Valuing the ecosystem service benefits of kelp bed recovery off West Sussex

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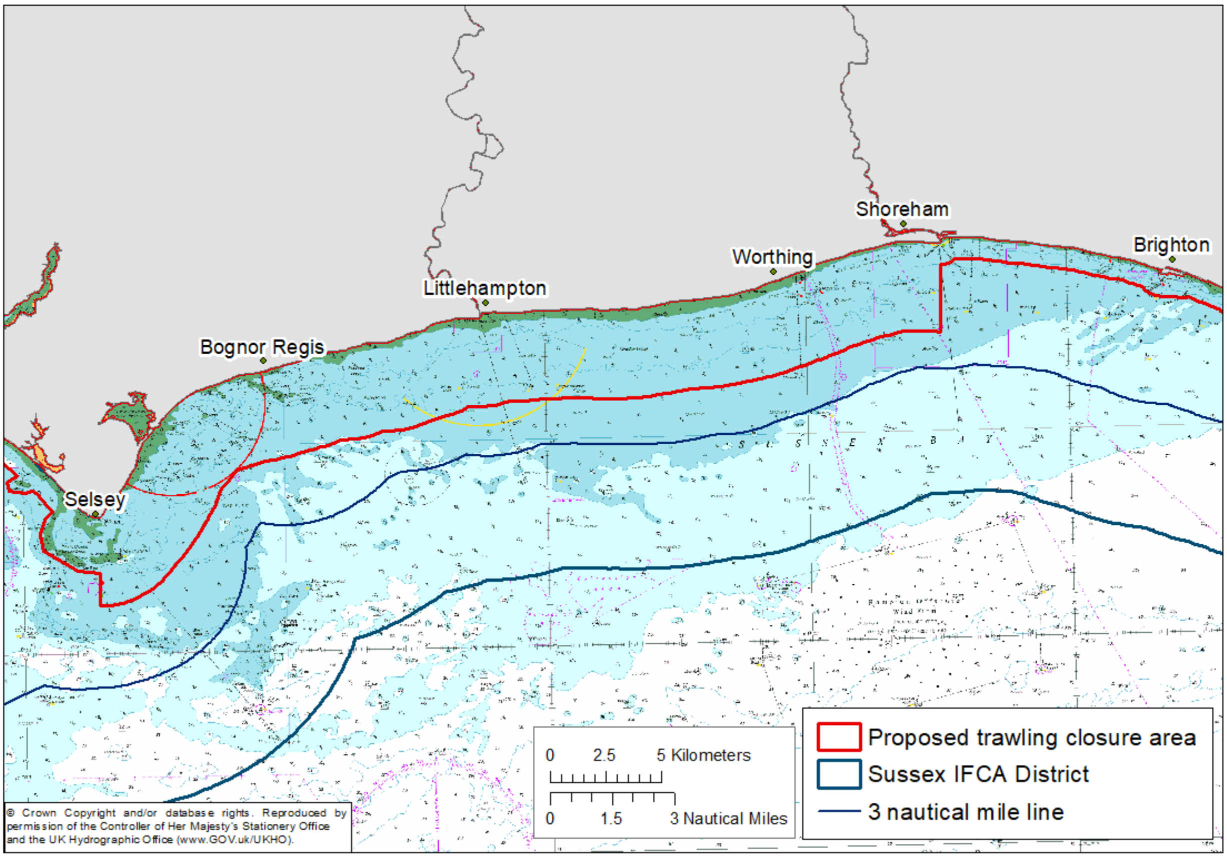
1. West Sussex

The English county of West Sussex is a historic county, bordering East Sussex, Hampshire, and Surrey with a coastline along the English Channel. With a population of more than 800,000 (1.5% of England total) and covering nearly 2000 km^2 , the county also contains a number of settlements from larger cities (Chichester and Crawley) to the smaller coastal towns (e.g. Selsey, Bognor Regis, Littlehampton and Worthing) as well as the industrial port town of Shoreham. West Sussex has a range of terrestrial and coastal habitats, mainly formed from Upper Jurassic and Lower Cretaceous rock layers, which have eroded over millennia. The two valleys of the River Arun (meeting the sea at Littlehampton) and River Adur (meeting the sea at Shoreham) are the main rivers, while Chichester Harbour forms the western border of the County.[1] The marine habitat in Sussex Bay (Selsey to Brighton) is mainly bedrock with a thin veneer of cobbles, coarse sediment and sand.[2]

Figure 1: Map of West Sussex including coastal towns with commercial fishing vessels. From West to East: Selsey, Bognor Regis, Littlehampton, Worthing, Shoreham-by-Sea including proposed management zones 1 and 2. Source: Sussex IFCA[3]

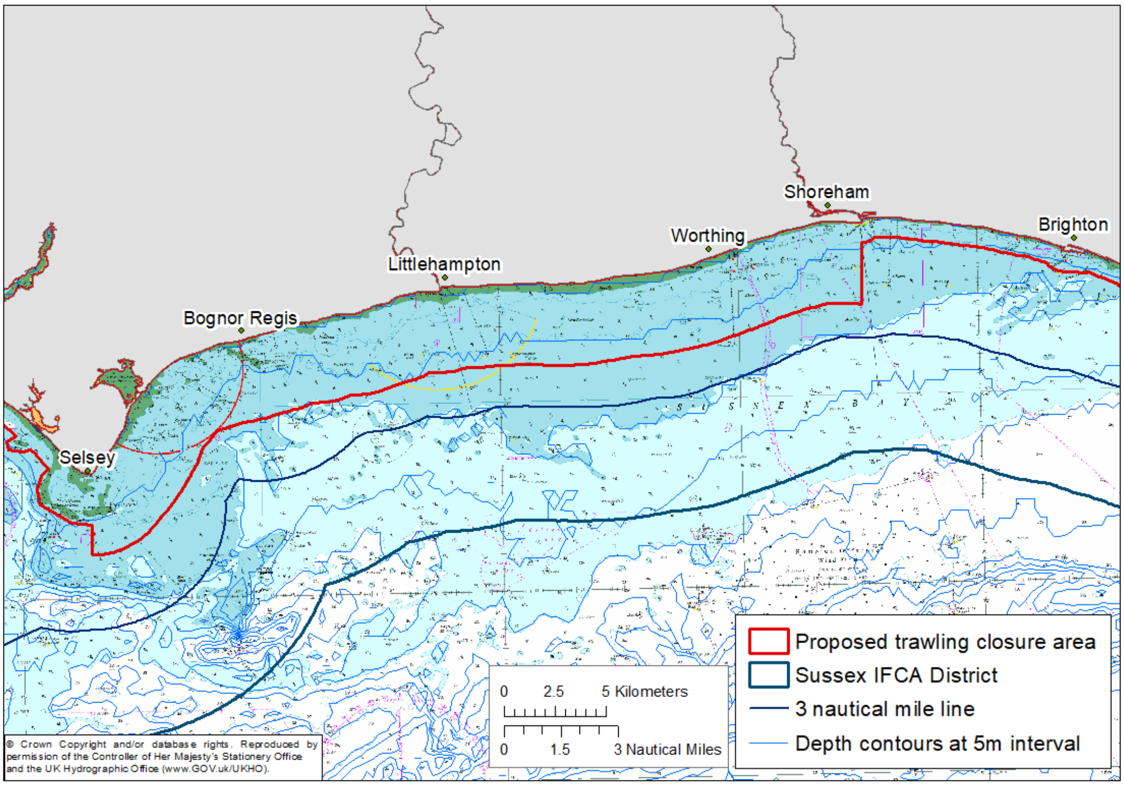


2. Fishing in West Sussex

Fishing Ports

As shown in figure 1 above, there are six coastal communities with active fishing fleets in West Sussex. The most significant commercial fishing port is Shoreham-by-sea, and some smaller inshore fishing ports and beach landing sites are also found along the coast: heading west from Shoreham, these are Worthing, Littlehampton, Bognor Regis, Selsey and Emsworth (Chichester Harbour). Pressures affecting the Sussex coastal include recreational activities, aggregate extraction, renewable energy and maintenance dredging as well as commercial fishing, using a variety of fishing methods across a diverse range of seabed habitats.[4]

Figure 2: Chart of West Sussex coastline and inshore depth contours main fishing ports and coastal towns. Source: Sussex IFCA



Vessels

According to the June 2019 MMO data, there are 65 under 10m vessels registered with home ports in West Sussex (Shoreham-by-sea, Littlehampton, Selsey, Worthing, Bognor Regis and Emsworth), with an average length of 6.8m. The majority are based in Shoreham. Of these, 25 have shellfish entitlements. None have scallop licenses. All non-sector (i.e. fish from the MMO quota pool for under 10m vessels or fish for non-quota species / shellfish).

According to the June 2019 MMO data, there are nine over 10m vessels registered with home ports in West Sussex (Shoreham and Selsey), with an average length of 17.8m. Three have shellfish entitlements. Five have scallop licenses. Six are members of the South West Producer Organisation and three are non-sector (i.e. fish from the MMO quota pool for under 10m vessels or fish for non-quota species / shellfish).

In 2016, 53 vessels landed seafood caught using towed gears. From 2012 to 2016, by weight, otter trawling accounted for 55% of Sussex landings, beam trawling accounted for 34%, and pair trawls accounted for 9%. In terms of species caught, plaice (29%), sole (15%), dogfish (7%), bream (7%), lemon sole (4%), and cuttlefish (3.7%) were the highest recorded by volume. The maximum landed by a single vessel was 170 tonnes.[5]

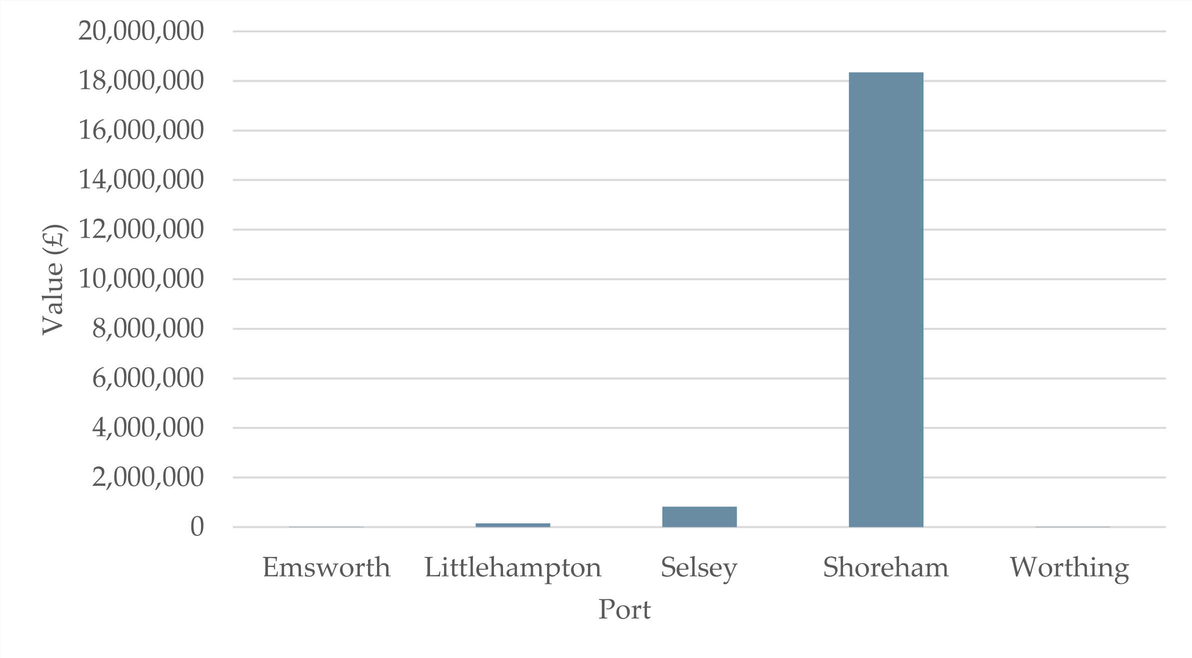
Landings

According to MMO landings data for 2016-2018 Shoreham is by far the largest port in terms of landings, with over £18 million in first sale landed value in 2018. Selsey at £829,680 is the second most significant coastal community in terms of landings. Littlehampton is 3rd at £154K, with Bognor Regis, Emsworth and Worthing all landing very low annual totals in 2017 and 2018. The Emsworth oyster landings had been considerable in 2016, thereby increasing the total. In terms of the main commercial landings, the species landed in each of the ports are similar but the focal point for some is shellfish and as a result of the majority of the fleet for these ports being under 10m in length the focus on shellfish and non-quota species such as bass and bream is notable.

Table 1: MMO landings for West Sussex ports in terms of value (£, rounded) 2016-2018. Source: MMO

Port	**2016**	**2017**	**2018**
Bognor Regis	56,717	42,439	22,018
Emsworth	62,449	7,727	5,055
Littlehampton	269,658	268,039	154,895
Selsey	1,106,690	965,193	829,680
Shoreham	9,104,892	12,837,659	18,351,640
Worthing	7,644	4,728	4,220

Figure 3: MMO landings for West Sussex ports in terms of value (£) 2016-2018. Source: MMO



In terms of key species, landings in ***Bognor Regis*** are dominated by lobsters (99% of 2018 landings in terms of value), with low landings of some other demersal species such as cod and shellfish such as crabs. Notably the landed value of lobsters has declined by over 50% between 2016 and 2018. Two tonnes of lobster were landed in Bognor Regis in 2018.

Table 2: MMO landings of lobster in Bognor Regis in terms of value (£, rounded) 2016-2018. Source: MMO

Bognor Regis	2016	2017	2018
Lobsters	£ 56,046.88	£ 42,438.68	£ 21,840.01

Emsworth has a mixed fishery for finfish and shellfish, and traditionally was a significant port for native oyster landings from Chichester Harbour. These landings however have declined since 2016 when £53K worth of native oyster were landed to 0 in 2018 as the fishery was closed. Other species landed include bass, sole and plaice as well as bream, smooth-hound and mackerel. 0.8 of a tonne were landed into Emsworth in 2018, making it by any English standard a tiny port without the oyster fishery.

Table 3: MMO landings for main species in Emsworth in terms of value (£, rounded) 2016-2018. Source: MMO

Emsworth	**2016**		**2017**		**2018**
Native Oysters	52,386	Bass	2,081	Sole	2,053
Bass	3,486	Native Oysters	1,595	Bass	1,482
Plaice	1,408	Mullet	624	Mackerel	396
Sole	889	Sole	563	Skates and Rays	246

Littlehampton is also a mixed fishery, where whelk have been the main species landed, followed by cuttlefish, bass and plaice as well as crabs and lobsters. Both bream and smooth hounds are also landed in Littlehampton and in total 71 tonnes were landed into Littlehampton in 2018, 60% of which were whelks.

Table 4: MMO landings for main species in Littlehampton in terms of value (£, rounded) 2016-2018. Source: MMO

Littlehampton	**2016**		**2017**		**2018**
Whelks	77,215	Whelks	112,627	Whelks	56,611
Cuttlefish	72,158	Cuttlefish	25,492	Sole	18,878
Bass	25,636	Crabs	23,062	Bass	15,963
Crabs	18,273	Lobsters	21,404	Plaice	15,895
Lobsters	16,164	Sole	20,040	Crabs	14,151
Sole	13,127	Smooth hound	18,619	Lobsters	10,244
Cod	9,631	Bass	16,309	Skates / Rays	4,958
Smooth hound	9,523	Plaice	9,482	Other Demersal	4,952
Bream	9,274	Bream	6,276	Cuttlefish	4,674
Plaice	9,128	Cod	2,510	Bream	3,932

Selsey landings are mainly focussed on shellfish, with lobster, crab and whelk the main species landed in terms of value. Cuttlefish are also landed, as are bass and sole. Skates and rays, bream and smooth hound are also landed at Selsey and 267 tonnes were landed into Selsey in 2018, 84% of the total comprised landings of lobster, crab and whelk.

Table 5: MMO landings for main species in Selsey in terms of value (£, rounded) 2016-2018. Source: MMO

Selsey	**2016**		**2017**		**2018**
Lobsters	418,139	Lobsters	384,123	Lobsters	322,457
Whelks	274,777	Crabs	217,312	Crabs	246,289
Crabs	223,390	Whelks	214,802	Whelks	117,029
Cuttlefish	70,629	Bass	76,003	Bass	66,193
Bass	63,394	Cuttlefish	32,372	Cuttlefish	31,483
Sole	28,962	Sole	17,173	Sole	19,929
Smooth hound	5,736	Smooth hound	5,982	Other Demersal	9,478
Native Oysters	4,336	Thornback Ray	4,484	Skates and Rays	6,296
Plaice	4,099	Plaice	2,758	Plaice	3,990
Bream	3,254	Bream	1,752	Mullet	1,797
Thornback Ray	3,249	Conger Eels	1,690	Bream	1,544

Shoreham-by-sea landings are dominated by scallops, caught by visiting and local vessels who dredge in Scallop grounds along the south coast. Scallop dredging is not permitted within 3 miles from shore via a Sussex IFCA byelaw. The remaining landings are dominated by whelks and sole and plaice, as well as cuttlefish, skates and rays, crabs, bass and bream. 8,212 tonnes were landed into Shoreham in 2018. For 2018, 6,374 tonnes of Scallops were landed, alongside 1,333 tonnes of whelks, 70 tonnes of sole, and 48 tonnes of cuttlefish, shown in Tables 6, 7 and Figure 4a/b below.

Table 6: MMO landings for main species in Shoreham in terms of value (£, rounded) 2016-2018. Source: MMO

Shoreham	**2016**		**2017**		**2018**
Scallops	5,387,016	Scallops	9,975,068	Scallops	14,770,161
Whelks	1,467,911	Whelks	1,310,572	Whelks	1,939,983
Sole	735,931	Sole	442,803	Sole	582,029
Cuttlefish	293,591	Plaice	169,200	Plaice	221,457
Plaice	245,820	Cuttlefish	146,976	Cuttlefish	175,752
Bass	154,928	Turbot	126,116	Bream	152,127
Turbot	127,566	Bream	120,148	Turbot	107,882
Bream	125,822	Brill	63,508	Skates and Rays	59,395
Brill	82,450	Red Mullet	56,918	Crabs	58,247
Lemon Sole	75,737	Squid	54,334	Brill	56,636

Table 7: MMO landings for top 15 species in Shoreham in terms of volume (tonnes, rounded) 2018. Source: MMO

	Species	**Volume (tonnes)**
1	Scallops	6374
2	Whelks	1333
3	Plaice	127
4	Sole	70
5	Bream	61
6	Cuttlefish	48
7	Skates and Rays	31
8	Dogfish	30
9	Other Demersal	25
10	Gurnard	25
11	Crabs	23
12	Turbot	12
13	Mackerel	11
14	Brill	9
15	Whiting	5

Figure 4a: MMO landings for Shoreham in terms of volume (tonnes) 2018. Source: MMO

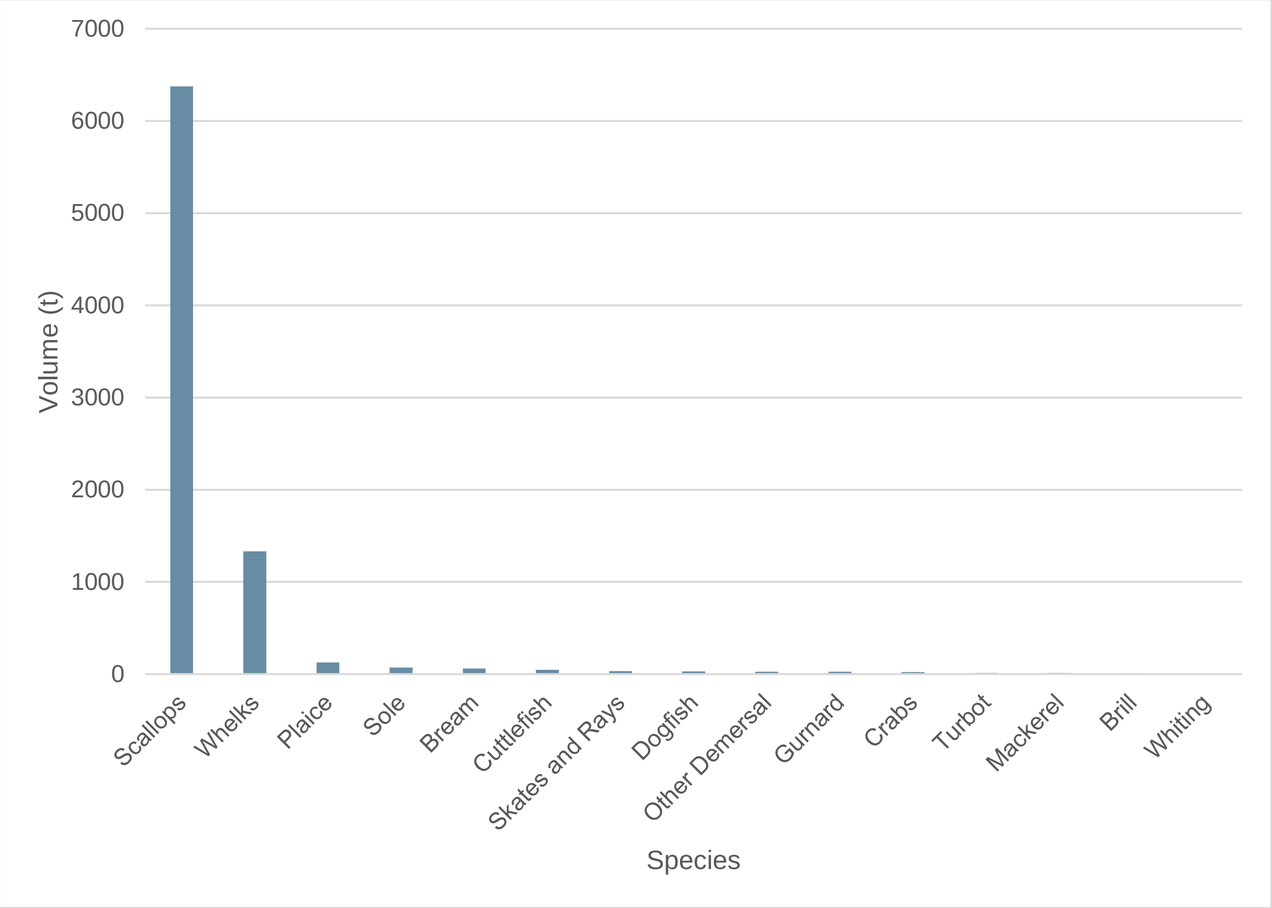
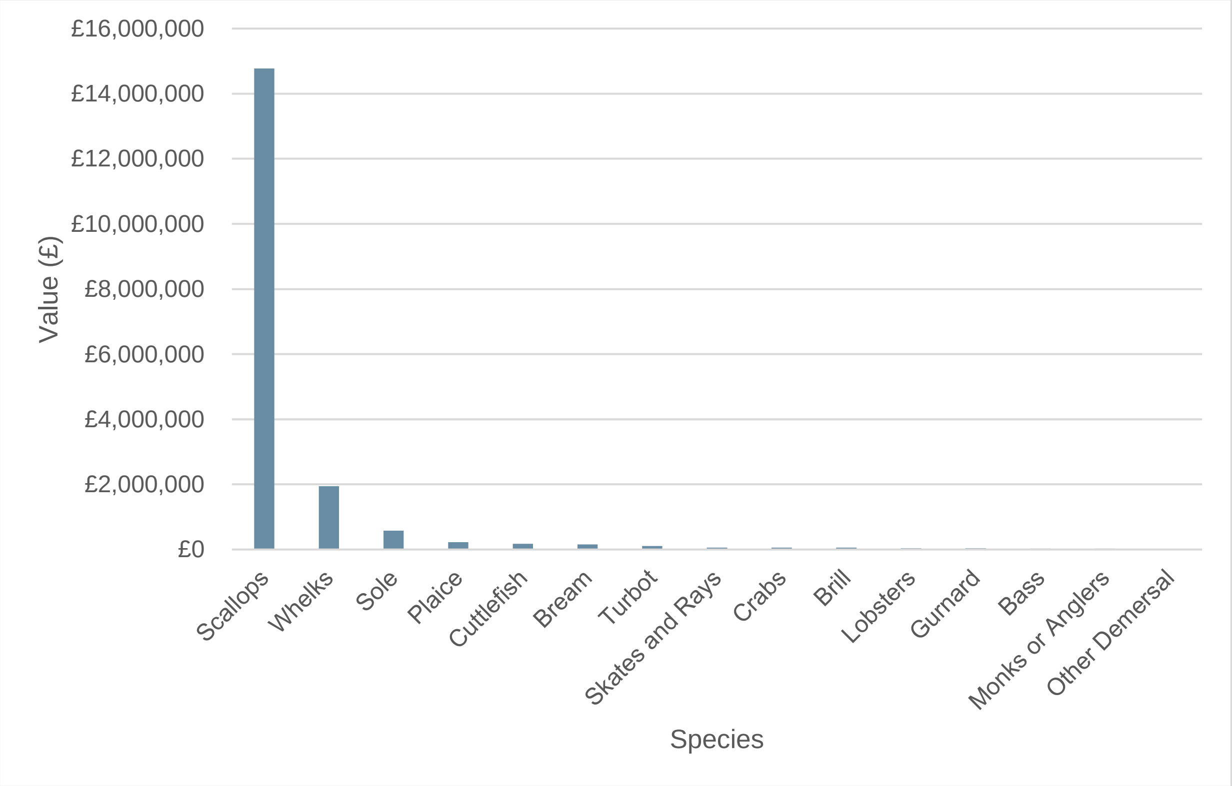


Figure 4b: MMO landings for Shoreham in terms of value (£) 2018. Source: MMO



Worthing has mixed landings, which include demersal finfish species and no shellfish in the top five species from any of the years 2016 to 2018. Nearly three tonnes were landed into Worthing in 2018.

Table 7: MMO landings for main species in Worthing in terms of value (£, rounded) 2016-2018. Source: MMO

Worthing	**2016**		**2017**		**2018**
Bass	2,2634	Mackerel	1,237	Other Demersal	732
Cod	1,203	Plaice	658	Bass	662
Plaice	843	Whiting	337	Whiting	522
Sole	663	Pouting (Bib)	323	Mackerel	508
Mullet - Other	579	Mullet - Other	295	Mullet	321
Dogfish	501	Sole	258	Plaice	252
Mackerel	374	Dogfish	240	Bream	206
Smooth hound	292	Black Seabream	204	Dogfish	182

Trawling

Beginning in the 1970s, the increase of towed fishing gear used (in particular pair trawling) off Worthing has been noted, alongside the homogenising effect on the seabed and associated biodiversity. Most notably, a dense kelp bed close inshore between Shoreham and Bognor Regis, reduced significantly in terms extent and density.[6]

Currently, Sussex IFCA trawlers fall into four categories, which are distinct:

• Under 14m beam trawler, utilising twin 4.5m beam trawls or a single beam trawl of an overall length that is less than 9m;

• Under 14m demersal otter trawler, utilising a rock hopper ground rope rig and steel otter boards;

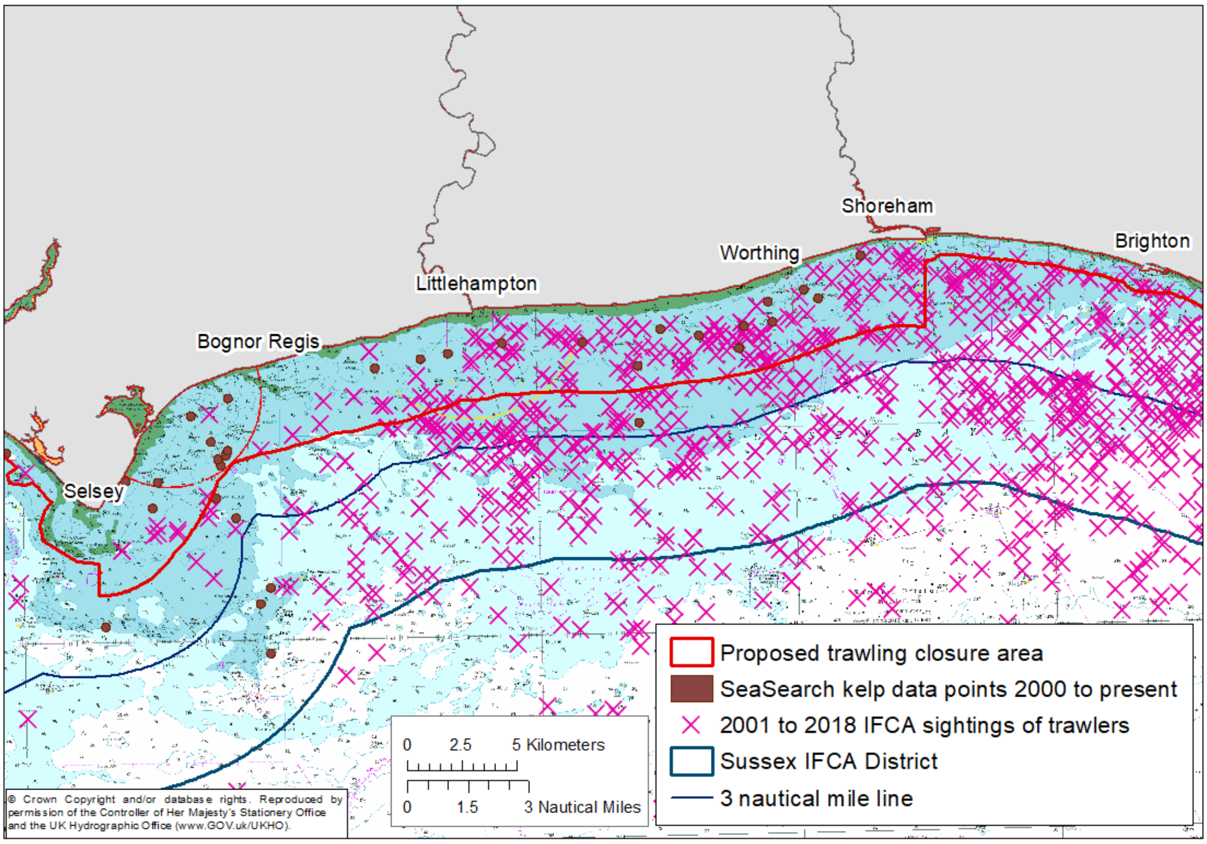
• Under 14m single, twin or triple trawlers, utilising one or more trawls simultaneously.

• Under 14m demersal pair trawlers also utilising a large diameter rubber rock hopper ground rope. [7]

Three trawlers operate from Shoreham and none operate from the other West Sussex ports. Seafish economic analysis showed trawling vessels which utilise the proposed exclusion area decreasing between 2014 (12) and 2018 (9), but landings volume increased from 2014 (60.5 tonnes) to 2018 (67.1 tonnes).[8]

Pair trawlers[9] target primarily black sea bream ('Bream') and bass (bass are now a bycatch only species)[10]. Possibly, as only a 1% unavoidable bycatch of bass was allowed, fishers have decided to increase the total amount landed to increase the amount of bass they could land.[11] MMO landings data showed bream dominated pair trawl landings, followed by smooth-hound, bass and grey mullet out of a total 57 species recorded and on average, pair trawlers account for 1% of landings into Sussex ports. [12] Sightings data (Figure 5) shows trawling occurs throughout the inshore waters of West Sussex, but suggests it is more common from Littlehampton eastwards past Shoreham. Figures 6a and 6b show the volume and value of pair trawl landings of bream and main bycatch species between 2009 and 2018.

Figure 5: Trawling activity within the Sussex District between 2001 and 2018, with specified distances from the coast and management areas indicated. Source: Sussex IFCA



SxIFCA sightings data indicates ~50% of pair trawl activity takes place in the proposed area, seasonally during the black seabream nesting season from April to June, where bass are also caught (originally as part of the fishery, and now as a bycatch – a large proportion of which needs to be discarded under EU regulations) – see table 8 below for landings data. Nine trawling vessels were sighted in the area in 2018, a decrease from 12 in 2014. In terms of average value landed, this was £134,196 (2018) with an average net profit of £32,638. The Impact Assessment undertaken by Sussex IFCA suggests these figures should be treated with caution as maximum landings and profit values affected by the proposed management measures, as they are likely to be overestimates (as multiple gears are used by many vessels, fishing activity takes place both inside and outside of the proposed management area and a SxIFCA seasonal exclusion of a quarter mile already operates). SXIFCA estimates a cost to the pair trawling fleet of £93,400[13]

Figure 6a: Pair trawl catches by volume (tonnes, landed weight) and species 2009-2018. Source: Sussex IFCA

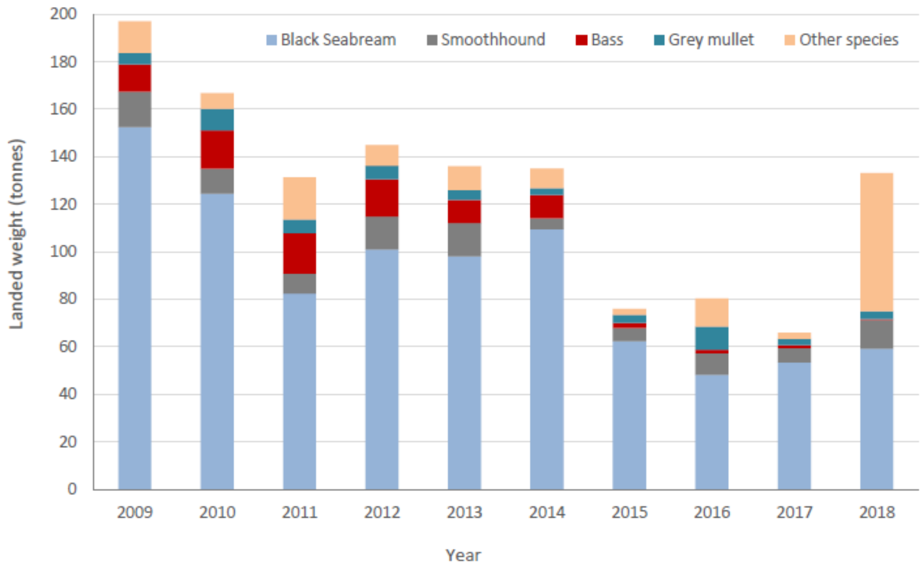


Figure 6b: Pair trawl catches by value (£) and species 2009-2018. Source: Sussex IFCA

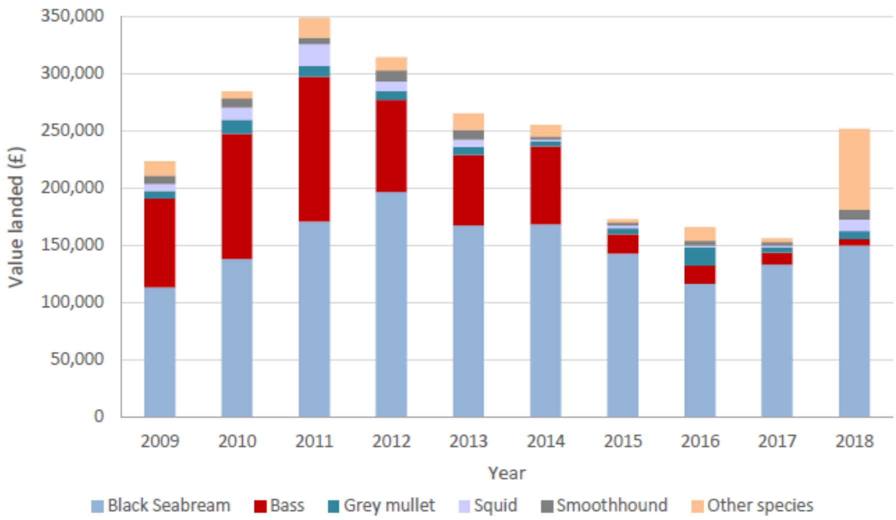


Table 8: MMO landings for bass and bream in Shoreham (£, rounded) 2016-2018. Source: MMO

Shoreham	**2016**	**2017**	**2018**	3-year average
Bass	£154,928	£38,382	£25,280	£72,863
Bream	£125,822	£120,148	£152,127	£132,699

Current management

The current Sussex IFCA Fishing Instruments Byelaw includes a provision for trawls and cod-end restrictions apply to pair trawls specifically. A trawling exclusion zone is also included, but has seasonal and spatial limits, with trawling prohibited May-October, out to 0.25nM from shore (and excluding areas to the west of Shoreham Harbour).

A Vessel Length Byelaw restricts vessels to under 14m, excluding those vessels with historic fishing rights (4 vessels) and no scallop dredging occurs within 3 miles of shore.[14]

In terms of the Sussex Sea Fisheries Committee ('SFCs' – which were replaced by IFCAs following the Marine and Coastal Access Act in 2009) it is useful to understand the Byelaw history from the 1990's, as there are two important Byelaws to consider, firstly the Fishing Instruments Byelaw and the Vessel Length Byelaw. During the 1990's the extent of the SFC's District changed from 3 to 6 miles from territorial baselines.[15] Therefore, any Byelaws that made prior to 18th March 1996, only apply to that those areas of the District within the 3 nautical mile limit. It is worth noting that virtually all of these regulations have been subsequently replaced or revoked.

Fishing Instruments Byelaw

The historic Byelaw records reveal that the fishing instruments byelaw underwent a significant change in on 28th July 1995, when the prior Byelaw was revoked and the new regulation allowed for pair trawling for both pelagic (anywhere) and demersal species (west of Shoreham Breakwater). This Byelaw enabled the commencement of the pair trawl fishery on black bream/bass and the associated expansion of trawling effort West of Shoreham to Selsey inside the 3 mile limit. In 1997 the fishing instruments Byelaw was amended further to take into account the extension of the District, including a provision for scallop dredging between the 3 and 6 mile limit (it is assumed the activity already occurred in this area).

Vessel Length Byelaw

Vessel length was used by all SFCs (and still is by IFCAs) as a proxy for individual vessel effort management. Originally, it was 12 metres (registered length) prior to the introduction of a new Byelaw (14th January 1990) which increased the size to 14 metres (overall length – longer than registered length). It is likely this change resulted in an increase in nearshore trawling effort. The ability of these larger vessels to come nearshore enabled the development of pair trawling.

On 17th September 1997 the vessel length Byelaw was revoked and remade to incorporate vessels operating from 3 miles to the new 6 mile limit, and grandfather rights (via written authorisation) were written into the Byelaw for those who wished to apply at the time. These rights have since reduced to a handful of vessels based on the same ownership as the original authorisation. An original 1982 Byelaw record specified that an otter trawl could not have a headline exceeding 15 metres. It is unclear whether this byelaw was ever enforced.

A thorough Byelaw review was undertaken following the transition from SFC to IFCA.

3. Proposed management by Sussex IFCA

Within East and West Sussex inshore waters to six nautical miles, Sussex IFCA manages the inshore fisheries legislation with a duty of promoting the sustainable use of the inshore marine environment. Sussex IFCA are proposing management to enhance documented sites of *historic dense kelp forest* from Bognor Regis to Brighton (shown in Figure 12 below), which have declined by over 90% since the 1980s as a result of changes in fishing practices and gear, water quality and storm damage. Macro-algae such as kelp are considered an 'ecosystem component critical to ecosystem services delivery'[16], meaning this habitat should be given special attention when considering management. Kelp specifically provides a wide range of associated ecosystem service benefits, which are described in detail below, including fish breeding, feeding and nursery grounds. Kelp habitat requires special attention when considering management, due to its role in the marine and coastal ecosystem. Furthermore, the Government has advised a precautionary approach should be adopted with fisheries management.[17] An ecosystem approach to fisheries management, which is promoted by Defra and underpins the current Sussex IFCA proposals, aims for more sustainable management and accounts for, and seeks to minimise, impacts on non-commercial species and the marine environment generally.[18,19]

Management should be evidence based[20] and bottom towed fishing gear (trawls and dredges) are the most widespread cause of seabed disturbance (causing comparatively greater damage than netting or potting). According to previous research, rock with seaweed was the habitat providing the greatest ecosystem services within coastal Sussex waters, while rock or sediment with seaweed were also the most sensitive habitats.[21] Evidence requirements become more stringent at the local level (if activities are restricted) compared to overarching national policy.[22] While it is not possible to determine the attribution of relative impacts on kelp from fishing, storms, pollution and climate change for example, fishing is the only variable which SxIFCA can manage (in general and in line with an ecosystem approach).

Sussex IFCA are reviewing management measures for nearshore trawling, with a view to consulting on these measures in autumn of 2019, to protect the nearshore Essential Fish Habitat (EFH) from damage. See ***Figures 1 and 2 above for management boundaries.***

Under these draft proposals, 308 km^2 of important nearshore habitat in the Sussex IFCA district would be protected from mobile fishing gear. This equates to 18% of the total district area of 1746 km^2, when including Chichester Harbour. The proposed nearshore trawling management will protect a range of sensitive and valuable habitats outside of Marine Protected Areas (MPAs) and the limited areas of the Sussex IFCA district, which are currently afforded some seasonal protection from trawling. There are areas of very high biodiversity throughout the district, in particular south of Selsey, within the nearshore area between Littlehampton and Shoreham, east of Eastbourne and near Rye.[23]

Ecosystem services benefits are central to rationale of the current management proposals, with Sussex IFCA adopting a move towards *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.[24] For management purposes with regards to the trawling management byelaw no distinction is made between the different types of mobile gear, or weight of gear being towed.[25]

Sussex IFCA is working with a variety of partners to deliver research, which focusses on kelp restoration and habitat enhancement and this paper contributes to this work stream.[26]

4. Kelp

Global importance of kelp to the marine ecosystem

The brown algae known as kelps (Order *Laminariales*) are globally important foundation species that occupy 43% of the world's marine ecoregions (found globally, except Antarctica). Kelps support a productivity per unit area[27,28,29,30] rivalling that of intensively cultivated agricultural fields or tropical rainforests, enhancing diversity and secondary productivity through the formation of biogenic habitat. [31] Kelps are found in subtidal rocky regions globally, where nutrients, light levels, temperatures and ocean currents and the extent of grazing (via urchins[32], snails or fish species) permits[33]. These forests form where few other plants can grow because of their holdfast system (see Figure 7 below). The shelter provided in combination with the habitat complexity, creates suitable habitat making kelp foundational species.[34,35] The effects of kelp forests extend beyond the boundaries including the formation of floating mats, which become detached after storms (microhabitats providing shelter in open water to fish and invertebrates).[36]

Kelp forests are characterised by high productivity, high biodiversity, habitat provision, food and shelter provision, the provision of reproduction and nursery areas and modifying wave action and coastal oceans currents.[37,38,39] Kelp forests are highly complex, dynamic, productive ecosystems that form key components of temperate coastal ecosystems globally, contributing to species richness and biodiversity (including fish, shellfish, mammals, other seaweeds and epibiota – species living directly on the kelp - e.g. an early UK study found 389 species on 72 holdfasts[40]).[41] Kelp provides habitat and the trophic foundation in complex food webs, underpinning inshore commercial fisheries.[42] Subtidal kelp forests are responsible large quantities of (marine) biomass in the northern hemisphere.[43] Kelp represent critical habitat for inshore fisheries and coastal biodiversity[44]. A multitude of species have been linked to kelp via trophic and habitat associations, by using kelp forests for protection from predation as well as feeding and nursery areas and it has been documented that changes in the abundance of kelp impact fish abundance directly. Furthermore, kelp forests reduce wave action (playing a notable coastal defence role), sequester carbon (directly via grazing or via detritus in food webs) and are therefore crucial components for healthy coastal ecosystems in rocky, temperate waters. Variations in kelp abundance have affected fish recruitment and densities of larger 'super spawners'.[45]

Globally, overfishing has contributed to the global decline of kelp forests by removing predators of urchins.[46] Widespread overgrazing of kelp bed habitat has been documented in the USA and Australia and has been directly linked to the impact of fishing. This is thought to reduce the resilience of kelp beds to climate change[47], which in turn may increase urchin numbers. Management to reduce the risk of catastrophic ecosystem phase shifts is a global concern regarding kelp habitat.[48] Direct kelp harvesting, declining water quality in terms of pollution, eutrophication, and sedimentation), as well as diseases and invasive species have compounded this loss further. This situation is expected to worsen as a result of climate change.[49] However, the dynamics of kelp forests in the North-East Atlantic region are likely to experience changes through ocean warming, as warm-water kelp species increase in abundance e.g. *Laminaria ochroleuca* – first detected in the UK in the late 1940s - which has increased in abundance in the South West of England over recent years and is now common. 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[50] and planting kelp to mitigate against climate change has also been proposed.[51]

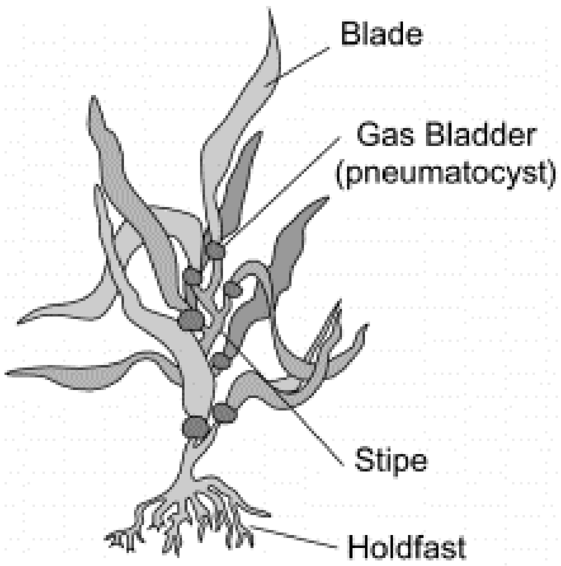
Ecosystem-based management, as a principle outlined in the Fisheries White Paper[52] must account for the contribution of kelp to the functioning of coastal habitats and the wider marine ecosystem[53]. EU directives have highlighted the importance of increased knowledge concerning the relationship between kelp forests and fisheries to inform fisheries management measures.[54]

Kelp biology and distribution

Kelps are photosynthetic algae that alternate between asexual (via the dispersal of zoospores) and sexual reproduction. Asexual reproduction allows species to extend their range over suitable habitats, while the dispersal and subsequent sexual reproduction promotes genetic diversity. The dispersal range of marine algal spores is generally tens of metres from the parent plant. Research on kelp (*L. hyperborea*) from Norway revealed the range of 200m from the parent plant. Fertilisation among kelps is synchronised by a combination of environmental factors and subsequently, kelp spores stay in the water column for a day and are dispersed by ocean currents and wave action. The spores attached to suitable rocky substrate, where the spores germinate. [55]

Growth in kelps is seasonal, with the highest in early spring to late summer. In autumn growth rates decrease when carbohydrate reserves are stored for winter, to enable immediate growth when light conditions are still below optimum for growth.[56] *Laminaria digitata* and *L. hyperborea* form extensive single species kelp beds. Kelp primary production creates new biomass, detritus, mucus and dissolved inorganic material. Up to 60% of carbon found in coastal invertebrates has been attributed to kelp productivity.[57] The area of UK habitat which is suitable for the presence of L. hyperborean, for example, has been estimated to be 15,984 km^2 and kelp has been estimated to account for ~45% of primary production in UK coastal waters, as well as 12% of marine production for the entire UK EEZ.[58]

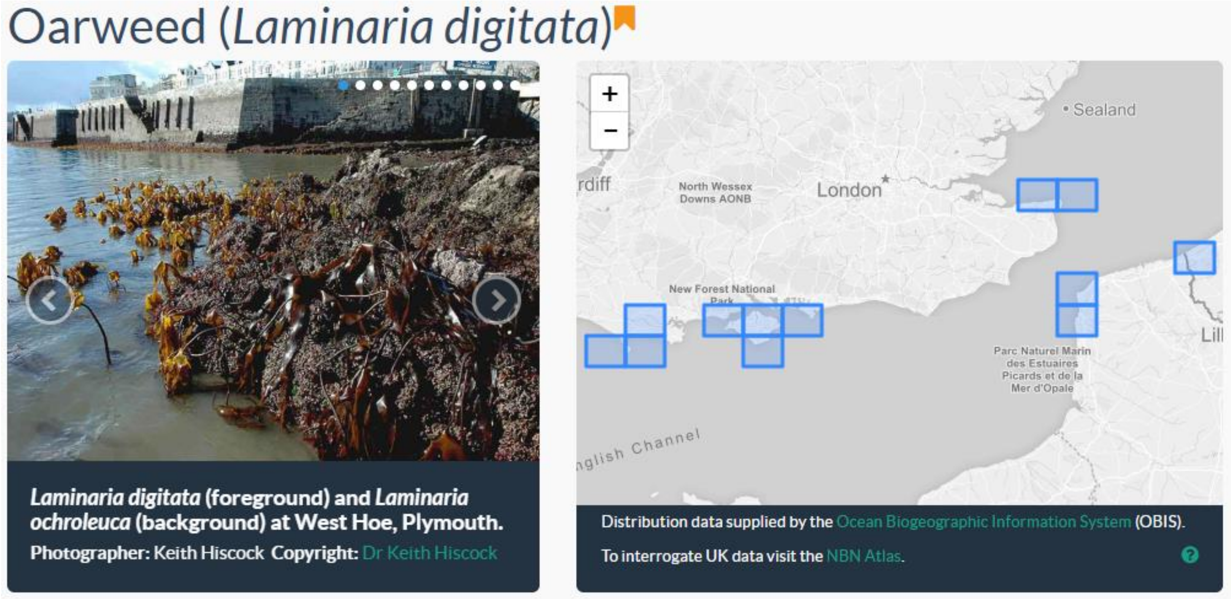
Figure 7: Kelp characteristics: blades, stipes, and holdfasts. Source: Project Oceanography[59]



Three species (described in detail below) have been recorded in Sussex: *Laminaria hyperborea*, *Laminaria digitata* and *Saccharina latissimi*. Between Newhaven and Eastbourne in East Sussex, kelp was recorded at a maximum depth of 9m before the water became too turbid to allow sufficient light penetration for growth.[60]

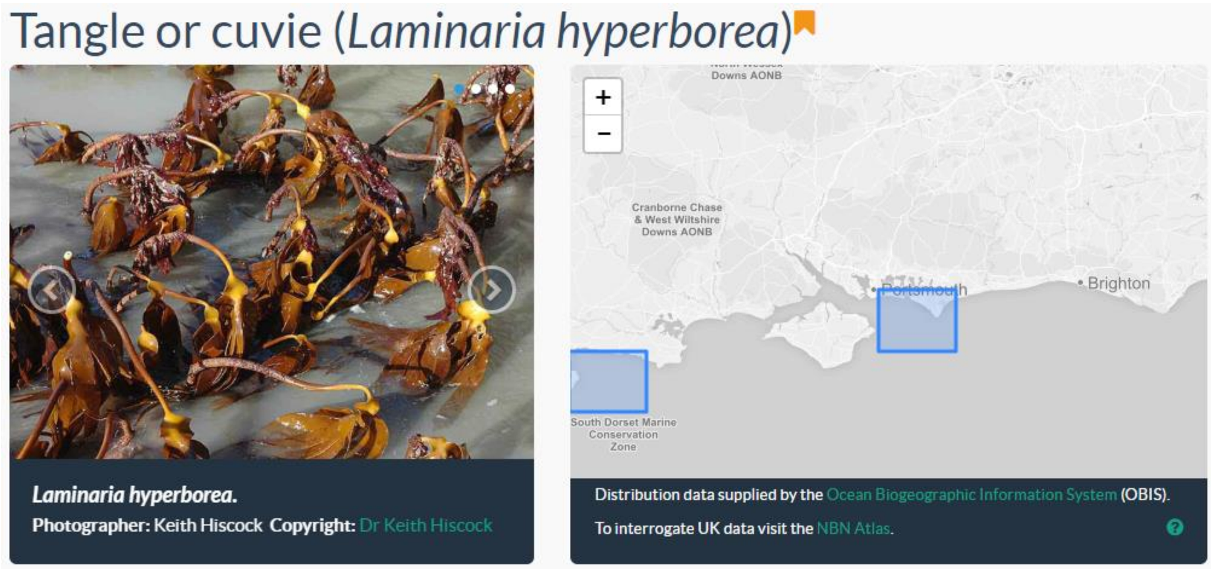
***Laminaria digitata* (Oarweed)** is a large kelp (up to 2m in length), commonly encountered at low water when exposed during spring tides on rocky shores from the Atlantic coasts of Europe and found along most coasts of Britain and Ireland, except the East coast of England and Thames estuary (due to turbidity and lack of suitable substrate - bedrock or other suitable hard substrata - in the lower intertidal and sublittoral fringe[61]). Found to a maximum depth from +1m to -20m in clear waters, *L. digitata* flourishes in moderately exposed areas with strong currents. The frond is broad, digitate (split into fingers) and dark brown with a leathery texture. The frond lacks a midrib, while the stipe is oval, smooth and flexible. The kelp is attached by a shallow dome-shaped holdfast. [62]

Figure 8: West Sussex distribution of L. digitata. Source: MARLin[63]



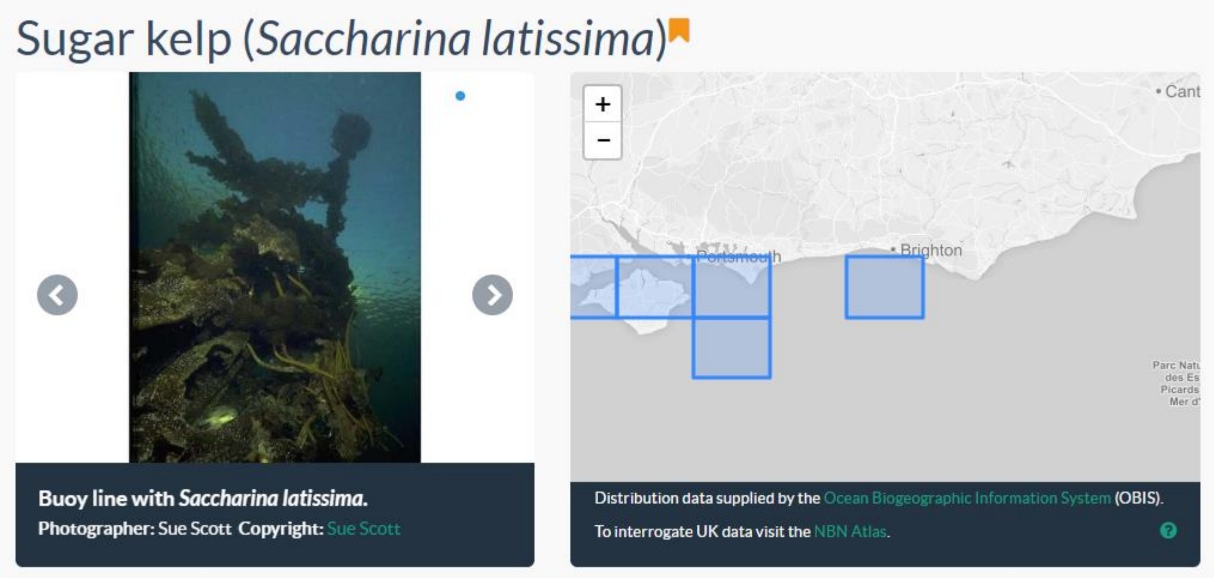
Laminaria hyperborea **('tangle')** is a large kelp (up to 3.5m in length). Restricted to the northeast Atlantic Habitat and found on most coasts of Britain, yet scarce along the south east coast due to a lack of suitable substrata[64,65]. *L. hyperborea* is found on bedrock or other stable substrata from extreme low water to depths from 8m to 36m in clearer waters and it grows as dense forests in suitable conditions. The large blade is broad, tough and flat with no midrib and is digitate (split into 5 - 20 straps or fingers). The blade is glossy and brown, while the holdfast is large, conical and branched. The stipe is stiff, rough, and thicker at the base. The stipe stands erect when emergent and is often covered with numerous other species (e.g. of red algae) due to the rough texture which accommodates epiphytes. *L. digitata* may be confused with young *L. hyperborea* plants, however, the stipe of *L. hyperborea* is circular in cross section and stiff. [66]

Figure 9: West Sussex distribution of L. hyperborea. Source: MARLin[67]



Saccharina latissima **('Sugar kelp'** - due to the white sweetish powder which forms on the fronds when dried) is a large brown kelp (up to 4m long) with a long, undivided and frilly frond, no midrib and short stipe. Recorded from the Atlantic coasts of Europe to the Eastern coast of America, Bering Straits and Japan as well as all coasts of Britain & Ireland, sugar kelp lives for 2 to 4 years and grows quickly from winter to spring. *S. latissima* is found from the sublittoral fringe (sometimes in rock pools) to a depth of 30m, usually in sheltered areas and may attach to substrata such as boulders and cobbles. It has a small branching holdfast and is yellowish-brown in colour.[68]

Figure 10: West Sussex distribution of S. latissima. Source: MARLin[69]



Sussex Kelp distribution and abundance from surveys

Historically, kelp forest was documented 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'*).[70] The area of kelp off Worthing extended two nautical miles from shore according to local fishers. Following winter storms, kelp was recorded washed up on the beaches from Lancing to Bognor (even said to covering the entire beach at Worthing in the 1960s[71]) and local farmers collected it to use as fertiliser on their fields. Sussex Seasearch[72] divers in the 1980's recorded the presence of kelp as 'abundant' or 'common' from Selsey to Eastbourne, in over 50% of dive sites surveyed (see annex 4 for the list of Seasearch survey forms completed). According to local fishers[73], the severe storms 1987 caused large amounts of kelp to be washed ashore, decreasing the density of the main kelp bed, which combined with mobile gear fishing inhibited the recovery of the kelp forest, alongside eutrophication and poor water quality. Three species were recorded: *Laminaria hyperborea*, *Laminaria digitata* and *Saccharina latissimi*.[74]

A report by Worthing Borough Council from 1987 indicated that the historic kelp bed was 177km² in total, equating to 10% of the Sussex IFCA District and within this area, 10km² was 'very dense' (>40 tonnes/hectare with peak densities of 100 tonnes/hectare).[75]

Sussex Seasearch 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 Km² (a 96.4% decline in terms of area coverage compared to 1987).[76] In total around 530 species were recorded in conjunction with kelp habitat during these dives (listed in Annex 3). Crab, whelk, wrasse, Cockle and lobster are all examples of commercially harvested species, which were also found on Seasearch surveys in kelp habitat.[77]

Figure 11 below shows sites dived by the volunteer Seasearch divers where they recorded the presence of kelp over the last 5 decades. The number of records from the 1990's is a reflection of increased survey effort. As mentioned above, 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. However, some kelp of several species is still present and there is an ambition to preserve this, as well as increasing the amount of kelp to historic levels.

Figure 11: West Sussex kelp data collected by Sussex Seasearch (1970-2019)

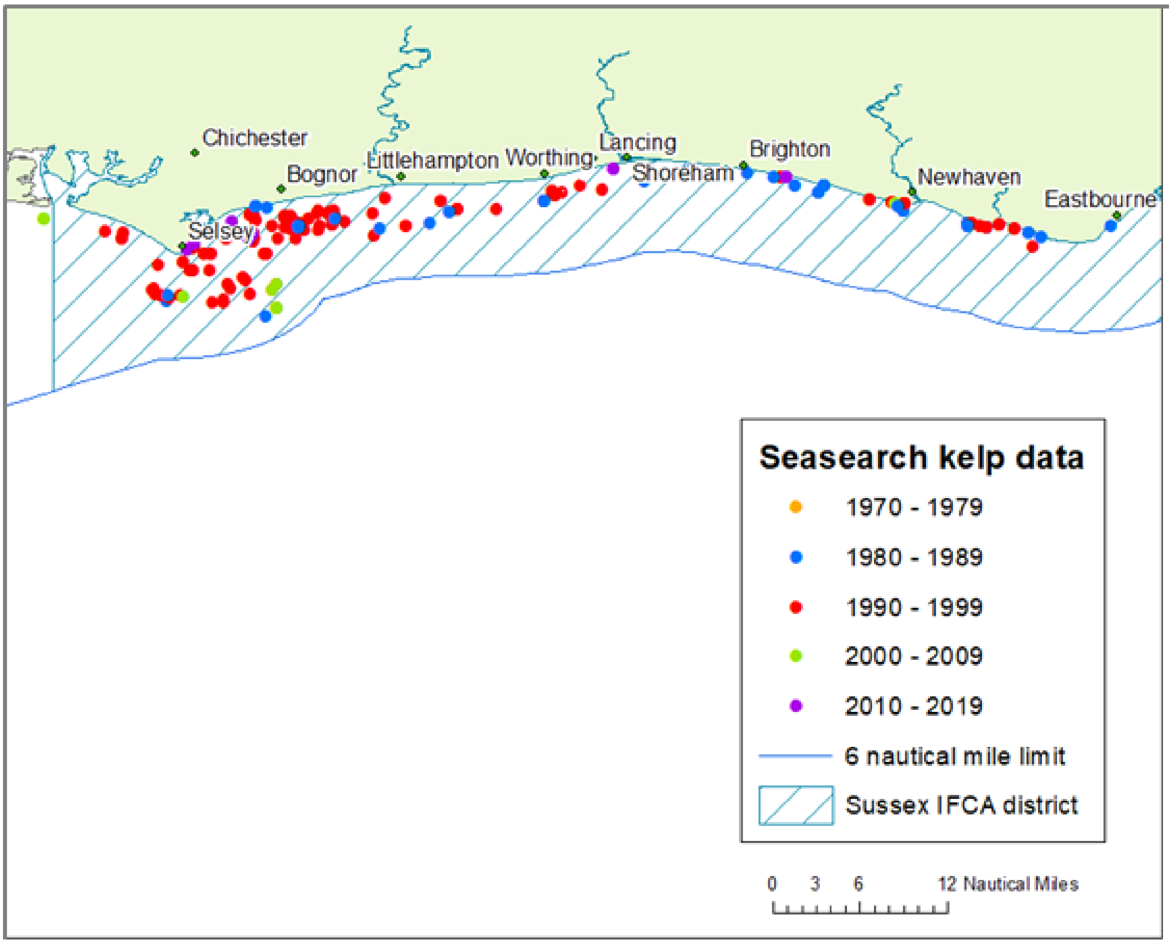


Figure 12: West Sussex Historic kelp bed extent (1950-1989) and kelp observations point data up to 2015 within the Sussex District. 1km and 4km management boundaries are illustrated[78] Source: Sussex IFCA

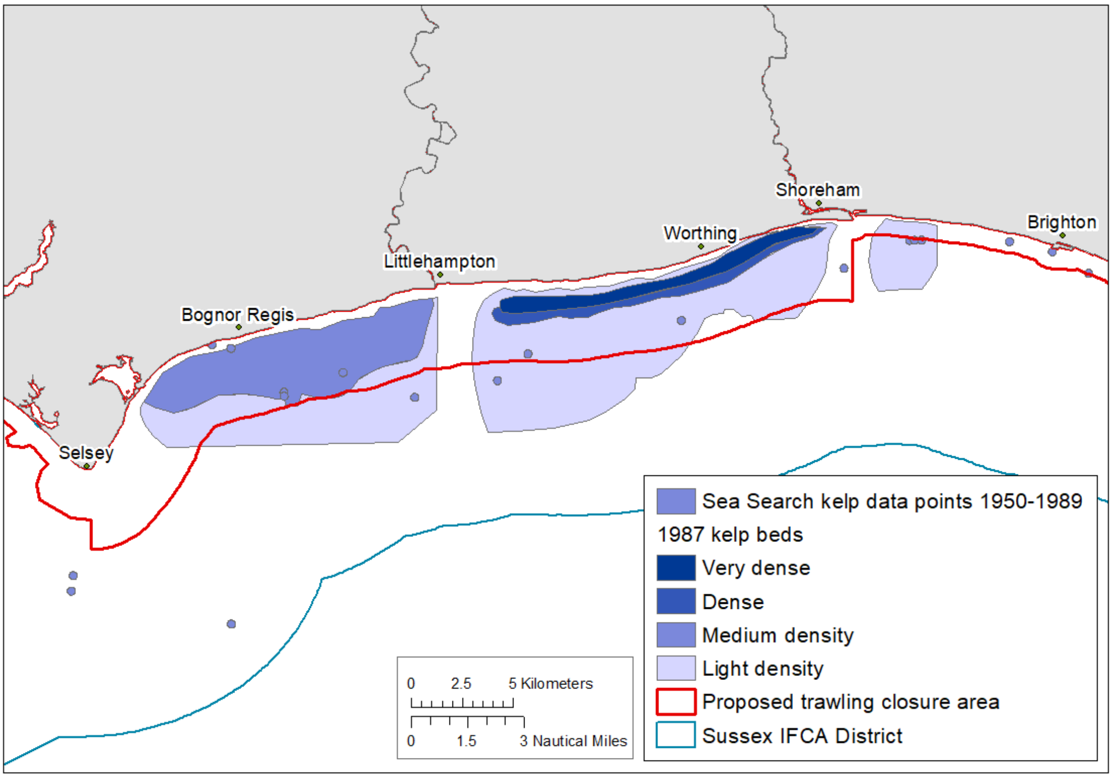
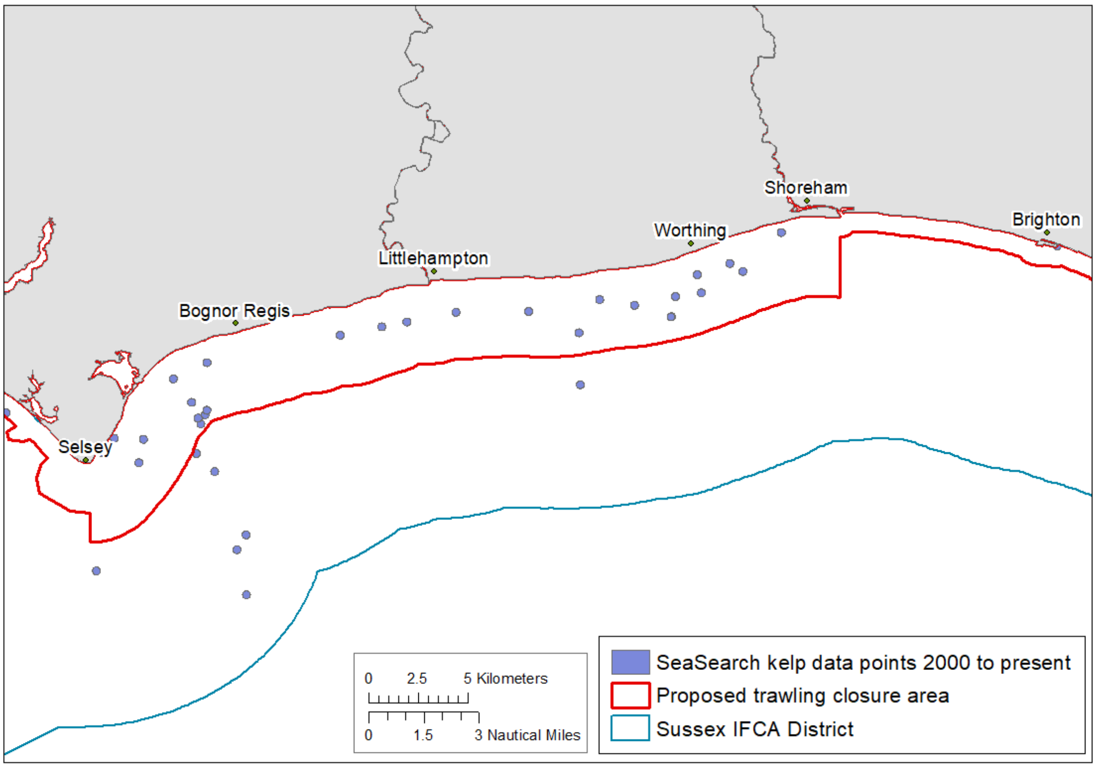


Figure 13: Seasearch kelp data points from 2000 onwards. Source: Sussex IFCA



Offshore from Littlehampton and towards Newhaven, coarse sediment are most common. Fine sands and fine muddy sands become more common inshore from Newhaven to Beachy Head, and become the dominant sediment type east of Eastbourne. All areas of West Sussex inshore waters where kelp is found are described in the recognised EUNIS[79] hierarchy system as "A3" (infralittoral rock and other hard substrata). The A3 coded areas when studied at higher EUNIS levels represent "kelp seaweed communities in rock dominated environments''. Kelp and seaweeds on infralittoral rock are predicted inshore from Selsey to Brighton, with areas of kelp and seaweed communities overlying sublittoral sediment.[80] Brown macroalgae such as kelp are important producers and they are considered critical to coastal ecosystem services, via habitat provision, biodiversity, food provision by supporting fish and crustacean populations through the food web, alongside shelter and coastal protection.[81] The West Sussex nearshore marine environment contains the highest proportion of areas deemed to have the highest ecosystem service provision, with 'high' and 'very high' priority classes of marine habitats occurring in just 5% of the Sussex inshore study area (with the highest priority area being between Selsey and Bognor Regis). The seabed habitat found in the highest priority area is a mixture of low-lying rock and sediment, mainly seaweed dominated. Rock with attached seaweed is one of the habitats stated to provide the highest ecosystem service values, while also being one of the most sensitive habitats. [82]

The Marine Aggregate Sustainability Fund (MALSF) Geology and Geophysics Survey Data which was collected between 2003 and 2010 also contains data on habitat types.[83] The EUNIS Sussex 2010 survey (a.k.a. the MALSF synthesis study), was undertaken on behalf of the MALSF and commissioned by the Marine Environment Protection Fund. Details of these findings and survey results can be found in the Sussex Coastal Inshore Pilot II: Marine Habitat and Bathymetry Modelling Project Report.[84]

5. Threats to kelp / Impacts of fishing on Kelp

Marine and coastal habitats and biodiversity are impacted through over-exploitation, pollution[85], land-use change and invasive species, leading to losses in productivity and diversity. [86,87,88] Climate change[89,90] and overfishing are the two most significant challenges to the structure and functioning of marine ecosystems.[91,92,93] Global declines of foundation species (such as seagrasses, corals, kelp and oysters) have been widely documented and their loss often reduces their beneficial flows (from carbon sequestration[94] to waste detoxification or recreation[95]) to humans, impacting well-being.[96] Kelp forests are also threatened by a variety of human impacts, including climate change, overfishing, and direct harvest.[97] Kelps are directly exposed to many coastal and marine human activities (e.g. harvesting, pollution, sedimentation, invasive species, fishing[98], recreation) and highly responsive to environmental conditions and kelps are therefore considered an indicator species. Despite their rapid growth rates, kelp forests face threats from over-grazing (often a result of the removal of urchin predators.)[99] Negative impacts from grazing of kelp by temperate sea urchin species creates barren areas as part of trophic cascades have documented globally.[100,101] Commercial harvesting in some regions threatens kelp forests, and this this is pushed by demand from pharmaceutical, aquaculture, and food companies. Pollution (sewage, industrial waste, inorganic fertilizers, and pesticides) in runoff present in rivers affects kelp growth and reproduction, alongside sedimentation leading to smothering. Kelp requires cold water for ideal growth condition, so climate change and sea temperature increases are a notable threat to kelp forests globally.[102] Increases in fish herbivory as a result of climate change potentially pose a significant threat to kelp-dominated ecosystems globally,[103] as could the impacts from increased storminess. [104]

Fishing affects seabed habitats globally but the effects are not uniform, varying with the habitat type and environment where they take place.[105] Demersal trawl fisheries are especially problematic regarding their wider environmental impacts.[106] Structurally complex habitats (e.g. seagrass meadows, biogenic reefs or kelp forests) and those that are relatively undisturbed (e.g. deep-water mud substrata) are more highly impacted by fishing than sediment habitats in shallow coastal waters and also have the longest recovery times to recover from damage. *L. hyperborea* beds recover well with respect to growth and biomass after trawling when the pressure is removed, but re-colonisation of the kelp forests by associated flora and fauna after disturbance is slower.[107] Evidence from Scotland showed that the pervasive nature of intensive trawling and dredging over the past 150 years in the Firth of Forth lead to damage that was dramatic and transformed near-shore and estuarine environments and the associated functioning of the marine ecosystem to a considerable extent. Fisheries management efforts to promote recovery of these severely degraded areas is a priority for Scotland regarding the marine environment.[108] Kelp and seaweed communities on sublittoral sediments are considered at high risk from hydraulic dredging for bivalves and at medium risk from otter trawling and scallop dredging[109], but are accepted as being detrimental to the benthic environment and associated biota.[110]

The ‘ecosystem approach’ or ‘ecosystem based management’ (holistic management systems and decision-making processes that balance ecological well-being with human and societal well-being in an equitable way)[111,112,113] to fisheries management needs to consider not only the target species and bycatches, but also the wider impacts on marine habitats resulting from fishing activity.[114,115] The impacts cover the disturbance of the upper layers of the seabed (re-suspension of sediments), direct removal, damage, displacement or death of flora and fauna living in / on the seabed, a short-term attraction of carrion consumers into the path of the fishing gear and finally the alteration of habitat structure.[116] These negative impacts can directly affect Essential Fish Habitats (EFH - habitats that are necessary for fish breeding, feeding or growth to maturity, such as spawning grounds, nursery grounds, feeding areas and migration corridors[117]) and therefore the future of the fishery and associated marine flora and fauna. Fishing also has indirect effects through the removal of predators (e.g. urchins). Research has documented the phase shifts in kelp forests as a result of fishing pressure.[118] Management regimes have often focussed on total or partial exclusion of towed bottom fishing gears, as a result and globally the number of areas closed to benthic trawling is rising, usually using MPAs with objectives around species and habitat conservation and restoration.[119,120] Bottom Towed fishing gears (trawls, dredges, drags, hydraulic devices) have for instance been excluded from European Marine Sites in the Southern IFCA district.[121] Possible conflicts and opportunities between kelp harvesting and fisheries as well as tourism have also been described in Scotland.[122]

Case studies from California show the long term impacts of trawling and kelp restoration projects (including the creation of artificial reefs, transplanting, adding suitable substrate and securing plants into sediment) which were successful (although this is a different species of Kelp, *Macrocystis pyrifera)*.[123] Further studies indicate that macroalgal export takes place globally beyond coastal habitats, suggesting that macroalgae may be an important source of *allochthonous* carbon, and therefore their contribution should be considered in Blue Carbon assessments.[124]

Fishing effort in inshore waters off West Sussex

In terms of fishing effort off West Sussex, Sussex IFCA have collected data on observed fishing activity whilst on sea patrols. Over 17,500 vessel sightings have been observed, 4,750 of which were between 2013 and 2017. The following figures summarise this data for inshore netting, potting and trawling. [125]

Figures 14-16 below displays the fishing effort for trawling, potting and netting vessels across the IFCA district between 2013 and 2017. Fishing effort is calculated as the annual average number of fishing vessels observed per kilometre squared of the sea patrolled by Sussex IFCA. The greatest fishing effort generally occurred 5km from shore, while the lowest fishing effort generally occurred 0.5km from the coast. Relatively low trawling effort takes place in the nearshore area. Seafish economic analysis (covering 2014-2018) noted that in terms landings by all trawling vessels fishing the potential closure area, plaice comprised the highest landed weight for a single species. [126]

*Figure 14: Inshore fishing effort (**netting**) observations for West Sussex (2013-17)*

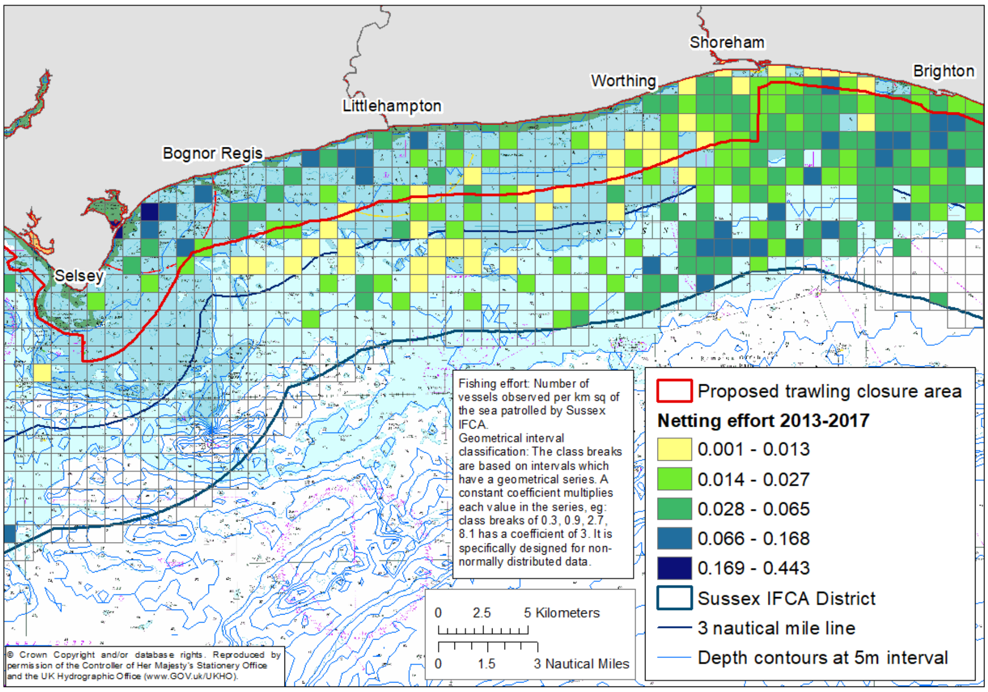
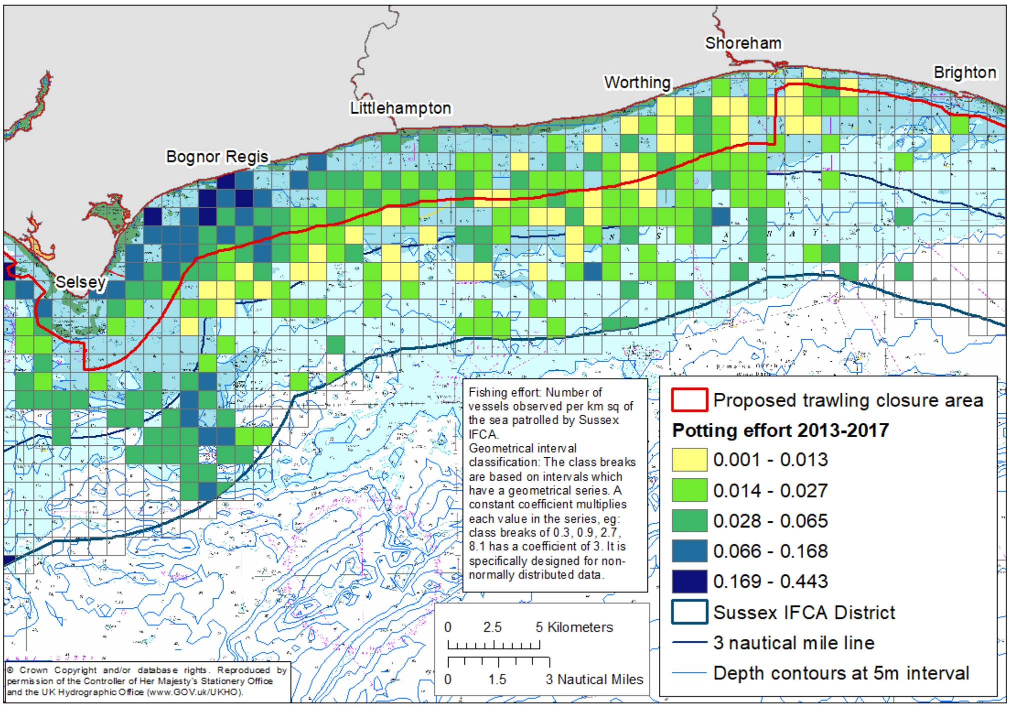
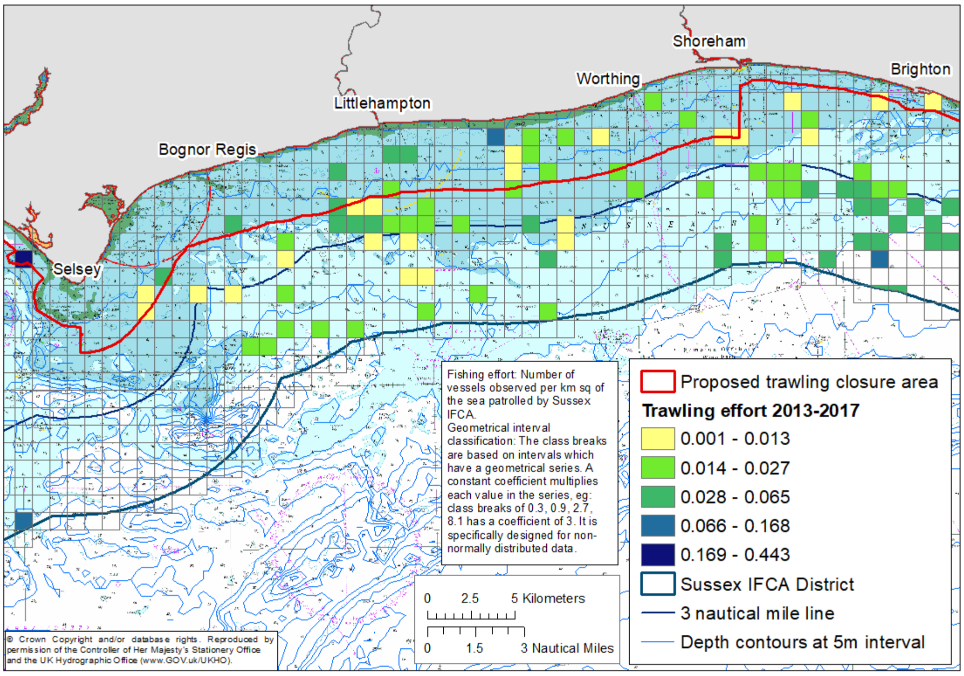


*Figure 15: Inshore fishing effort (**potting**) observations for West Sussex (2013-17)*



The potential exclusion of may increase the use of static gears such as nets and pots. The ongoing management proposals for inshore netting[127] as part of the Authority's historic byelaw review, and the Sussex IFCA's Shellfish Permit Scheme[128] (which restricts potting effort) aim to ensure the levels of static gear use and effort are not excessive.

*Figure 16a: Inshore fishing effort (**trawling**) observations for West Sussex (2013-17)*



All UK commercial fishing vessels above 12m are required to have a UK government-approved satellite-tracking device, known as a vessel monitoring system (VMS), transmitting their position.[129] The majority of the inshore fishing fleet comprises vessels under 12m, creating a data gap regarding their fishing effort so sightings data is used.[130]

*Figure 16b: Inshore fishing effort (**pair trawling**) observations for West Sussex (2013-17)*

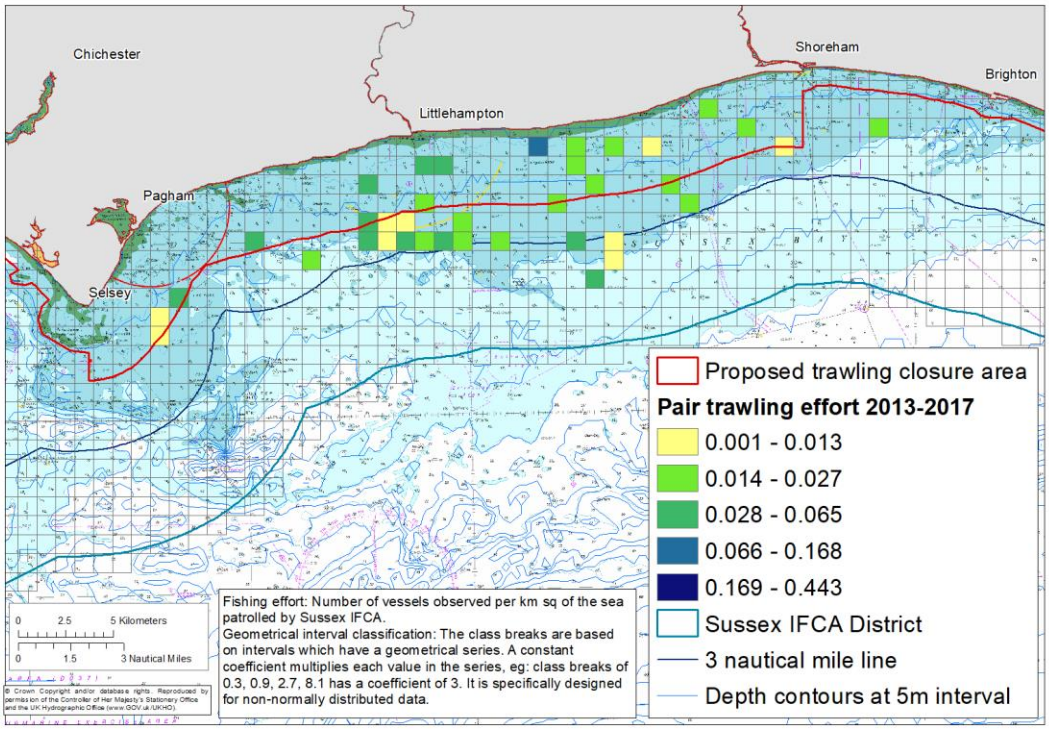


*Figure 17a, Sightings data for **towed gear** and kelp observations within the Sussex IFCA district, data from 2014 to 2018. Source: Sussex IFCA*

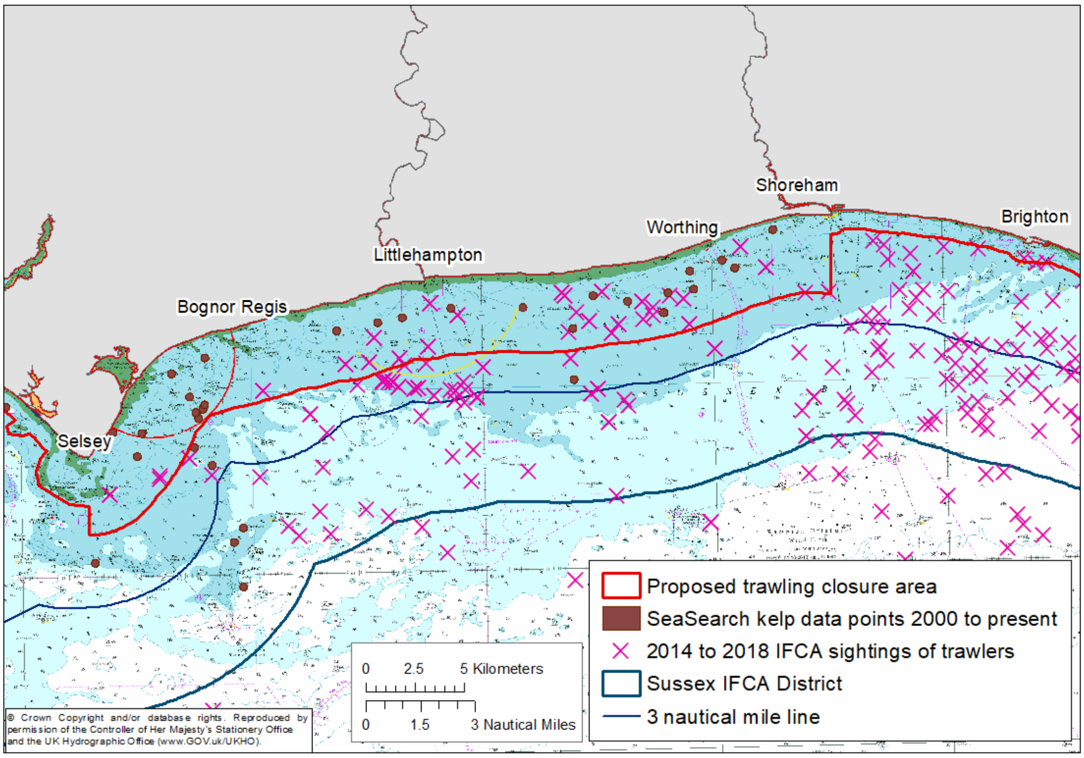
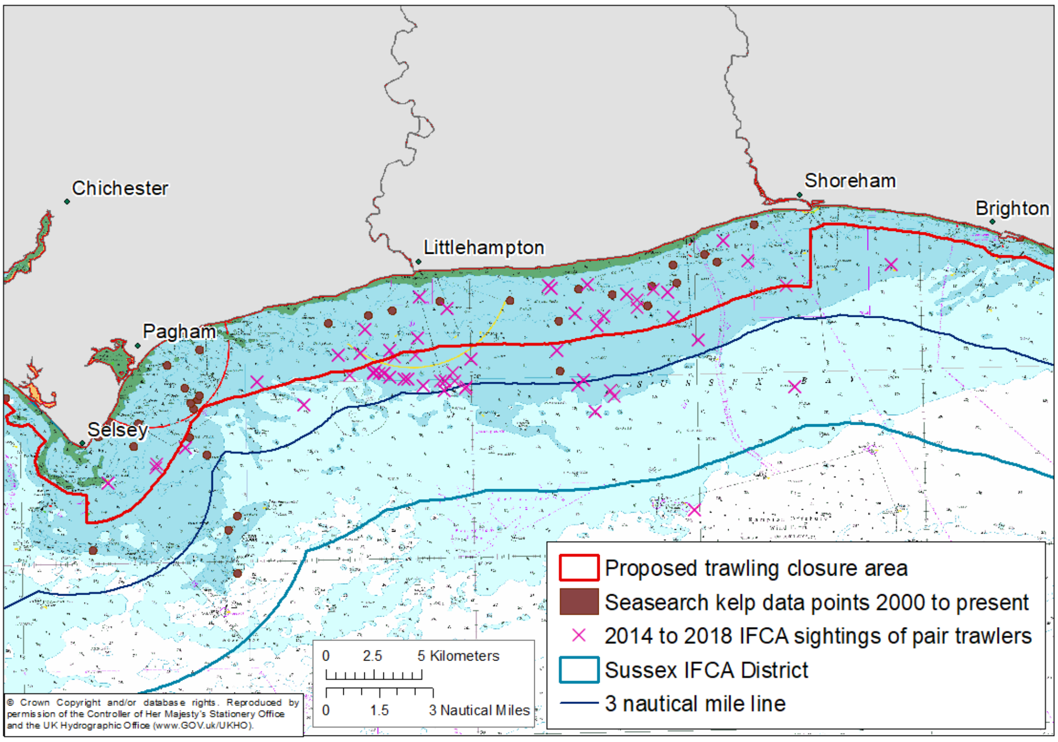


*Figure 17b, Sightings data for **pair trawling** and kelp observations within the Sussex IFCA district, data from 2014 to 2018. Source: Sussex IFCA*



6. Natural Capital and Ecosystem Services of kelp

Natural Capital

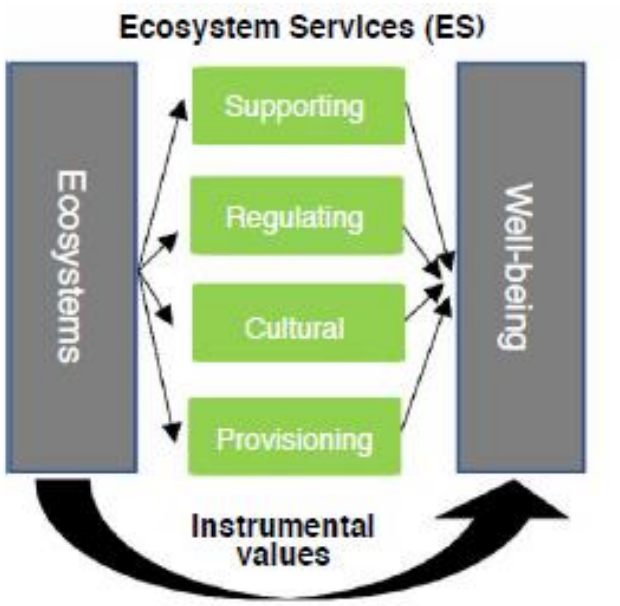
Natural capital refers to the stock of renewable / non-renewable resources, which combine to yield flows of benefits to humans.[131] The elements of nature that directly or indirectly produce benefits for people, which can be material or non-marketed and include a myriad of examples: ecosystems, biodiversity / species, climate regulation, fresh water, erosion control, land, minerals, the air and oceans, as well as natural processes and functions are all covered by the concept of Natural Capital.[132,133] The beneficial *flows* are termed 'ecosystem services', which stem from the Natural Capital *stocks* 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).[134] Natural Capital and ecosystem services are concepts used to communicate society's dependence on nature and to develop economic theory and practise to capture the myriad of externalities (causing environmental degradation), which arise from human activity.[135,136] There remain challenges with this approach,[137,138] as it remains a broad concept, with few applied examples of best and the reality that many of nature's benefits cannot be valued in monetary terms.[139] Research has shown that in the UK, despite the potential and receptive policy landscape, has not yet fully realised the approach in policy and management contexts, especially within the marine environment, where it is especially difficult.[140]

Ecosystem services (ES)

The functions and products from nature that can be turned into human benefits with varying degrees of human input are referred to as 'ecosystem services' (ES).[141] This utilitarian concept was developed with the aspiration of becoming the political lever to reduce biodiversity and habitat loss, making the benefits we derive from nature visible in economic decision-making.[142] These beneficial flows are dynamic and interact with each other. They represent the benefits people derive (including economic goods and services), directly or indirectly, from ecosystem functions, which sustain and fulfil human life[143]. Therefore, they evolve in time and space, as do the ecological processes and resources. The wider processes are value-neutral, but the goods and services are valued in a societal sense even if they are not mediated through markets.[144'145]

Crucially, ecosystem services influence human well-being, amongst many others including: secure and adequate livelihoods, food, shelter, clothing, health, a healthy physical environment, good social relations, security, and protection against natural and human induced disasters,[146] Humans are part of global ecosystems that drives ecosystem change both directly and indirectly, impacting human well-being. The impact of economic, cultural and social factors influence people, who in turn shape ecosystems, together with natural forces.[147] The links between these flows and well-being were described by the Millennium Ecosystem Assessment (MEA, 2005)[148,149] which first drew global attention to the concept[150] and has helped conceptualise these interactions between ecosystems and people.[151]

Figure 18: From Ecosystem Services to human wellbeing. Source: Ellis et al (2019).[152]



The MEA raised the question as to how changes in ecosystems impact on human well-being and how that information can be communicated to decision-makers. Before the MEA, the economic value of non-marketed services was almost non-existent and the costs of the depletion of these services was not tracked in national economic accounts [153] (and still do not feature in Gross Domestic Product (GDP) calculations). Both natural capital and ecosystem service approaches are aspirational, in that their potential to support decision-making, especially in the marine environment are yet to be realised for both policy and management.[154155]

Valuation should support decision-making with regards to policy making, regulation and management.[156] ES valuation is considered widely to be a tool to improve societal choices through presenting the costs of ecosystem degradation and the benefits of restoration. Understanding the importance of action (or inaction) is a requirement for improved management. Valuations have been described in three categories: decisive, technical and informative. 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 may also be unclear or change over time, but need to be presented, discussed and acknowledged as part of the process. [157]

Ecosystem Disservices

The converse of ecosystem services are ecosystem disservices, e.g. allergens, invasive species, pathogens etc which may negatively impact human well-being or increase human impact via increased consumption of resources to deal with the disservices. Any distinction between an ecosystem 'service' and 'disservice' is context dependant and will impact different human groups differently.[158]

Ecosystem Service Classification

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 nonphysical benefits that humans obtain from ecosystems) and ***Supporting services*** (those necessary for the production of all other ecosystem services.[159'160]

Kelp forest Ecosystem Services

Kelps forests provide both commercial and wider ecosystem services to people[161'162], e.g. through harvesting (as a source of potash to make gunpowder in World War I) or today in Ireland, Scotland or Norway for *algin* (used as a gelling agent in foods, pharmaceuticals, and the fabric industry). Kelp is also harvested as a food or food supplement and as a component in fertilizers and even biofuels. The kelp forest habitat itself provides ecosystem services, by slowing ocean currents and reducing wave action, creating shelter, reducing erosion and providing recreational and tourism benefits in locations globally[163]. Kelp also provides a habitat and contribution to the food chain for commercially and recreationally important fish and shellfish species.[164] Kelp forests in the UK and Ireland provide habitat for molluscs, crustaceans, and echinoderms, including ecologically and commercially important species e.g. European lobster, swimming crabs and seasonal spider crab migrants. Kelp forests also provide nursery habitat for cod and pollock, feeding grounds for ballan wrasse and goldsinny wrasse and as a result attract large predators such as sea bass, pollack, and conger eels as well as seals.[165] Kelp are 'Keystone Species' whose presence supports many others in the marine and coastal ecosystem.[166] Removal therefore has further indirect negative impacts and can lead to phase shifts in coastal waters.[167] Kelp are the dominant biogenic habitat provider in many coastal ecosystems and changes in kelp abundance influences the entire ecosystem.[168,169]

Globally, vegetated marine habitats and biogenic reefs provide elevated ecosystem services compared to other habitats.[170] As such, kelp forests provide ecosystem services, from fisheries to nutrient cycling, and shoreline protection, which in the USA have been valued in the range of billions of dollars annually, with changes in abundance a concern with far reaching impacts.[171] As kelps have fast growth rates the potential for recovery and enhancement of ecosystem service provision is also a key focal point. [172] Regarding kelp, local impacts and regional variation may have more of an impact when compared to other biogenic habitats e.g. coral reefs where climate change and sea temperatures resulting in bleaching have global causes with local impacts aggravating these.[173] Previous research valued the ecosystem service benefits of coastal seagrass/algal beds at an annual value of $19,000 per hectare,[174,175] while research from California valued the ecosystem services provided by kelp forests at $7,600 an acre per year.[176]

Globally important carbon stores are found in coastal and marine ecosystems (saltmarshes, seagrass beds, kelp forests and coral reefs) and kelp forests are critical short-term carbon sinks which need to be safeguarded. Some of this captured carbon also forms long-term carbon stores in marine sediments. The impacts of ocean acidification will reduce the amount of carbon remaining trapped in marine sediments. Both these carbon sinks are impacted by rising climate change via increasing seawater temperatures and through disturbance from bottom towed fishing gears. Shifts in species composition from long-lived shell forming organisms (e.g. oysters) being replaced by short-lived and soft-bodied species (e.g. worms) have also been predicted.[177]

A meta-analysis[178] showed a positive kelp–fishery relationship because of the protection of kelp habitats and supported the protection of kelp habitats stated by current EU environmental directives. Data on the importance of European kelp forests for the functioning of coastal ecosystems are more fragmented and limited in the EU compared to those from North America or Australia.[179] The majority of studies showed increases in abundance or the presence of adults of fish species associated with kelp, while some showed positive responses of kelp-associated recruits and juveniles and use of kelp beds as preferred spawning areas. An overall increase in the species diversity of fish assemblages in kelp habitats was also reported as were positive effects of kelp as a source of food for fish, as well as commercially valuable crustaceans (market landings).[180] The importance of *Laminaria* beds as habitat for the American lobster (*Homarus americanus*) was explained through the provision of habitable space and the complex architecture which can positively affect recruitment and the population size structure of several crustacean species. Benefits with regard to EFH for European lobster and juvenile cod, which between them yielded about £30 million in the UK economy in 2011 were also noted.[181]

Using ES assessment in management takes place for two reasons: primarily to raise awareness of the importance of nature to people and, secondly, to provide a transparent and objective means to reach decisions. Understanding trade-offs between different uses (or conservation or restoration) of nature is a crucial component of sustainable management. [182]

Table 9 on the following page presents the types of ES benefit flows documented from kelp forest.

Table 9: Ecosystem services (ES) provided by Kelp forests globally

Type of Ecosystem service	Types of benefit flows
Provisioning services: products / goods people obtain	Commercial, recreational and subsistence harvesting[183]
	Primary productivity (very high compared to other algal communities), including high levels of nutrient uptake, photosynthesis and growth. [184,185]
	Aquaculture / food production / food for intertidal birds [186]
	Habitat provision for various species of commercially valuable fish[187] and shellfish[188] as shelter.[189]
	Materials (alginates) for pharmaceutical and industrial use by the cosmetic and agrochemical industries and for biotech applications. [190]
	Fertilizer and use in building materials[191]
Regulating services: benefits people obtain from the regulation of ecosystem processes.	Water quality maintenance / filtration [192]
	Protection of coastlines from storm surges and waves[193.194]
	Reduction of shoreline erosion[195,196]
	Carbon sequestration [197,198]
	Stabilization of submerged land by trapping sediments [199,200]
Supporting services: while not providing direct services themselves, supporting services are necessary for the production of all other ecosystem services.	Cycling of nutrients [201]
	Alteration of energy flows and modifying bottom currents.[202]
	Kelp beds provide (nursery[203] and breeding) habitat for species of fish (gadoids and salmon), including protection for juveniles, which are

	harvested in recreational and commercial fisheries.[204]
	Provide additional substrata for sessile macrofauna e.g. sponges, anemones, bryozoans and sea squirts, increasing shelter available, providings habitat for prey species and a forage base. Contribution to diversity is more pronounced in otherwise relatively 2- dimensional environments. [205,206]
	Kelp is an important food source for a number of species of echinoderm, mollusc and herbivorous fish as well as some bird species. [207,208]
	Kelp forest particles (detritus) provide important food for filter feeders such as mussels and clams as well as amphipods, crustaceans and sea cucumbers. [209]
	Biodiversity of kelp forests prevent invasions of non-native species.[210]
Cultural services: nonmaterial benefits people obtain from ecosystems	Tourism and recreation (improving recreational fisheries and water quality for tourism.)[211,212]
	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. [213]
	Symbolic of coastal heritage. [214]

7. Methodology

ES Valuation is used to support policy development and assess the long-term sustainability of blue growth and marine management decisions, while also raising awareness of the, often invisible, benefits provided by healthy marine ecosystem and the wider importance of tour seas to society and in the economy.[215] Valuation generally focuses on "Use values". In an economic sense, these refer to ecosystem services, which are instrumental to our economies and societies, e.g. those that provide us with clean air or water, productive soils for agriculture and recreational opportunities. Nonetheless, nature cannot only be conceived as instrumental to human economies, as nature has equally 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[216]. These are often called "non-use values". The sum of "use values" and "non-use values" makes the total economic value (TEV) of an ecosystem, species (flora or fauna) or resource.[217,218]

The economic valuation of ecosystem services is the process of expressing a value for these services in monetary terms, to bring hidden costs and benefits to view – and more importantly bring these to the attention of decision makers and incorporated into decision-making frameworks such as Cost-Benefit Analysis (CBA).[219,220] All investment decisions and interventions involve trade-offs and valuation of ecosystem services is a step towards more inclusive decision making by making these trade-offs explicit, transparent[221] 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 trade-offs.[222,223] Economic valuation of biodiversity is complex and uncertain. Limitations and uncertainty need to be understood when interpreting the results. These are not the 'correct' answer, they are simply a means to contribute and improve on the decision making process. Valuation can help level the playing field so that not only extractive used with market values are presented in a CBA, and that wider environmental, economic and social concerns are presented, alongside distributional impacts as there are different courses of action where the costs and benefits are apportioned differently.[224]

For this study a model was developed that incorporates the economic valuation for seven ecosystem services. These ecosystem services are presented in Table 10. In discussion with SxFICA at a workshop on 27th June 2019, these seven services were decided upon as they represented the key ecosystem functions[225] of the kelp bed habitat and where it was possible to obtain secondary data to estimate unit area valuations for these services.

Table 10: Ecosystem services provided by Kelp included in the model

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

Finding values for the kelp bed context of the Sussex coastline was not possible given the confines of the study. Instead, secondary data was taken both from previous studies exploring the economic value of kelp ecosystem services and, if this was not available, they were taken from studies valuing seagrass ecosystem services (see Annex 3). For Provisioning Services (Fishery resources and Harvesting), economic proxies were taken from a recent study that explored the economic valuation of kelp forests in northern Chile[226]. For certain Regulating and Supporting Services (Water quality maintenance; Protection of coastlines from storm surges waves/ reduction in shoreline erosion; and Nursery habitats for commercial fish species), there was limited kelp-specific data available. Instead, seagrass ecosystem proxies were used. Whilst this is not ideal, the characteristics of seagrass habitats do share similarities with kelp.[227] As such, while acknowledging the limitations of this approach, it is believed these values provide indicative values for these ecosystem services in the economic valuation model. Some studies exploring kelp ecosystem services valuation, whilst insightful and of interest, were not used in the model as it was not possible to determine a value for unit area of kelp bed (for example, Blamey and Bolton, 2017[228]). The sources for each ecosystem service value, the methods used to calculate them, and all assumptions are presented in Annex 5.

In the model, a percentage of each ecosystem service's valuation is given depending on kelp bed density. This is categorised as follows for six of the services: Low density (25%), Medium density (50%), High Density (75%) and Very High Density (100%). Categorisation for 'Harvesting e.g. materials (alginates) for pharmaceutical and industrial use' is different to the other six services. Here, 0% is given for Low, Medium and High Density, with 100% for Very High Density. This is to reflect how kelp harvesting is unlikely to occur to any great extent unless there is substantial kelp forest present. Table 11 presents the valuation percentages for kelp bed density assigned to each ecosystem service.

Table 11. Ecosystem service valuation percentages for kelp bed density

Ecosystem service	Low	Medium	High	Very High
Fishery resources	25%	50%	75%	100%
Harvesting e.g. materials (alginates) for pharmaceutical and industrial use	0%	0%	0%	100%
Water quality maintenance	25%	50%	75%	100%
Protection of coastlines from storm surges waves/ reduction in shoreline erosion	25%	50%	75%	100%
Carbon sequestration	25%	50%	75%	100%
Nursery habitats for commercial fish species	25%	50%	75%	100%
Tourism and recreation (e.g. diving)	25%	50%	75%	100%

Displacement of fishing as a result of any management measures introduced could mean ecosystem services are reduced in areas where more fishing effort is displaced into. Any changes in fishing effort outside 4km have not been valued or modelled in this research.

8. Scenarios

Using the model, we developed various scenarios for kelp bed restoration. After discussions at a workshop with SxIFCA on June 27th 2019, three different scenarios were chosen for analysis: the current scenario, the past extent (1987 – as recorded in the Worthing Council report) and a hypothetical maximum. Data provided by SxIFCA provided estimations for kelp bed extent (in km2) and its density (in %). These are presented below in Table 12. For the hypothetical maximum scenario, estimates were determined by bathymetry and substrate that were possible for the growth of kelp. Note also, that for this scenario is actually less than the 1987 past extent, which points to potential inaccuracies of past data.

Table 12. Kelp bed extent and densities for each scenario

	Kelp bed extent (km2)	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

9. Results

Table 13 presents the ecosystem services valuation for the current kelp habit off the West Sussex coastline, estimated at £79,170 per annum. According to SxFICA and Seasearch data, there is only around 6.28 km2 of kelp bed remaining, the majority of which is low density. The small area of kelp bed coverage ensures that there is only a small value of fishery resources associated with kelp habitat (£3,569, or 5% of the total) and there is no value in harvesting kelp as a resource. The highest valued ecosystem service is linked to kelp's contribution in protecting coastlines from the impacts of storm surge and coastal erosion (£30,861, 39% of the total). With little kelp bed extent, the tourism value associated with the kelp ecosystem is also low (£7,008, 9% of the total).

Table 13. Ecosystem services valuation for current kelp habitat scenario

	Value per km2 (£)	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	£2,066	90%	10%	0%	0%	£2,920	£649	£-	£-	£3,569
Harvesting e.g. materials (alginates) for pharmaceutical and industrial use	£10,288	90%	10%	0%	0%	£-	£-	£-	£-	£-
Water quality maintenance	£5,703	90%	10%	0%	0%	£8,059	£1,791	£-	£-	£9,849
Protection of coastlines from storm surges waves/ reduction in shoreline erosion	£17,870	90%	10%	0%	0%	£25,250	£5,611	£-	£-	£30,861
Carbon sequestration	£9,046	90%	10%	0%	0%	£12,782	£2,840	£-	£-	£15,623
Nursery habitats for commercial fish species	£7,099	90%	10%	0%	0%	£10,031	£2,229	£-	£-	£12,260
Tourism and recreation	£4,058	90%	10%	0%	0%	£5,734	£1,274	£-	£-	£7,008
									Total ecosystem services value	£79,170

Table 14 presents the ecosystem services valuation if the kelp bed returned to 1987 levels. With kelp bed extent estimated as 2800% greater in 1987 than present day as well as considerably more kelp bed categorised as high/very high density, there is a significant difference in value £3,630,605 per annum. In this scenario, fishery resource and nursery habitats for commercial fish species supported by kelp are estimated as approximately £700,000 per annum (19% of the total). The proportion of the kelp bed that is very high density ensures harvesting for materials like alginates could occur if appropriate, with estimates of £182,095 per annum. Protection of coastlines from storm surges waves/ reduction in shoreline erosion provides the most value, £1,344,264, 37% of the total. Tourism and recreation associated with kelp bed significantly increases in this scenario, with more activity such as diving taking place in the restored habitat (£305,273 compared to £7,008 in the present day scenario).

Table 14. Ecosystem services valuation for kelp habitat to 1987 past extent scenario

	Value per km2 (£)	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	£2,066	60%	20%	10%	10%	£54,864	£36,576	£27,432	£36,576	£155,447
Harvesting e.g. materials (alginates) for pharmaceutical and industrial use	£10,288	60%	20%	10%	10%	£-	£-	£-	£182,095	£182,095
Water quality maintenance	£5,703	60%	20%	10%	10%	151,419	£100,946	£75,709	£100,946	£429,020
Protection of coastlines from storm surges waves/ reduction in shoreline erosion	£17,870	60%	20%	10%	10%	474,446	316,297	£237,223	£316,297	£1,344,264
Carbon sequestration	£9,046	60%	20%	10%	10%	240,176	£160,117	£120,088	£160,117	£680,498
Nursery habitats for commercial fish species	£7,099	60%	20%	10%	10%	188,473	£125,649	£94,237	£125,649	£534,008
Tourism and recreation	£4,058	60%	20%	10%	10%	£107,743	£71,829	£53,872	£71,829	£305,273
							Total ecosystem services value			**£3,630,605**

Finally, Table 15 presents the ecosystem services valuation if the kelp bed was restored to hypothetical maximum. The values are similar to those found in 1987 past event scenario given the similar area of kelp bed extent (167km^2 compared to 177km^2) and similar distribution of densities. 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. As mentioned earlier, the difference between 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.

Table 15. Ecosystem services valuation for kelp habitat for hypothetical maximum scenario

	Value per km2 (£)	Area by kelp bed density (%)				Value of areas of kelp bed density (£)				Total value (£)
		Low	Med.	High	Very High	Low	Medium	High	Very High	
Fishery resources	£2,066	50%	40%	5%	5%	£43,137	£69,019	£12,941	£17,255	£142,351
Harvesting e.g. materials (alginates) for pharmaceutical and industrial use	£10,288	50%	40%	5%	5%	£-	£-	£-	£85,904	£85,904
Water quality maintenance	£5,703	50%	40%	5%	5%	119,053	£190,486	£35,716	£47,621	£392,877
Protection of coastlines from storm surges waves/ reduction in shoreline erosion	£17,870	50%	40%	5%	5%	£373,034	£596,855	£111,910	£149,214	£1,231,013
Carbon sequestration	£9,046	50%	40%	5%	5%	£188,839	£302,142	£56,652	£75,536	£623,168
Nursery habitats for commercial fish species	£7,099	50%	40%	5%	5%	£148,188	£237,100	£44,456	£59,275	£489,019
Tourism and recreation	£4,058	50%	40%	5%	5%	£84,714	£135,542	£25,414	£33,885	£279,555
									Total ecosystem services value	£3,243,886

Table 16 below summarises the ecosystem service valuations developed by the model for all three scenarios and categorises value by four ecosystem services types: ***provisioning, regulating, supporting and cultural.***

Table 16. Value per annum for kelp ecosystem services by ecosystem service type

	Provisioning services	Regulating services	Supporting services	Cultural services	Total ecosystem services
Current scenario	£3,569	£56,333	£12,260	£7,008	**£79,170**
% total	5%	71%	15%	9%	
1987 past extent	£337,542	£2,453,782	£534,008	£305,273	**£3,630,605**
% total	9%	68%	15%	8%	
Hypothetical maximum scenario	£276,575	£2,247,058	£489,019	£279,555	**£3,243,886**
% total	7%	69%	15%	9%	

10. Impacts

Stakeholders have diverse interests from commercial gain to recreation or conservation. Balancing these different interests entails negotiation and dialogue 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. [229] In this case the costs in the short term all accrue to the trawling fleet that fish within 4Km 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.[230] Balancing short-term economic costs to industry versus 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.

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.[231] High uncertainty defines many aspects of marine management, but decisions need to be made used best available evidence and expert judgement is an essential informational component to contribute to decision making.[232] 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.[233] Precautionary management measures to limit the use of fishing gears which negatively impact marine habitats are necessary and widely advocated in global literature.[234,235,236,237,238]

11. Conclusions

From the research undertaken some conclusions can be drawn:

- 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 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. 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.[239]
- 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. The extend of kelp coverage has declined by over 96% since the area was surveyed by Worthing Council and fishing practises (especially pair trawling), pollution and storm damage[240] have driven this change. If the 1987 report can be considered a 'Natural Capital Asset register'[241] (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[242]. While this is not common practise, 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. These registers should follow the EUNIS hierarchy.[243]
- 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.[244]
- It was not possible to find any ecosystem value for kelp forests as a whole in the UK or Europe in academic or industry publications, nor grey literature. Active research is on-going in this area in Scotland, particularly in relation to kelp blue carbon contributions to long-term stores in coastal sediments. More research on kelp's

contribution to food webs (including shellfish) is needed. Valuations of kelp detritus in surface organic matter are also currently ongoing, but as yet unpublished. The value of kelp as habitat for young stages of commercially harvested finfish is also a focus of ongoing research. A single number that translates all those vital ecosystem functions into the monetary value of their service to humans is currently not available. Therefore, applying a benefits transfer approach from similar studies was the only option to develop the valuation (e.g. provisioning services values from kelp valuation study in northern Chile and regulating/supporting services values from Mediterranean seagrass context). There are numerous caveats with this approach; the species, region and context are different and the benefits in terms of biodiversity, productivity and habitat are also not equal – however *Posidonia* seagrasses forms less complex ecosystems than *laminiarian* kelps, and is therefore likely an underestimate when used as a proxy. To ensure caution, we have used lower values, supported by feedback from experts in kelp ecosystem services in both England and Scotland. Developing a good metric for kelp is an urgent priority for those working in the area and to inform the Impact Assessments supporting kelp habitat protection and restoration in the UK and EU more widely.

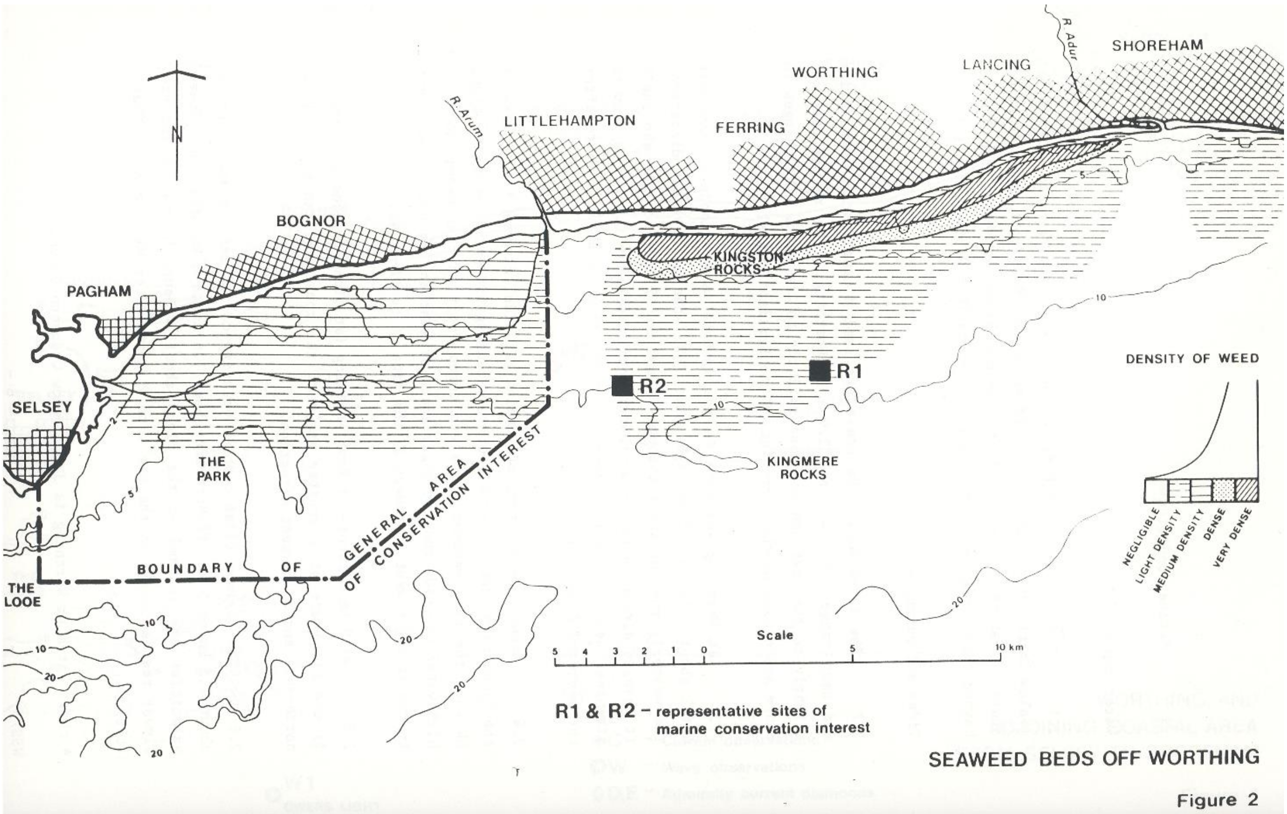
- Uncertainty remains a barrier for all decision-making regarding the marine environment and while this uncertainty needs to be made explicit in decision-making there is also a clear role for using *best available evidence* and being clear (in the assumptions, scenarios and findings) what the limits of that information are. Using an interdisciplinary approach to bridge between scientific / academic and local ecological knowledge in the formulation of management strategies is essential.[245, 246,247]
- Removing the pressure from mobile fishing gear in the coastal strip, as proposed by Sussex IFCA provides an opportunity to develop the ecosystem approach (both with regards to the local coastal environment of Sussex but also to the wider context of fisheries management and marine planning[248]) to the protection and restoration of natural capital (kelp forest) and the myriad of ecosystem services / benefits, which people derive from a healthy, functioning marine environment.
- An important factor in using an ecosystem approach to management is to use valuation as part of a transparent, objective framework to inform management decisions. There are trade-offs between human uses of the sea and conservation and these 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.[249] 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.[250]
- There are a range of possible scenarios of the long-term benefits of the restoration of kelp forest which have been modelled, 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).

- 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.[251]

ANNEXES

Annex 1: West Sussex kelp bed (1987). Source: Worthing Council



Annex 2: Seasearch Marine Recorder data snapshot listing all species in samples biotope as including kelp (either a Seasearch SCT 'biotope' of KF/KP or a full JNCC biotope). *Alphabetical order.*

Abietinaria abietina, Acanthodoris pilosa, Acrochaetium rosulatum, Actinia equina, Actinia fragacea, Actiniaria, Actinothoe sphyrodeta, Adamsia carciniopados, Aeolidia papillosa, Aetea anguina, Aglaophenia kirchenpaueri, Aglaophenia parvula, Aglaophenia pluma, Aglaozonia (asexual cutleria), Agonus cataphractus, Ahnfeltia plicata, Alcyonidium, Alcyonidium diaphanum, Alcyonidium gelatinosum, Alcyonidium hirsutum, Alcyonium digitatum, Algae, Ammodytes, Amphilectus fucorum, Amphipoda, Ancula gibbosa, Anemonia viridis, Anguilla anguilla, Annelida, Anomia ephippium, Antho (Antho) dichotoma, Anthopleura ballii, Antithamnion cruciatum, Antithamnionella spirographidis, Aplidium, Aplidium densum, Aplidium punctum, Aplysia fasciata, Aplysia punctata, Aplysilla, Apoglossum ruscifolium, Archidistoma aggregatum, Arenicola, Arenicola marina, Arthrocladia villosa, Ascidia, Ascidia conchilega, Ascidia mentula, Ascidiacea, Ascidiella, Ascidiella aspersa, Ascidiella scabra, Asparagopsis armata, Asperococcus bullosus, Asterias rubens, Athanas nitescens, Atherina presbyter, Austrominius modestus, Balanus, Balanus balanus, Balanus crenatus, Balistes capriscus, Barnea parva, Bispira, Bispira volutacornis, Bittium, Bivalvia, Blenniidae, Bonnemaisonia asparagoides, Bonnemaisonia hamifera, Botrylloides leachii, Botryllus schlosseri, Bowerbankia citrina, Brongniartella byssoides, Bryopsis hypnoides, Bryopsis *plumosa, Bryozoa, Bryozoa indet crusts, Buccinum undatum, Bugula, Bugula flabellata, Bugula plumosa, Bugula turbinata, Calliblepharis, Calliblepharis ciliata, Callionymus lyra, Callionymus reticulatus, Calliostoma zizyphinum, Callithamnion corymbosum, Cancer pagurus, Carcinus maenas, Caridea, Caryophyllia (Caryophyllia) smithii, Cellaria, Cellepora pumicosa, Celleporella hyalina, Centrolabrus exoletus, Ceramium, Ceramium cimbricum, Ceramium diaphanum, Ceramium secundatum, Ceramium virgatum, Cerastoderma edule, Cereus pedunculatus, Cerianthus lloydii, Chartella papyracea, Chelidonichthys cuculus, Chelon labrosus, Chlorophyceae, Chlorophyta, Chondria dasyphylla, Chondrus crispus, Chorda filum, Chordaria flagelliformis, Chromista, Chromophycota indet. (crusts), Chrysaora hysoscella, Chylocladia verticillata, Ciliata mustela, Ciliatocardium ciliatum ciliatum, Ciocalypta penicillus, Ciona intestinalis, Cirripedia, Cladophora, Cladophora pellucida, Cladophora rupestris, Cladophorales, Cladostephus spongiosus, Clathria (Microciona), Clathria (Microciona) atrasanguinea, Clathrina coriacea, Clavelina lepadiformis, Cliona celata, Codium fragile, Colaconema chylocladiae, Colaconema endophyticum, Conger conger, Conopeum reticulum, Corallina, Corallina officinalis, Corallinaceae, Cordylecladia erecta, Corella parallelogramma, Crangon crangon, Crepidula fornicata, Crimora papillata, Crisia, Cryptopleura ramosa, Ctenolabrus rupestris, Cutleria multifida, Cyclopterus lumpus, Cystoclonium purpureum, Decapoda, Delesseria sanguinea, Dendrodoa grossularia, Derbesia, Derbesia marina, Dercitus (Dercitus) bucklandi, Desmarestia aculeata, Desmarestia ligulata, Dicentrarchus labrax, Dictyosiphon, Dictyosiphon foeniculaceus, Dictyota dichotoma, Didemnidae, Didemnum, Didemnum coriaceum, Dilsea carnosa, Diplosoma listerianum, Diplosoma spongiforme, Dipturus batis, Doris pseudoargus, Doto, Doto coronata, Drachiella spectabilis, Dudresnaya verticillata, Dynamena pumila, Dysidea fragilis, Ectocarpus, Electra pilosa, encrusting algae indet., Ensis siliqua, Erythrotrichia carnea, Escharoides coccinea, Eualus, Eubranchus pallidus, Eulalia viridis, Eupolymnia nebulosa, Facelina, Facelina auriculata, Filamentous brown algae, Filamentous green algae, Filograna implexa, Flabellina, Flabellina lineata, Flabellina pedata, Flustra foliacea, Flustrellidra hispida, Foliose brown algae, Foliose green algae, Foliose red algae, Fucus serratus, Fucus vesiculosus, Galathea, Galathea intermedia, Galathea squamifera, Galathea strigosa, Galatheidae, Gastropoda, Gelidium pusillum, Gibbula cineraria, Gibbula umbilicalis, Gobiidae, Gobius, Gobius niger, Gobius paganellus, Gobiusculus flavescens, Goniodoris nodosa, Gracilaria bursa-pastoris, Gracilaria gracilis, Gracilariales, Grantia compressa, Grateloupia doryphora, Grateloupia filicina, Griffithsia, Griffithsia corallinoides, Gymnogongrus crenulatus, Halarachnion ligulatum, Halcampa chrysanthellum, Halecium halecinum, Halichondria, Halichondria (Halichondria) bowerbanki, Halichondria (Halichondria) panicea, Haliclona, Haliclona (Haliclona) oculata, Haliclona (Haliclona) simulans, Haliclona (Reniera) cinerea, Halidrys siliquosa, Halopithys incurva, Halurus equisetifolius, Halurus flosculosus, Haraldiophyllum bonnemaisonii, Harmothoe, Hemimycale columella, Henricia oculata, Heterosiphonia plumosa, Hiatella arctica, Hildenbrandia, Himanthalia elongata, Hippolyte varians, Hippothoa flagellum, Homarus gammarus, Hyas, Hyas araneus, Hyas coarctatus, Hydrallmania, Hydrallmania falcata, Hydrozoa, Hymeniacidon fallax, Hymeniacidon perlevis, Hypoglossum hypoglossoides, Idotea, Inachus, Inachus dorsettensis, Inachus leptochirus, Inachus phalangium, Jania rubens, Janolus cristatus, Jassa, Jassa falcata, Jujubinus striatus, Kallymenia reniformis, Kirchenpaueria pinnata, Labridae, Labrus bergylta, Labrus mixtus,* *Lacuna vincta, Laminaria, Laminaria digitata, Laminaria hyperborea, Laminariales, Lanice conchilega, Laomedea flexuosa, Lepadogaster lepadogaster, Leucandra aspera, Leucosolenia, Leucosolenia botryoides, Leucosolenia variabilis, Limacia clavigera, Lineus longissimus, Lineus ruber, Liocarcinus, Liocarcinus depurator, Liocarcinus holsatus, Liparis, Liparis montagui, Lipophrys pholis, Lithophyllum incrustans, Lithothamnion, Littorina littorea, Littorina obtusata, Loligo, Lomentaria articulata, Lomentaria orcadensis, Lophozozymus incisus, Macropodia, Maja brachydactyla, Maja squinado, Mastocarpus stellatus, Membranipora membranacea, Membranoptera alata, Metridium senile, Mimachlamys varia, Molgula, Molgula citrina, Molgula manhattensis, Mollusca, Monosporus pedicellatus, Morchellium, Morchellium argus, Mullus surmuletus, Muricoidea, Mustelus asterias, Myoxocephalus scorpius, Myriocladia, Mysida, Mysidae, Mytilus edulis, Myxicola infundibulum, Myxilla, Myxilla (Myxilla) incrustans, Myxilla (Myxilla) rosacea, Naccaria wiggii, Nassarius, Nassarius incrassatus, Nassarius reticulatus, Necora puber, Nemertesia, Nemertesia antennina, Nemertesia ramosa, Neoamphitrite figulus, Nephtys, Nereis, Nerophis lumbriciformis, Nitophyllum punctatum, Nucella lapillus, Nudibranchia, Obelia, Obelia geniculata, Ocenebra erinaceus, Okenia aspersa, Onchidoris bilamellata, Ophiothrix fragilis, Ophiura, Opisthobranchia, Osmundea pinnatifida, Ostrea edulis, Pachymatisma johnstonia, Paguridae, Pagurus, Pagurus bernhardus, Pagurus prideaux, Palaemon, Palaemon serratus, Palio nothus, Palmaria palmata, Parablennius gattorugine, Parasmittina, Patella, Patella pellucida, Patella vulgata, Peachia cylindrica, Pecten maximus, Pentapora foliacea, Perophora, Peyssonnelia, Phaeophyceae, Pholadidae, Pholas, Pholas dactylus, Pholis gunnellus, Phorbas fictitius, Phorbas plumosus, Phormidium roseum, Phoronis hippocrepia, Phyllodoce lamelligera, Phyllodoce maculata, Phyllophora crispa, Phyllophora pseudoceranoides, Phymatolithon laevigatum, Phymatolithon lamii, Phymatolithon lenormandii, Phymatolithon purpureum, Pilumnus hirtellus, Pisces, Pisidia longicornis, Platichthys flesus, Pleurobranchus membranaceus, Pleuronectes platessa, Pleuronectidae, Plocamium cartilagineum, Polinices, Pollachius pollachius, Polycarpa scuba, Polycera faeroensis, Polycera quadrilineata, Polychaeta, Polydora, Polydora ciliata, Polyides, Polyides rotunda, Polymastia, Polymastia boletiformis, Polymastia mamillaris, Polymastia penicillus, Polyplacophora, Polysiphonia, Polysiphonia elongata, Polysiphonia fibrata, Polysiphonia fucoides, Polysiphonia nigra, Polysiphonia stricta, Pomatoschistus, Pomatoschistus microps, Pomatoschistus minutus, Pomatoschistus pictus, Porcellana platycheles, Porifera, Porifera indet crusts, Prostheceraeus vittatus, Psammechinus miliaris, Pseudolithoderma extensum, Pseudopotamilla reniformis, Pterothamnion plumula, Pycnoclavella aurilucens, Pycnoclavella stolonialis, Pycnogonum litorale, Pylaiella littoralis, Radicilingua thysanorhizans, Raja clavata, Raspailia (Clathriodendron) hispida, Raspailia (Raspailia) ramosa, Rhodomela confervoides, Rhodophyceae, Rhodophycota indet. (non-calc. crusts), Rhodophyllis divaricata, Rhodophyta, Rhodothamniella floridula, Rhodymenia holmesii, Rhodymenia pseudopalmata, Rissoa parva, Sabella pavonina, Sabellaria, Sabellaria spinulosa, Sabellidae, Saccharina latissima, Saccorhiza polyschides, Sagartia elegans, Sagartia troglodytes, Salmacina dysteri, Sarcodictyon roseum, Sargassum muticum, Schizomavella discoidea, Scinaia furcellata, Scrupocellaria, Scrupocellaria scruposa, Scyliorhinus canicula, Scytosiphon lomentaria, Securiflustra securifrons, Semibalanus balanoides, Sepia officinalis, Sepiola atlantica, Serpulidae, Sertularella polyzonias, Sertularella rugosa, Sertularia, Sertularia argentea, Sphacelaria cirrosa,* *Sphaerococcus coronopifolius, Spirobranchus, Spirobranchus lamarcki, Spirobranchus triqueter, Spirorbinae, Spirorbis (Spirorbis) spirorbis, Spondyliosoma cantharus, Sporochnus pedunculatus, Spyridia filamentosa, Stelligera rigida, Styela clava, Stypocaulon scoparium, Suberites, Suberites carnosus, Suberites ficus, Sycon ciliatum, Symphodus melops, Syngnathus acus, Taonia atomaria, Taurulus bubalis, Terebellidae, Tethya, Tethya aurantium, Tethya citrina, Thorogobius ephippiatus, Titanoderma pustulatum, Trachinus draco, Trachurus trachurus, Trapania pallida, Tricellaria inopinata, Triglidae, Trisopterus luscus, Trisopterus minutus, Tritonia lineata, Trivia, Trivia arctica, Trivia monacha, Trochidae, Tubularia indivisa, Tubulipora lobifera, Tunicata, Turbinidae, Ulva, Ulva intestinalis, Ulva lactuca, Umbraulva olivascens, Urticina felina, Venerupis, Venerupis corrugata, Vertebrata lanosa, Vesicularia spinosa, Zeus faber.*

Annex 3: Species that may potentially be associated with kelp habitats (found associated with *Laminaria hyperborea* and *L. digitata* at different times of the year) based on research in Ireland.

Flora

Chlorophyceae: *Cladophora rupestris*

Rhodophyceae: *Phycodrys rubens, Pterosiphonia pennata, Lithophyllum spp., Lithothamnion spp., Phyllophora crispa, Polysiphonia spp., Polysiphonia lanosa, Corallina officinalis, Palmaria palmata , Lomentaria articulate, Ptilota gunneri, Delesseria sanguinea, Cryptopleura ramose, Membranoptera alata*

Phaeophyceae: *Laminaria digitate, Saccorhiza polyschides*

Fauna

Porifera: *Scypha compressa, Pachymatisma johnstonia, Myxilla spp., Hemimycale columella*

Cnidaria: *Dynamena pumila, Anemonia viridis*

Annelida: *Nereis pelagica, Pomatoceros lamarcki, Spirorbis spirorbis , Sabellaria alveolata Pomatoceros lamarcki, Filograna implexa, Megalomma vesiculosum*

Crustacea: *Copepods, Leptomycis spp., Juvenile crab , Calliopius laeviusculus , Semibalanus balanoides , Balanus crenatus , Gammarus spp., Pinnotheres pisum , Verruca stroemia*

Mollusca: *Aplysia punctata , Patella spp. , Mytilus edulis, Gibbula cineraria , Helcion pellucidum Acanthochitona crinitus , Calliostoma zizyphinum , Retusa truncatula , Clam sprat*

Bryozoa: *Conopeum reticulum , Scruparia chelata , Alcyonidium spp. , Callopora lineata , Electra pilosa , Celleporella hyalina , Cellaria spp., Membranipora membranacea*

Echinodermata: *Marthasterias glacialis , Asterias rubens , Asterina gibbosa , Ophiotrix fragilis , Echinus esculentus*

Tunicata: *Ascidiella aspersa , Dendrodoa grossularia , Didemnum coriaceum , Botryllus schlosseri Aplidium spp. , Molgula spp. , Distomus variolosus , Corella parellelogramma , Morchellium argus , Distomus variolosus*

Chordata: *Gobiusculus flavescens , Laminaria digitata*

Flora

***Rhodophycea**: Palmaria palmata , Polysiphonia macrocarpa , Plocamium cartilagineum , Ptilota gunneri , Brongniartella bysoides , Crustose coralline algae*

Phaeophyceae: *Fucus spp.*

Fauna

Cnidaria: *Dynamena pumila , Gonothyraea loveni , Litosiphon spp.*

Annelida: *Spirorbis spirorbis* , *Pomatoceros triqueter*
Crustacea:*Balanus balanus*
Mollusca: *Helcion pellucidum* , *Littorina obtusata* , *Littorina littorea* , *Mytilus edulis* , *Anomia ephippium* , *Heteranomia squamula*
Bryozoa: *Membranipora menbranacea*
Tunicata: *Ascidiella aspersa* , *Distomus variolosus* , *Egg capsules* [252]

Annex 4: Sussex Seasearch survey forms received (1999-2018)

Year	Total no. of forms received
1999	28
2000	48
2001	17
2002	56
2003	19
2004	33
2005	35
2006	28
2007	13
2008	7
2009	60
2010	49
2011	39
2012	50
2013	55
2014	17
2015	38
2016	21
2017	26
2018	23

Annex 5: Assumptions for economic valuations for ecosystem services associated with kelp forests

<table>
<tr><td rowspan="7">Fishery resources</td><td>Economic value per km2 per year (£)*
*adjusted for inflation</td><td>£2,066.43</td><td rowspan="7">REFERENCES

Vásquez et al.</td><td rowspan="7">NOTES/ASSUMPTIONS

Annual total estimates for Kelp Harvesting and Associated Fisheries taken from 10-year estimates (US$409,527,000 and US$ 8,3297,97 divided by 10, respectively). Area of kelp bed extent roughly estimated as 3500km2 for study area (700km coastline of study area by 5km offshore, based on rough bathymetry of potential for kelp growth (less than 50m depth). Value for per km2 calcuated by dividing annual total with area.</td></tr>
<tr><td>Valuation Method</td><td>Assumed / Revealed / Stated preference techniques</td></tr>
<tr><td>Year</td><td>2012</td></tr>
<tr><td>Country / Region</td><td>Northern Chile</td></tr>
<tr><td>Habitat type</td><td>Kelp</td></tr>
<tr><td>Economic valuation from source</td><td>2350.22 USD</td></tr>
<tr><td>Conversion (£)</td><td>£1880.18</td></tr>
</table>

Harvesting e.g. materials (alginates) for pharmaceutical and industrial use	Economic value per km2 per year (£)* *adjusted for inflation	**£45,767.20**	**REFERENCES** Vásquez et al.	**NOTES/ASSUMPTIONS** Annual total estimates for Kelp Harvesting and Associated Fisheries taken from 10-year estimates (US$409,527,000 and US$ 8,3297,97 divided by 10, respectively). Area of kelp bed extent roughly estimated as 3500km2 for study area (700km coastline of study area by 5km offshore, based on rough bathymetry of potential for kelp growth (less than 50m depth). Value for per km2 calcuated by dividing annual total with area.
	Valuation Method	Assumed / Revealed / Stated preference techniques		
	Year	2012		
	Country / Region	Northern Chile		
	Habitat type	Kelp		
	Economic valuation from source	11700.77 USD		
	Conversion (£)	£9360.62		
Water quality maintenance	Economic value per km2 per year (£)* *adjusted for inflation	**£5,703.16**	**REFERENCES** Weatherdon et al (2017)[253] Campagne et al (2015)[254]	**NOTES/ASSUMPTIONS** n/a
	Valuation Method	Benefit transfer		

<table>
<tr><td rowspan="5"></td><td>Year</td><td>2015</td><td rowspan="5"></td><td rowspan="5"></td></tr>
<tr><td>Country / Region</td><td>Mediterranean</td></tr>
<tr><td>Habitat type</td><td>Seagrass</td></tr>
<tr><td>Economic valuation from source</td><td>60 EUR</td></tr>
<tr><td>Conversion (£)</td><td>£54</td></tr>
<tr><td rowspan="7">Protection of coastlines from storm surges waves/ reduction in shoreline erosion</td><td>Economic value per km2 per year (£)*
*adjusted for inflation</td><td>£17,870</td><td rowspan="7">REFERENCES

Weatherdon et al (2017)[255]

Campagne et al (2015)[256]</td><td rowspan="7">NOTES/ASSUMPTIONS

n/a</td></tr>
<tr><td>Valuation Method</td><td>Damage cost avoided</td></tr>
<tr><td>Year</td><td>2015</td></tr>
<tr><td>Country / Region</td><td>Mediterranean</td></tr>
<tr><td>Habitat type</td><td>Seagrass</td></tr>
<tr><td>Economic valuation from source</td><td>188 EUR</td></tr>
<tr><td>Conversion (£)</td><td>£169.20</td></tr>
</table>

Carbon sequestration	Economic value per km2 per year (£)* *adjusted for inflation	**£9,046.17**	**REFERENCES** Bayley et al (2017)[257]	**NOTES/ASSUMPTIONS** Total area of kelp in Falkland Islands waters calculated as 644.05 km2. Total carbon sequestration for this area estimated as 0.239 million tonnes CO2 equivalent. Total divided by area is multiplied by the cost per tonne of CO2, estimated as £24.01 (taken from https://markets.businessinsider.com/commodities/co2-european-emission-allowances on 10th July)
	Valuation Method	Calculation		
	Year	2017/2018		
	Country / Region	Falkland Islands		
	Habitat type	Kelp		
	Economic valuation from source	8909.85 GBP		
	Conversion (£)	£8909.85		
Nursery habitats for commercial fish species	Economic value per km2 per year (£)* *adjusted for inflation	**£7,098.81**	**REFERENCES** Unsworth (2010)[258]	**NOTES/ASSUMPTIONS** n/a
	Valuation Method	Market price		
	Year	2010		
	Country / Region	Australia		
	Habitat type	Seagrass		

	Economic valuation from source	78 USD		
	Conversion (£)	£62.40		
Tourism and recreation (e.g. diving)	Economic value per km2 per year (£)* *adjusted for inflation	**£4,058.13**	**REFERENCES** Expert Knowledge	**NOTES/ASSUMPTIONS** Value estimated from roughly 5 diving schools providing approximately 100 trips a year at approximately £40 per trip
	Valuation Method	Calculation		
	Year	2019		
	Country / Region	Sussex, UK		
	Habitat type	Kelp		
	Economic valuation from source	n/a		
	Conversion (£)	£4,058.13		

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