet influence our well-being (Gómez-Baggethun and De Groot, 2010). These "non-use values" combined with "use values" comprise the total economic value (TEV) of an ecosystem, species (flora or fauna) or resource (Tinch et al., 2019; Williams et al., 2019).

Economic valuation is the process of expressing a value for ecosystem services in monetary terms to be incorporated into decision-making frameworks such as Cost-Benefit Analysis (CBA) (Northern Economics Inc, 2009; Börger et al., 2014). Any investment decision and intervention involve trade-offs and the valuation of ecosystem services can support more inclusive decision making through making trade-offs explicit, transparent (Mckinley et al., 2019) and comparable in monetary terms. A full valuation of the wide array of services provided by kelp would enable decision makers to better understand and compare environmental, economic and social trade-offs (Northern Economics Inc, 2009; Börger et al., 2014).

MATERIALS AND METHODS

Case Study Area, West Sussex, England

West Sussex has a coastline along the English Channel (**Figure 1**) and a range of terrestrial and coastal habitats, including bedrock with a thin veneer of cobbles, coarse sediment and sand (Sussex IFCA, 2019b). The presence of kelp forests (including the species *Laminaria hyperborea*, *Laminaria digitata* and *Saccharina latissimi*) (Sussex IFCA, 2019b) have been identified off West Sussex through coastal and scuba dive surveys as well as oral history ("*it is impossible to write a history of Worthing without mentioning seaweed, which has been a periodic problem since 1805"*) (Williams and Davies, 2019). Kelp washed up on beaches, after storms has traditionally been used to fertilize agricultural land. Two severe storm events in the in the last century are believed to have reduced the extent of the kelp forests (Sussex IFCA, 2019a; Williams and Davies, 2019). This loss, combined with climatic and trophic level changes as well as an increase in mobile gear fishing effort using dredges and trawls is believed to have inhibited the recovery of the kelp forests, alongside the cumulative impacts of eutrophication and poor water quality (Sussex IFCA, 2019b).

A nearshore trawling byelaw (Sussex IFCA, 2019a), 308 km^2 of important, biodiverse nearshore habitat would be protected from mobile fishing gear (**Figure 1**) in the district. This equates to 18% of the total district area of 1,746 km^2, that is managed by the Sussex Inshore Fisheries and Conservation Authority (IFCA—the regional local government funded fisheries and environmental regulator for the "inshore" marine environment in England out to 6 miles from the coast) [Marine and Coastal Access Act [MACAA], 2009]. There are areas of very high biodiversity throughout the district, in particular south of Selsey, within the nearshore area between Littlehampton and Shoreham (also shown in **Figure 1**), east of Eastbourne and near Rye (Sussex IFCA, 2019a).

Ecosystem services benefits are central to rationale underpinning this byelaw, with Sussex IFCA adopting a move toward *ecosystem-based fisheries management*, which comprises a more holistic approach considering multiple objectives. These include maintaining sustainable trawling activity and aiming to restore historic kelp beds in the region by prohibiting damaging activity (Sussex IFCA, 2012). No distinction is made between the different types of mobile gear, or weight of gear being towed (Sussex IFCA, 2019b).

Figures 2, **3** below show kelp point data from dive surveys conducted by Sussex Seasearch (**Figure 2**) and Sussex IFCA sightings data for trawling activity (**Figure 3**).

Data Requirements

To determine how policy measures that enable the recovery of kelp habitats may influence the levels of ecosystem service benefits the following composite data products are required.

1. Historic and current kelp distribution and density maps.
2. Monetary valuations of ecosystem service (including proxies and benefit transfer) from global literature.
3. The development of plausible scenarios for kelp bed recovery.

Kelp Distribution Off West Sussex

To determine the historic extent of kelp beds in the case study area the following data sources were used:

Worthing Borough Council Study

A report by Worthing Borough Council from 1987 represents our historic marker for the extent of the kelp bed (shown in **Figure 1**). The report, based on surveys, indicated that the kelp bed was 177 km^2 in total in that year, equating to 10% of the current Sussex IFCA District. Within this area, 10 km^2 was considered "very dense" (>40 tons/hectare with peak densities of 100 tons/hectare) (Binnie and Partners, 1987/1988; Sussex IFCA, 2012).

Sea Search Dive Surveys (Dates)

Seasearch (a United Kingdom-wide citizen science scheme) divers recorded the presence of kelp as "occasional" or "rare" at less than 5% of their dive sites in the 1990s. By the late 2010's, only small patches of kelp were still present, covering an area of 6.28 Km^2 (a 96.4% decline in terms of area coverage compared to 1987) shown in **Figure 1** (Sussex IFCA, 2012). In total, around 530 species were recorded in conjunction with kelp habitat during these dives. **Figure 2** above shows sites dived by the volunteer Seasearch divers where they recorded the presence of kelp over the last 5 decades. Increased records from the 1990's reflect increased survey effort. The proportion of dive sites that had kelp present and the abundance of kelp both declined from the 1980's to 1990's and beyond as **Figures 1**, **2** show.

Valuation Model

The starting point for the ecosystem services valuation model was a literature review (provided in **Supplementary Information**) on the ecosystem service benefits of kelp and kelp forests globally. Ecosystem service benefits associated with kelp habitats (as presented in **Table 1**) were listed. From this starting point, valuations and financial proxies for measurable changes in these ecosystem services, particularly values related to changes per unit area of kelp bed per annum were extracted from the global literature. The figures were assessed for their transferability to a United Kingdom context (kelp species, temperature, depth and density of the study) and incorporated in the model with

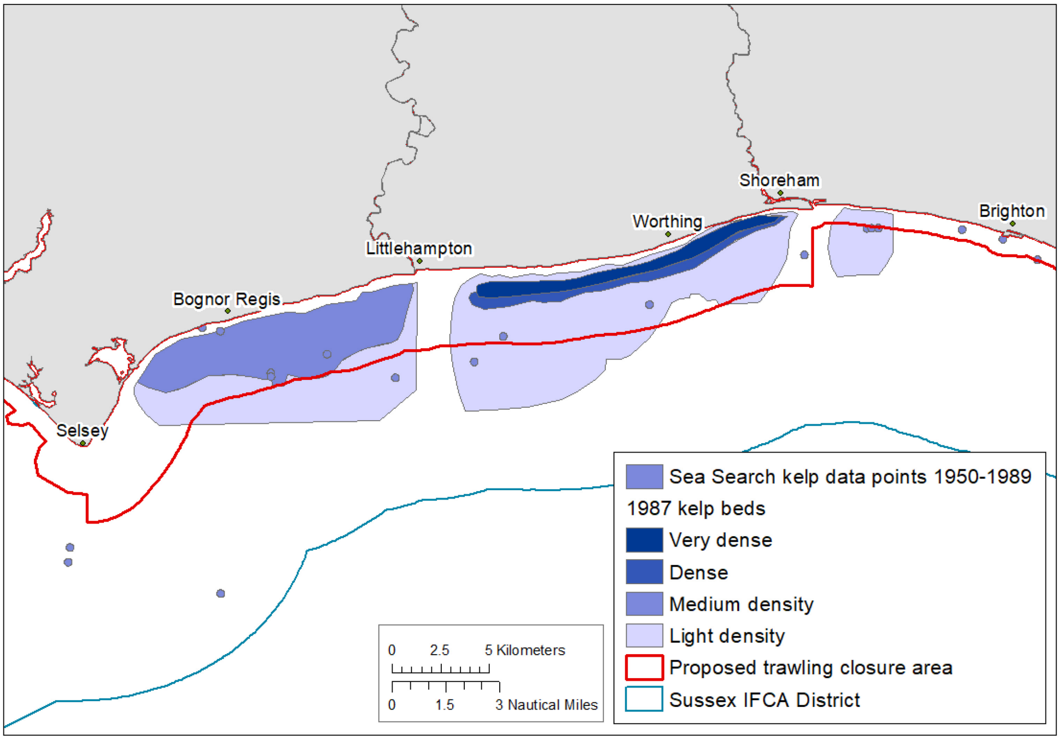

FIGURE 1 | West Sussex Historic kelp bed extent (1950–1989) and kelp observations point data (shown as dots) up to 2015 within the Sussex District. 1 and 4 km management boundaries are illustrated (Sussex IFCA, 2019a) Source: Sussex IFCA.

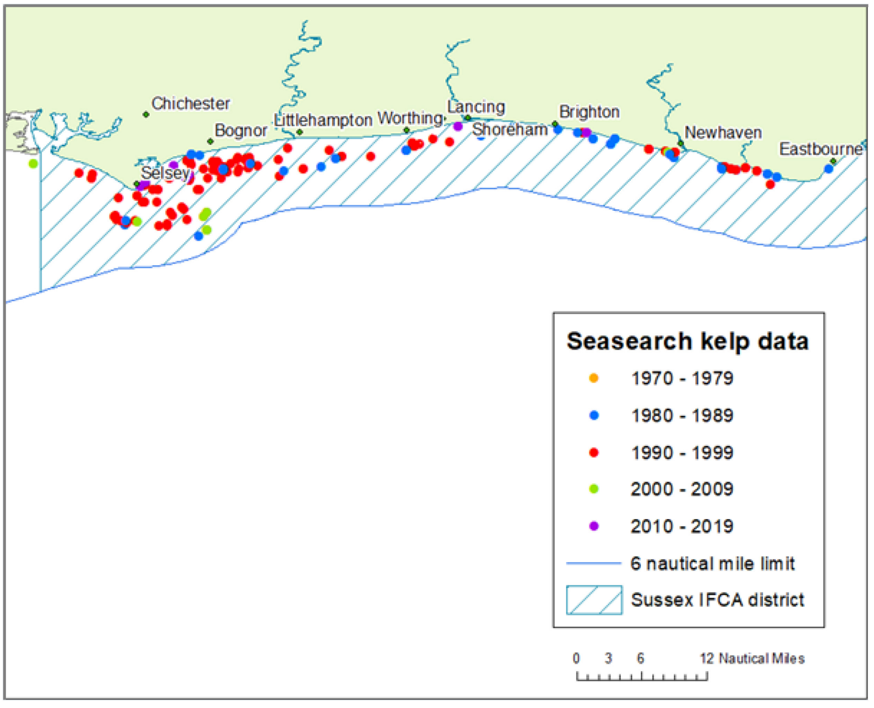

FIGURE 2 | West Sussex kelp observations point data from dive surveys (1970–2019) within the Sussex District. Source: Sussex Seasearch.

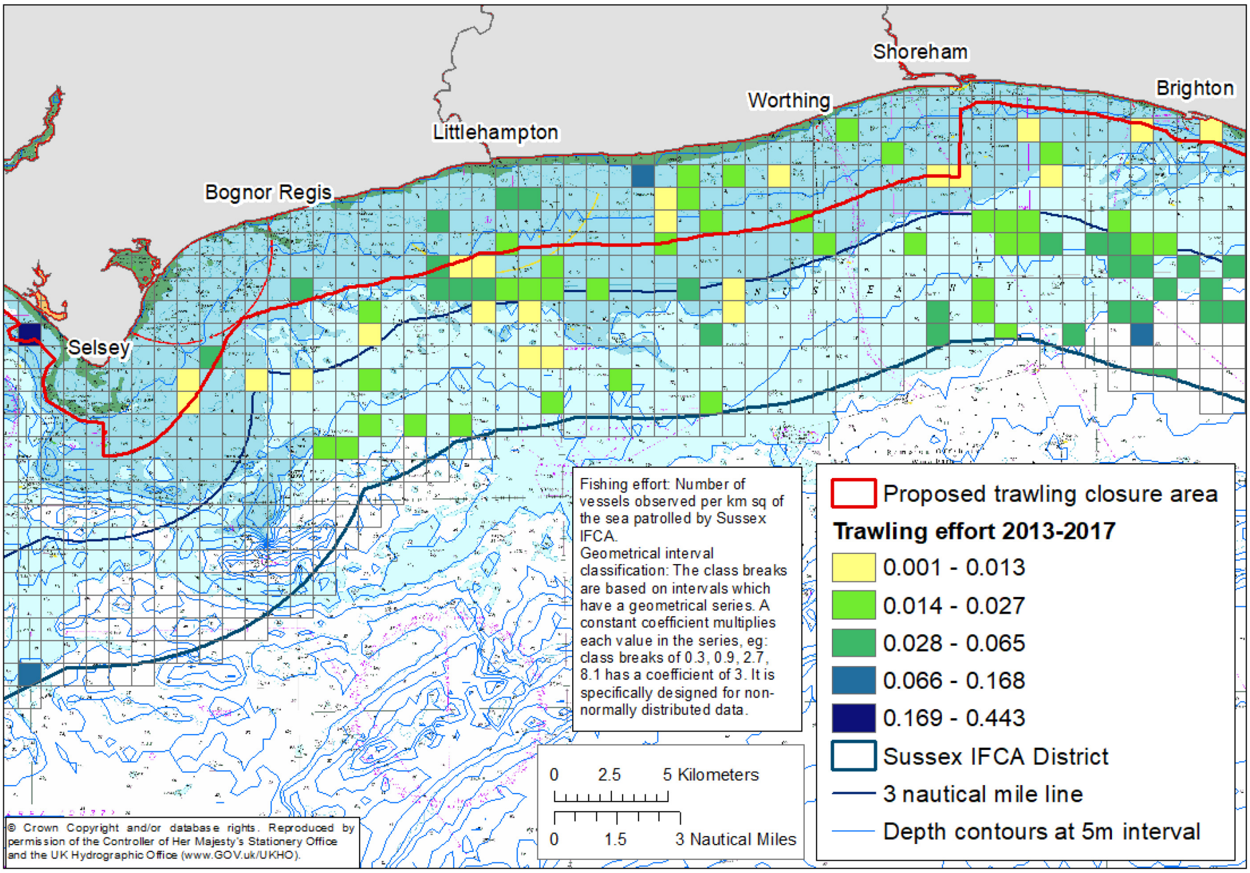

FIGURE 3 | Sightings data for towed gear and kelp observations within the Sussex IFCA district, data from 2014 to 2018. Source: Sussex IFCA.

caveats and assumptions relating to their transferability listed in **Supplementary Information B**. This was deemed necessary as the model estimates economic value through considering area and density of kelp bed (the densest standings of kelp are considered "kelp forests" with higher associated ecosystem service benefits). Some studies were not used in the model as it was not possible to determine a value per unit area of kelp bed (for example, Blamey and Bolton, 2018) (Vásquez et al., 2014).

Following this review of kelp ecosystem service valuations and discussion with Sussex IFCA, seven of these ecosystem services were used in the model as representing the key kelp habitat ecosystem functions (Smale et al., 2016) with the potential to be used to estimate unit area valuations for these services (presented in **Table 2**).

The model was developed in excel and adopts a *benefit transfer* approach to estimate increases in ecosystem service values, defined by Johnston and Wainger (2015) as "the use of research results from pre-existing primary studies at one or more sites (often called study sites) to predict welfare estimates, such as willingness to pay (WTP), for other, typically unstudied sites (often called policy sites)" (Johnston and Wainger, 2015). This approach is used for modeling of this type, when there is insufficient time, resources and primary data from the specific site being assessed. Acknowledging

TABLE 2 | Ecosystem services provided by kelp included in the model.

1. Fishery resources
2. Harvesting e.g., materials (alginates) for pharmaceutical and industrial use
3. Water quality maintenance
4. Protection of coastlines from storm surges waves/reduction in shoreline erosion
5. Carbon sequestration
6. Nursery habitats for commercial fish species
7. Tourism and recreation (e.g., diving)

limitations around both measurement and generalization error when using benefit transfers is important (Johnston and Wainger, 2015). Addressing these limitations in modeling assumptions and reporting can improve the degree of confidence in the valuation without risk of over- or under-claiming. The model provides indicative values from the best available evidence in a rapid, low-cost, transparent and replicable manner to be further developed over time.

Specific information for valuing kelp ecosystems is sparse globally, but especially in a United Kingdom context. As such, confidence in the relevance of these values to both the case-study context (Southern England) and the specific environment (kelp bed habitat) varied across the ecosystem services selected. Therefore each ecosystem service was assigned a confidence rating on the value's relevance to the specific case-study context. Highest confidence (level 3) was assigned to peer reviewed studies that provided values from a comparable United Kingdom site, moderate confidence (level 2) was assigned to values from overseas sites provided in peer-reviewed literature, or gray literature that provided values from United Kingdom and comparable European sites. Lowest confidence (level 1) was assigned to values from reported expert opinion.

Applying benefit transfer methods was the only viable approach to estimating ecosystem service benefits in this case study area given budget and time constraints. This approach is however, limited and potentially less accurate than baseline data collection *in situ* (this may be a result of "generalization error," where values are transferred without fully accounting for those differences). We attempt to explicitly account for the differences between the proxies used and ecological variation through using lower level estimates (Brander et al., 2020).

Value Transfer

This section described the process for selecting the values, assumptions and caveats for the benefit transfers used in the excel model.

For Provisioning Services (fishery resources and harvesting), economic proxies were taken from a recent study exploring the economic valuation of kelp forests in northern Chile (Vásquez et al., 2014; Blamey and Bolton, 2018), giving financial values of £2,066 and £10,288 per km^2 per annum, respectively. These values were calculated by first taking the annual mean from 10-year estimates for kelp harvesting and associated fisheries (US$409,527,000 and US$83,298, respectively). The area of kelp bed extent in this study was estimated as 3,500 km^2 (700 km coastline by 5 km offshore, based on rough bathymetry of potential for kelp growth in suitable habitat shallower than 50 m) (Burrows et al., 2014). The value per km^2 was then calculated by dividing the annual total by area, before applying currency conversion and adjusting for inflation. A limitation to these proxies is the different regional context between Chile and England. Additionally, the capture production (tons) of fisheries in Chile and the United Kingdom differ with the Chilean fisheries capture production approximately 2,122.4 thousand tons in 2018, compared to the United Kingdom value 700.2 thousand tons in 2018 [Food and Agriculture Organization [FAO], 2020].

For Regulating Services, limited kelp-specific data was available so again a seagrass proxy was used. For two ecosystem services (Water quality maintenance; and Protection of coastlines from storm surges waves/reduction in shoreline erosion), seagrass ecosystem proxies from Campagne et al.'s (2015) study based in the Mediterranean (Campagne et al., 2015) were used. There are clearly limitations in this approach, in that seagrass provides habitat for a different range of species and biodiversity, productivity and therefore ecosystem service benefits to those of kelp. Seagrass habitats do share similarities with kelp (Marine Scotland, 2016). Furthermore, *Posidonia* seagrasses forms less complex ecosystems than *laminarian* kelps, and is therefore likely an underestimate when used as a proxy (Como et al., 2008; Blamey and Bolton, 2018; Brander et al., 2020). Campagne et al. (2015) estimate the protection of coastlines from storm surges/waves and a resultant reduction in shoreline erosion through an estimation of expenditure of European protection against erosion. Converted from Ha to km^2, converted from € to £; and adjusted for inflation, the value used here is £17,870 per km^2 per annum. For water quality maintenance, Campagne et al. (2015) use the amount of the environmental tax for the preservation of natural resources in France, i.e., 0.19 €/m^3, with the value assigned for wastewater treatment by the coastal system achieved by splitting the value into three (1/3 estuaries, 1/3 coastal system and 1/3 open ocean). Converted from m^2 to km^2, converted from € to £ and adjusted for inflation, the value used was £5,703 per km^2 per annum.

The carbon sequestration value was taken from a Falkland Islands' based study that explored the *blue carbon* potential of the area's kelp habitats (Bayley et al., 2017) providing the value of £9,046 per km^2 per annum. This was calculated using the following values: the total area of kelp habitat in the Falkland Islands (644.05 km^2) and the total carbon sequestration for this area estimated as 0.239 million tons CO^2 equivalent. The total is divided by cost per ton of CO^2, estimated as £24 (as of 10/07/2019) and then adjusted for currency and inflation accordingly.

Nursery habitats for commercial fish species [supporting services, valued at £7,099, was calculated from a 2010 Australian study Unsworth et al. (2010) in Dewsbury et al. (2016)] which calculated a value for a seagrass habitat as $78 USD per Ha per annum. Acknowledging the aforementioned caveats of using seagrass related proxies, this value was converted into £ and adjusted for inflation. One Cultural Service was included in the model, i.e., tourism and recreation (e.g., diving). This proxy was estimated through local expert knowledge from diving schools in the region and their ability to offer diving opportunities in the case-study site and forecasts on how increases in kelp coverage could increase diving-related tourism (by estimating the current annual value per km^2). With a current kelp bed extent of 6.28 km^2, there are five diving schools offering approximately 100 trips a year at around £40 per trip. This equals around £4,058 per km^2 per annum.

The excel model applied a density percentage in a simple, linear manner: Low density (25%), Medium density (50%), High Density (75%) and Very High Density (100%). Except for the "Harvesting e.g., materials (alginates) for pharmaceutical and industrial use" category. Here, 0% is given for Low, Medium and High Density, with 100% for Very High Density. This is to reflect that kelp harvesting is unlikely to occur at an industrial level unless there is substantial kelp forest present. In reality, the relationship between ecosystem service and kelp bed density is more complicated. Nevertheless reflecting differences in kelp bed density and the effect on ecosystem services in some form was necessary. There exists potential to update these percentages with improved data in the future.

Three scenarios for kelp bed recovery in consultation with SxIFCA were developed: the current scenario, the past extent (1987, as recorded in the Worthing Council report by Binnie and Partners, 1987/1988) and a hypothetical maximum. Data provided by SxIFCA provided estimations for kelp bed extent (in km^2) and density (as a%). These are presented below in

TABLE 3 | Kelp bed extent and densities for each scenario.

	Kelp bed extent (km^2)	Proportion of kelp bed densities (%)
Current scenario	6.28	90% low density 10% medium density
Past extent (1987)	177	60% low density 20% medium density 10% high density 10% very high density
Hypothetical maximum	167	50% low density 40% medium density 5% high density 5% very high density

Table 3. For the hypothetical maximum scenario, estimates were determined by bathymetry and substrate that were possible for the growth of kelp. Note also, that this scenario is actually less than the 1987 past extent, which points to potential inaccuracies of past data.

Table 4 below shows the existing valuations per unit area used for benefit transfer, including the year, geographical location of study, value (converted to £ and adjusted for inflation), confidence rating as well as the year and references of the peer reviewed studies undertaken.

RESULTS

The ecosystem services valuation for the current extent of kelp habit off the West Sussex coastline, based on benefits transfer was estimated at £79,170 per annum using the figures presented in **Table 5** below.

A percentage of each ecosystem service's valuation depending on kelp bed density was modeled. This was categorized as follows for six of the services: Low density (25%), Medium density (50%), High Density (75%) and Very High Density (100%) and as 0% for Low, Medium and High Density, and 100% for Very High Density for Kelp harvesting.

Around 6.28 km2 of kelp bed remains, the majority of which is low density. The small area of kelp bed coverage means there is only a small fishery value associated with kelp habitat (£3,569, or 5% of the total) and there is no current value in harvesting kelp as a resource. The highest value ecosystem service is kelp's contribution to protecting coastlines from the impacts of storm surge and coastal erosion (£30,861, or 39% of the total). With little kelp extent, the tourism value associated with the kelp ecosystem is also low (£7,008, or 9% of the total).

We calculated the ecosystem services values if the kelp bed were returned to 1987 levels of coverage and density. With kelp bed extent estimated as 2,800% greater in 1987 than 2020 as well as considerably more kelp bed categorized as high/very high density, there is a significantly higher historic valuation of £3,630,605 per annum. In this scenario, fishery resource and nursery habitats for commercial fish species supported by kelp are estimated at approximately £700,000 per annum (19% of the total). Kelp harvesting for materials like alginates could occur (although this is extremely unlikely given the small area and low density of kelp at present), with estimates of £182,095 per annum for the highest density areas. Protection of coastlines from storm surges waves/reduction in shoreline erosion provides the most value, £1,344,264, or 37% of the total. Tourism and recreation associated with kelp bed significantly increases in this scenario, with more activity such as diving possible in the restored habitat (£305,273 compared to £7,008 in the present day scenario).

Restoring kelp beds to a hypothetical maximum was estimated as similar to 1987, given the similar area of kelp bed extent (167 km^2 compared to 177 km^2) and similar distribution of density. A noticeable difference is the value for harvesting materials such as alginates, where 1987 past extent had an estimated value of £182,095 per annum, the hypothetical maximum has only £85,904 per annum. This is due to lower extent of very high-density bed.

Figure 4 summarizes the ecosystem service valuations modeled for all three scenarios and categorizes value covering four ecosystem services types: *provisioning, regulating, supporting and cultural services,* combined.

Figure 5 presents a comparison of the scenarios modeled in terms of financial value estimate by ecosystem service type.

DISCUSSION

This study demonstrates that there are potential economic and societal benefits linked to the recovery of kelp habitats in this case study area. There are however, a number of constraints and opportunities linked to this modeling exercise, which warrant discussion.

Lack of Transferable Economic and Spatial Data to Make Meaningful Place-Based Decisions

This study had demonstrated that whilst valuations may be possible using value/benefit transfer as economic tools the associated confidence to inform place-based decision making is still very low as more empirical data are needed to reliably inform such models.

Specific valuations for kelp ecosystem services in the United Kingdom, as globally, are limited, with coral reefs, salt marshes and mangroves more often the focus of study (Services, 2019). Searching valuation databases such as the Ecosystem Service Valuation Database (ESVD)[1] and Environmental Valuation Reference Inventory (EVRI)[2] highlights this: the ESVD contains over 600 studies, with only a handful exploring kelp habitats (Unsworth et al., 2010; Dewsbury et al., 2016; Blamey and Bolton, 2018; Business Insider, 2020), while there are only seven studies in the EVRI that mention the term "kelp" in a database containing over 4,000 studies.

Kelp-dominated habitats along much of the NE Atlantic coastline have been chronically understudied and a lack of field-based research currently impedes the ability to conserve and manage these crucial marine ecosystems. The structure of kelp

[1] https://www.esvd.info/

[2] www.evri.ca

TABLE 4 | Kelp ecosystem service valuations used in model.

Ecosystem service type	Ecosystem service	Economic value per km^2 per year (£)* *adjusted for inflation	Year	Country/ Region	Habitat type	Confidence rating (1 = low, 2 = medium, 3 = high)	Economic valuation from source	Currency	Currency conversion	References
Provisioning services	Fishery resources	£2,066.43	2012	Northern Chile	Kelp	2	2350.22	United States Dollar	1880.18	Vásquez et al., 2014
	Harvesting e.g., materials (alginates) for pharmaceutical and industrial use	£10,287.87	2012	Northern Chile	Kelp	2	11700.77	United States Dollar	9360.62	Vásquez et al., 2014
Regulating services	Water quality maintenance	£5,703.16	2015	Mediterranean	Seagrass	2	60	Euros	54.00	Weatherdon et al., 2017 Campagne et al., 2015
	Protection of coastlines from storm surges waves/reduction in shoreline erosion	£17,869.91	2015	Mediterranean	Seagrass	2	188	Euros	169.20	Weatherdon et al., 2017 Campagne et al., 2015
	Carbon sequestration	£9,046.17	2017/ 2018	Falkland Islands	Kelp	2	8909.85	GBP	8909.85	Bayley et al., 2017
Supporting services	Nursery habitats for commercial fish species	£7,098.81	2010	Australia	Seagrass	2	78	United States Dollar	62.40	Unsworth et al., 2010 Dewsbury et al., 2016
Cultural services	Tourism and recreation (e.g., diving)	£4,058.13	2019	Sussex, United Kingdom	Kelp	1	n/a	GBP	4058.13	Expert Knowledge and estimates (Sussex Seasearch)

TABLE 5 | Calculations of current ecosystem service benefits of kelp used in the model.

	Kelp bed extent (km^2)	Value per km^2 (£)	Area by kelp bed density (%)				Value of areas of kelp bed density (£)				Total value (£)
			Low	Medium	High	Very High	Low	Medium	High	Very High	
Fishery resources	6.28	£ 2,066.43	90%	10%	0%	0%	£ 2,920	£ 649	£ -	£ -	£ 3,569
Harvesting e.g., materials (alginates) for pharmaceutical and industrial use	6.28	£ 10,287.87	90%	10%	0%	0%	£ -	£ -	£ -	£ -	£ -
Water quality maintenance	6.28	£ 5,703.16	90%	10%	0%	0%	£ 8,059	£ 1,791	£ -	£ -	£ 9,849
Protection of coastlines from storm surges and waves Reduction of shoreline erosion Stabilization of submerged land by trapping sediments	6.28	£ 17,869.91	90%	10%	0%	0%	£ 25,250	£ 5,611	£ -	£ -	£ 30,861
Carbon sequestration	6.28	£ 9,046.17	90%	10%	0%	0%	£ 12,782	£ 2,840	£ -	£ -	£ 15,623
Nursery habitats for commercial fish species	6.28	£ 7,098.81	90%	10%	0%	0%	£ 10,031	£ 2,229	£ -	£ -	£ 12,260
Tourism and recreation	6.28	£ 4,058.13	90%	10%	0%	0%	£ 5,734	£ 1,274	£ -	£ -	£ 7,008
										Total ecosystem services value	£ 79,170

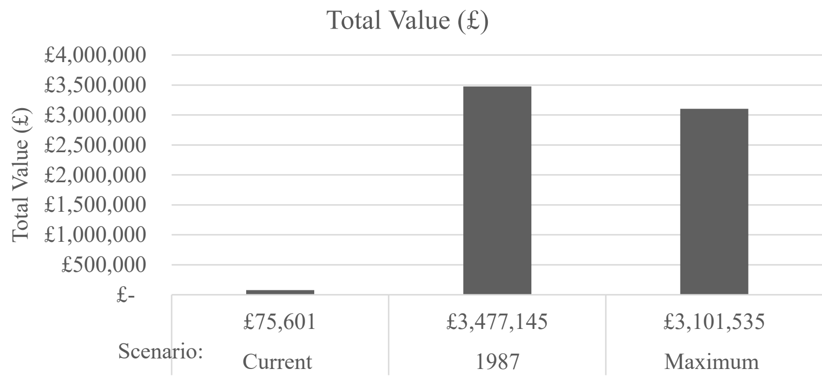

FIGURE 4 | Comparison of total value under three scenarios.

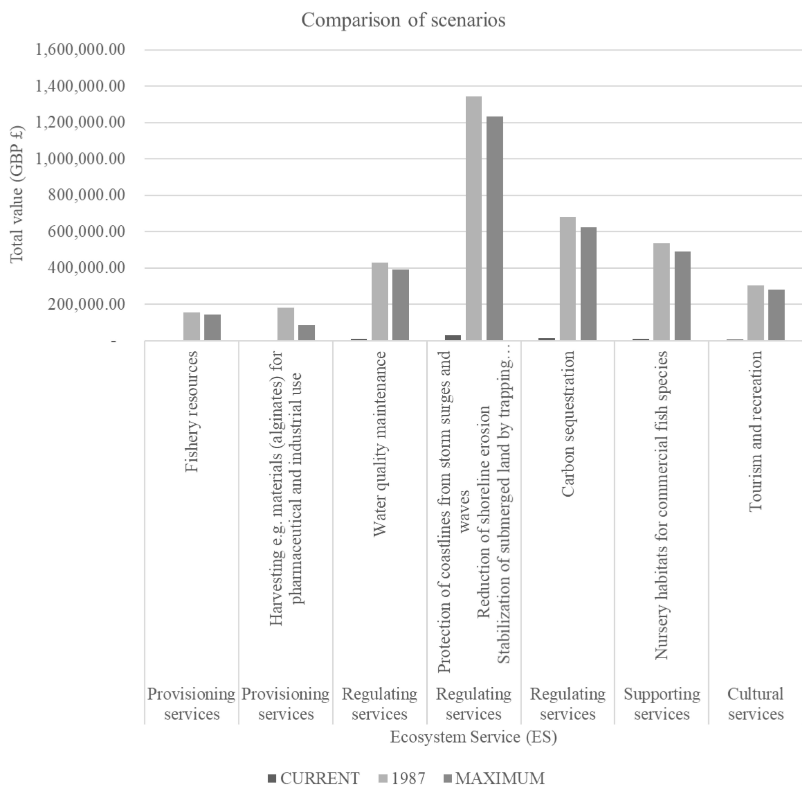

FIGURE 5 | Comparison of the results for all three scenarios.

forests in the NE Atlantic region is changing in response to both climate- and non-climatic stressors, with major implications for the structure and functioning of coastal ecosystems. Fisheries management cannot account for these larger scale global changes. Supporting greater understanding of the resistance and resilience of kelp to stressors, including climate change, is becoming increasingly important and the sustainable management of kelp systems depends on integrated approaches, spanning multiple ecosystems (Smale et al., 2013).

Spatial aspects of ecosystem valuation need to be mapped and assessed and a natural capital portfolio approach (which uses existing marine data sets and assessment results) which also examines ecosystem degradation is needed (Austen et al., 2019). Without a wider approach the impacts of changing fisheries management are unlikely to halt indirect degradation.

Uncertainty remains a barrier for all decision-making regarding the marine environment and while this uncertainty needs to be made explicit in decision-making there is also a clear role for using *best available evidence* and being clear (in the assumptions, scenarios and findings) what the limits of that information are. Monitoring changes and determining the economic and social impacts over time will help the evidence base and enable future valuations to be based on site-specific information. Using an interdisciplinary approach to bridge between scientific/academic and local ecological knowledge in the formulation of management strategies is essential (Börger et al., 2014; Hooper et al., 2019; Tinch et al., 2019).

During the modeling of benefits of kelp recovery, the difference between the 1987 scenario and hypothetical maximum raise interesting questions about the quality of the data from that time period, as well as how to define the hypothetical maximum kelp bed restoration in this context. Again, monitoring (as proposed through Sussex Seasearch and Sussex Wildlife Trust) will help inform the accuracy of future modeling.

Distribution of Costs and Benefits

Stakeholders have diverse interests from commercial gain to recreation or conservation. Balancing these different interests entails negotiation and dialog and power relations are never equal, nor are the value systems. Therefore an acknowledgement of financial interest of some fishers affected, as well as the inequality in power, the conditions which shape that dynamic and a transparent presentation of those who are likely to gain or lose from management decisions need to be presented openly (Ellis et al., 2019). In this case the costs in the short term all accrue to the trawling fleet that fish within 4 km from the West Sussex shoreline, while the medium to long-term beneficiaries are likely to include static gear fishermen, anglers, divers, coastal tourists and to a notable extent coastal residents—through shoreline protection and carbon sequestration—but are not limited to those due to the documented fisheries benefits of kelp forests cited from the available literature and oral history (Davies and Nelson, 2019). The most notable ecosystem services in terms of the valuation presented in the model would not accrue to individual sea users, but to society overall. Balancing short-term economic costs to industry vs. long-term gains in biodiversity and natural habitat restoration is to a large extent incommensurable, but management decisions need to take account of the full range of costs and benefits and acknowledge they are not evenly felt. The distributional reality is that the costs and benefits will not be allocated evenly between stakeholders. It has been shown that engagement with stakeholders and those affected by management decisions in the marine environment is valuable to better understand the trade-offs, possible feedback loops and wider consequences of management decisions (Börger et al., 2014).

Trajectories of Kelp Recovery

The coastal waters off West Sussex were once kelp dominated for a wide extent of the platform extending from Selsey through to Bognor Regis, Littlehampton and Worthing (**Figure 1**). The extend of kelp coverage has declined by over 96% since the area was surveyed by Worthing Council and fishing practices (especially pair trawling), pollution and storm damage (Davies and Nelson, 2019) have driven this change. If the 1987 report can be considered a "Natural Capital Asset register" (Hooper et al., 2019) (i.e., an inventory of the extent and health of the Kelp beds) this can be used as a baseline. The Natural Capital Committee (NCC) also proposed the development of a risk register, where those activities, which present the greatest threat, are addressed first in the process (Hooper et al., 2019) although these include climate change and trophic changes which are indirect impacts outside the control of fisheries management bodies at a regional level. While this is not common practice, this management issue presents an opportunity to adopt that advice. Starting an asset register now, in the current degraded condition, while not ideal, presents an opportunity for a baseline which the impact and success of management can be measured against. This would link the efforts at local scale to others, e.g., through the North Devon Marine Pioneer project, which has also developed a marine natural capital asset register (Rees et al., 2019), but comprehensive monitoring of changes will also be necessary (Sheehan et al., 2013).

Fisheries Management Has a Role in the Delivery of Nature Based Solutions

Removing the pressure from mobile fishing gear in the coastal strip, as proposed by Sussex IFCA provides an opportunity to develop the ecosystem approach to fisheries management and marine planning in the United Kingdom) (Börger et al., 2014).

A factor in using an ecosystem approach to management is the role of valuation to inform management decisions. Trade-offs between human uses of the sea and conservation need to be understood, presented to stakeholders, experts and decision-makers and used in conjunction with deliberation to reach decisions on local level management to support sustainability (Beaumont et al., 2018). Possibly to concept of "natures contribution to people" could be used in conjunction with the language of natural capital and ecosystem services to ensure that a plurality of both values and language are used, as it has been shown that not all people find the economic framing helpful (IPBES, 2019).

Examples of the effective use of an ES approach in management are limited both in spatial extent (as the approach is more effective at a local level) and a sub-set of ES that can be more accurately valued (Beaumont et al., 2018). High uncertainty defines many aspects of marine management, but decisions need to be made using best available evidence and expert judgment as an essential informational component to contribute to decision making (Beaumont et al., 2018).

Externalities from market failure (overfishing or the destruction of EFH through fishing and pollution) mean socially inefficient and undesirable outcomes, so policies are needed (whether taxes, subsidies, quotas, permits, regulations or bans/closures) to ensure societal preferences are represented (Tinch et al., 2019). Precautionary management measures to limit the use of fishing gears which negatively impact marine habitats are necessary and widely advocated in global literature (Jones, 1992; FAO/UNEP, 2010; Börger et al., 2014; Beaumont et al., 2018; Caddell, 2018; Sumaila, 2018; Laffoley et al., 2019). Longer-term benefits to fisheries from kelp habitat recovery are also likely, and important to consider in trade-offs or cost—benefit analysis. For instance, European Atlantic Area kelp habitat provide nursery and adult habitat for multiple commercially targeted species

(Gonzalezgurriaran and Freire, 1994; Sarno et al., 1994; Kelly, 2005; Norderhaug et al., 2005; Peteiro and Freire, 2009; Sundblad et al., 2013). In other temperate kelp habitats, where management has restricted extractive fisheries to aid habitat recovery or restoration, biomass of commercially and recreationally targeted species increased consistently in all sites (Caselle et al., 2015; Jaco and Steele, 2020). Potential economic benefit was also available to commercial and recreational fisheries, as biomass of targeted species also increased outside managed sites (Caselle et al., 2015; Jaco and Steele, 2020). Increase in populations of predatory crab and lobster species may also limit populations of urchin species, that adversely impact kelp habitats, thereby, further enabling long-term provision of multiple ecosystem service benefits (Pederson and Johnson, 2006; Ling et al., 2009).

CONCLUSION

There are a range of possible scenarios of the long-term benefits of the restoration of kelp forest which have been modeled using benefits transfer from available peer reviewed literature (often for other contexts, regions and species). The results suggest that regulating services have the highest likely benefits, followed by supporting services and provisioning services. The lower contribution of cultural services may change over time, as indeed could any of the others (e.g., through increases to fish and shellfish stocks as a result of a larger extent of supporting kelp forest habitat).

A low cost, rapid model developed using existing valuations from other contexts and environments is not ideal, but in the absence of good spatial assessments in the particular location where nature-based solutions are proposed and management of human activity is required, these serve as the only available proxy unless primary data is collected. Collecting data to support ecosystem-based management (e.g., linking the landings by species in the West Sussex ports to the interaction with kelp and determining what the impact on fisheries could be) is needed to ensure the decision-making process can rely on local data and incorporate the knowledge of local stakeholders effectively as well as to improve and update valuation models. When using benefit transfer, transparency (around the assumptions used) is key to avoid over or under-claiming the value of ecosystem services from a different context, species or region.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

CW and WD provided the original research and valuation, which were supported by SR, MA, and ES. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fevo.2022.642775/full#supplementary-material

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