Seagrass Natural Capital Assessment: The Isles of Scilly Complex SAC

Using natural capital indicators to explore the distribution and condition of seagrass in the Isles of Scilly Complex Special Area of Conservation (SAC) and the ecosystem services seagrass provides to society

Accessible version

Second edition October 2022

Natural England Commissioned Report NECR419

About Natural England

Natural England is here to secure a healthy natural environment for people to enjoy, where wildlife is protected and England's traditional landscapes are safeguarded for future generations.

Further Information

This report can be downloaded from the Natural England Access to Evidence Catalogue. For information on Natural England publications contact the Natural England Enquiry Service on 0300 060 3900 or email enquiries@naturalengland.org.uk.

Copyright

ISBN 978-1-78354-911-5

Catalogue code: NECR419

Report details

Natural England commission a range of reports from external contractors to provide evidence and advice to assist us in delivering our duties. The views in this report are those of the authors and do not necessarily represent those of Natural England.

Please note that this is a version of the original report which has been formatted to make it more accessible. Some table and figure numbers may be different to the original report.

Author(s)

Emily Howard-Williams

Contractor

Westcountry Rivers Ltd.

Natural England Project Manager

Joanne Bayes, Senior Specialist, Natural England

joanne.bayes@naturalengland.org.uk

Keywords

Marine, natural capital, seagrass, Special Area of Conservation, Isles of Scilly Complex

Acknowledgements

The authors would like to thank all who contributed to the creation of this report, including, Fiona Crouch, Maija Marsh, Zeenat Qadir, Kate Sugar, Hazel Selley, Dr Ken Collins, Dr Matt Ashley, Dr Sian Rees, Tom Hooper, Phil Horton, Cat Palmer and Mark Parry.

LIFE Recreation ReMEDIES (LIFE18 NAT/UK/000039) is financially supported by LIFE, a financial instrument of the European Commission. ReMEDIES is led by Natural England in partnership with The Royal Yachting Association, Marine Conservation Society, Ocean Conservation Trust and Plymouth City Council/Tamar Estuaries Consultative Forum.

Citation

HOWARD-WILLIAMS, E. 2022. Seagrass Natural Capital Assessment: The Isles of Scilly Complex SAC. NECR419. Second edition. Natural England.

Executive summary

England's varied marine environment, its ecosystems, geodiversity and seascapes, provides people with a wide range of benefits, upon which human wellbeing depends. These benefits include thriving wildlife, cultural and spiritual enrichment, food, clean water and air and reduced risks from environmental hazards, such as flooding. Seagrass beds are a unique ecosystem which provide a suite of benefits from carbon sequestration, enhancing water quality, to the provision of nursery habitat for commercial fish species.

This place-based mapping report, one of a series of five, and the accompanying literature review, use Natural England's natural capital indicators to review and map the state of the seagrass within the Isles of Scilly Complex SAC and the ecosystem services the seagrass provides. Habitat suitability data illustrates the potential area of seagrass distribution if pressures were to be removed/reduced. Data from previous seagrass studies illustrates the potential for increased ecosystem services within the Isles of Scilly Complex SAC.

By applying a natural capital approach to better understand the links between healthy seagrass habitats and the ecosystem services they provide, we hope to increase public awareness of the importance of these habitats and the wider environmental, societal and economic benefits they provide.

Contents

ReMEDIES project overview

The Life Recreation Reducing and Mitigating Erosion and Disturbance Impacts affEcting the Seabed (ReMEDIES) project is lead by Natural England and will improve the condition of five Special Areas of Conservation (SACs) between Essex and the Isles of Scilly. This will be achieved by habitat restoration and reducing recreational pressures. Promoting awareness, communications and inspiring better care of sensitive seabed habitats will be key. An element of this project is to improve the public knowledge of these habitats by applying the natural capital approach to describing the ecosystem services and wider benefits of healthy seagrass and maerl beds.

England's varied marine environment, its ecosystems, geodiversity and seascapes, provides people with a wide range of benefits, upon which human wellbeing depends. These benefits include thriving wildlife, cultural and spiritual enrichment, food, clean water and air and reduced risks from environmental hazards, such as flooding. Seagrass habitat is a unique ecosystem which provides a suite of benefits from carbon sequestration, enhancing water quality, to the provision of nursery habitat for commercial fish species.

Using Natural England's natural capital indicators this document illustrates the state of the seagrass within the Isles of Scilly Complex and the ecosystems services it provides. Habitat suitability data illustrates the potential area of seagrass distribution were pressures to be removed/reduced. Data from previous seagrass conservation shows the potential for increased ecosystems services within the Isles of Scilly Complex.

What is natural capital?

Natural capital means "the elements of nature that directly or indirectly produce value to people, including ecosystems, species, freshwater, land, minerals, the air and oceans, as well as natural processes and functions" (Natural Capital Committee, 2017).

It is helpful to consider natural capital in the form of a logic chain that shows the links between ecosystem assets, services, benefits and value to people (Figure 1). Figure 1 shows that how much, how good and where natural assets are, affect the ecosystem services, benefits and value people get from them. It shows how management interventions, as well as pressures and drivers of change, influence this chain. Other capital inputs are also often needed for people to obtain the benefits from ecosystem services (a simple example is the processing of trees to produce wood products).

As an example, an area of woodland (ecosystem asset) may reduce air pollution created by traffic on a nearby road. This woodland is therefore improving air quality (ecosystem service) in the local area which results in cleaner air and improved health in the adjacent residential street (benefit). This cleaner air has a value because we know it impacts the health and wellbeing of communities. Sometimes we can use economic methods to put a value on benefits in monetary terms.

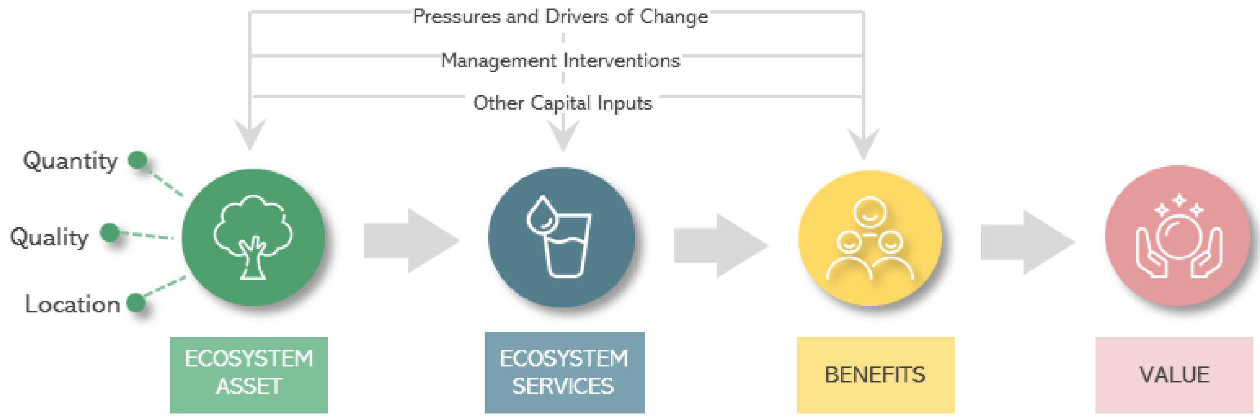


Figure 1: Generalised natural capital logic chain (Wigley et al., 2020).

Figure 2 shows how natural capital assets support the provision of ecosystem services, benefits and value. The roots of the tree show how aspects of asset quality are critical to the provision of ecosystem services. The roots also show that geodiversity underpins the ecosystem assets and therefore the ecosystem services and benefits they can provide. It is important to remember that this diagram, and natural capital frameworks more generally, are a simplification of how nature works in practice.

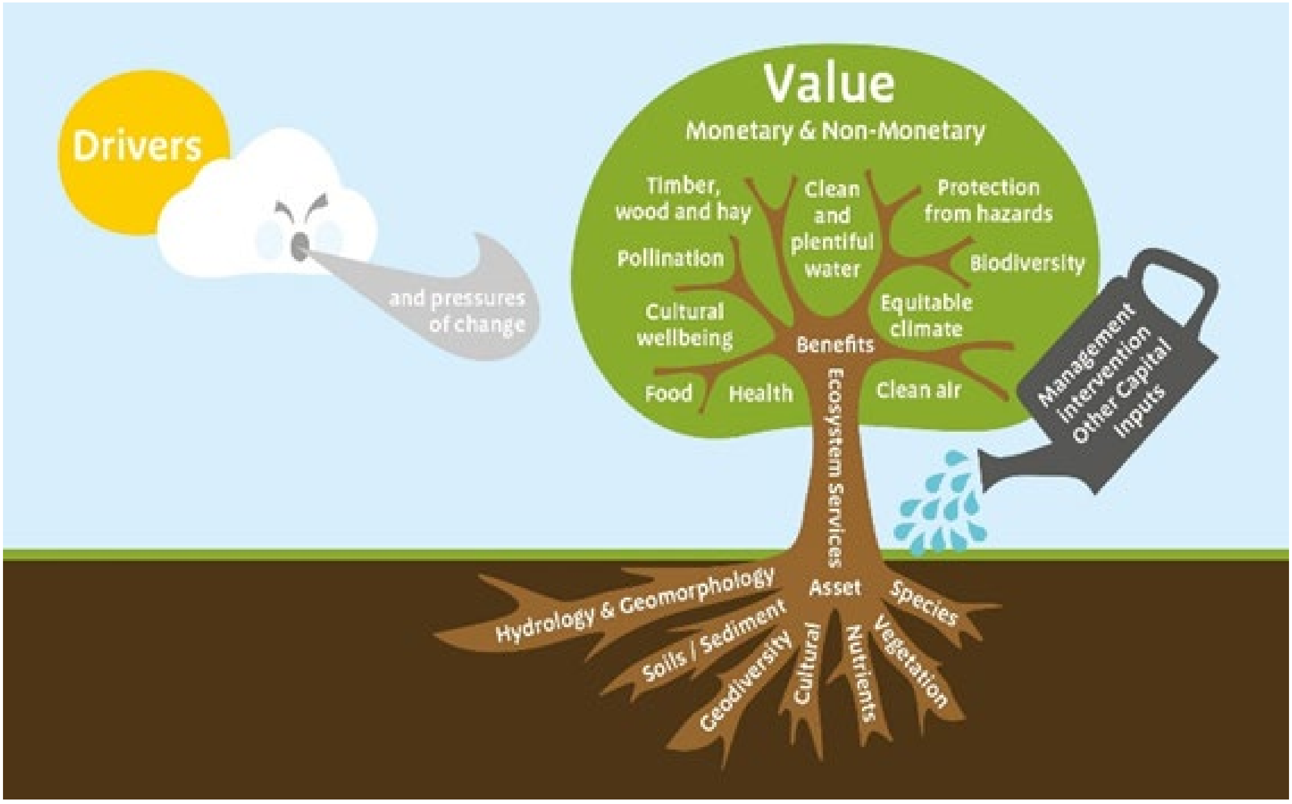


Figure 2: Natural capital attributes from Sunderland et al. (2019). Image created by Countryscape 2019.

Measuring our natural capital

In 2018, Natural England published ‘Natural Capital Indicators: for defining and measuring change in natural capital’ (Lusardi *et al.*, 2018). This report identified key properties of the natural environment vital for the long-term sustainability of benefits, which can act as indicators of change.

Natural England developed an innovative, systematic approach to identify attributes of the natural environment underpinning the provision of ecosystem services. This approach took account of the expert opinion of nearly 90 specialists in Natural England and the Environment Agency. From this list of attributes, indicators for measuring change were selected and prioritised into short list and long list indicators. Principles were established for defining robust indicators, stating that they should be; transparent, relevant, meaningful, knowable, actionable and scalable. Datasets that could potentially be used to map these indicators were also identified. Logic chains were used to identify the attributes relevant to the provision of ecosystem services within each broad habitat. Only the key ecosystem services were analysed for each habitat and not all attributes were identified as indicators. For an example of a logic chain see the marine wild animals, plants and algae and their outputs logic chain below.

Example

Example logic chain showing the characteristics that link marine assets to the ecosystem service; Provisioning: wild animals, plants and algae and their outputs. Short-list indicators have “short-list” in brackets after the indicator name. Quantity means extent of (area, % cover).

Quantity:

- Intertidal rock
- Subtidal rock
- Shallow subtidal sediment
- Shelf subtidal sediment
- Seagrass beds
- Maerl beds
- Reefs

Quality - Sediment processes:

- Sediment accumulation rates
- Slopes
- Seabed form
- Channel depths
- Erosion-deposition cycles
- Substratum area and distribution (ha), depth (m), type

- Sediment properties (including stability)
- Sediment biota (short-list)

Quality - Nutrient (& chemical) status:

- Nutrient status of sediment & seawater (N, P, Si)
- Chemical status of sediment & sea water: toxic contaminants (short-list)
- pH (short-list)
- Dissolved oxygen (short-list)
- Bacterial and viral water quality (short-list)

Quality - Hydrology:

- Water depth
- Temperature - changes
- Salinity - changes
- Turbidity (mg/l) – changes

Quality - Habitat & species (including algae; plankton, invertebrates; fish; birds; mammals):

- Abundance (no.)
- Biomass (kg)
- Net productivity by species (kcal/ha/yr) (short-list)
- Productivity: biomass ratios
- Species diversity (diversity indices)
- Number of trophic levels & community composition in each level (short-list)
- Amount & number of decomposers/decomposition rate (kg/ha/year)
- Predator:prey ratios
- Population dynamics (recruitment, age classes, male: female -ratios, age at maturity, growth rates)
- Changes in genetic diversity
- Non-native species
- Phenology eg phytoplankton blooms (& synchronicity with zooplankton & fish larvae), fish migrations
- Cold:warmer water species ratio

Ecosystem service flow:

- Fish, shellfish, seaweed and other products (tonnes)
- Quality of fish & shellfish (age/length profile; % affected by disease)
- Seaweed quality (% affected by disease)

Benefits:

- Products from the sea eg fish, shellfish & seaweed for food, fertiliser, angling bait, medicines

Value:

- It is difficult to measure the value of products from the sea; the provision food should be considered, as well as social, cultural and environmental value

Report structure

This report illustrates the state of seagrass natural capital in the Isles of Scilly Complex SAC. It maps a series of indicators of the quantity, quality and location of the seagrass and the ecosystem services the habitat supports. Seagrass as an ecosystem asset is discussed initially, with descriptions of anthropogenetic pressures the habitat is exposed to. The quality chapter is divided into direct and indirect indicators of quality. The remaining chapters illustrates data which indicates the ecosystem services provided locally and the potential for increased benefit if the recreational pressures were reduced. The chapters are laid out in the following order:

- Ecosystem asset: seagrass
- Ecosystem services from seagrass
- Seagrass quantity and quality
- Ecosystem service flows
- Pressures and drivers of change
- Potential
- More about ReMEDIES
- Literature cited
- Dataset sources - map and table captions each contain a number relating to the data sources used to create them, which are identified in this section.

Ecosystem asset: seagrass

Two species of seagrass are found in England, *Zostera marina* (*Z. marina*) and *Zostera noltii* (*Z. noltii*). A third *Zostera angustiflolia* was thought to be a separate species but is now considered a sub-species of *Z. marina* (Guiry and Guiry, 2020). *Ruppia maritima* is included under the 'Seagrass' category of Features of Conservation Interest (marine features that are particularly threatened, rare, or declining species and habitats) (Marine Life Information Network, 2022) but, although it is often found with seagrasses, it is not a true seagrass (Tyler-Walters and d'Avack, 2015). This report will focus on *Z. marina* and *Z. noltii*.

Seagrasses are marine flowering plants found in sheltered subtidal and intertidal zones at flow velocities below 1.5 m/s, down to depths of 10m depending on water clarity and species (Borum *et al*., 2004; Jackson *et al*., 2013). Seagrasses have variable growth rates, dispersal and range expansion can occur sexually through seed dispersal or through the spread of rhizomes. In *Z. marina* and *Z. noltii* the dispersal of rhizomes can only occur over a gentle topological gradient.

Seagrass beds form in sheltered areas near the coast in sandy sediments. They require high light availability and low nutrient input to remain stable and in good ecological health. A key feature of seagrass habitat is the formation of rhizome mattes which store mobilised sediments. This stabilisation occurs as the leaves of the plants slow wave energy over the beds, allowing the mobilised sediments to settle within the seagrass. This process has multiple benefits including, improving water quality by reducing turbidity, removing excess nutrients (N and P) as well as sequestering organic carbon, each one an important ecosystem service. Globally, seagrasses occupy less than 0.2% of the seabed (Fourqurean *et al.,* 2012), but they are estimated to store around 10% of the yearly ocean organic carbon (Duarte *et al*., 2005) and have similar soil carbon storage potential as temperate forests (Fourqurean *et al*., 2012). There is estimated to be more carbon stored in the top 1m of seagrass sediments than the combined global estimates of carbon emissions from fuels used for international aviation and maritime transport, fossil fuel (combustion and oxidation) and cement production in 2018 (Fourqurean *et al*., 2012; Green *et al*., 2018; Friedlingstein *et al*., 2019). Fragmented and patchy seagrass beds, with percentage cover below 60% are more vulnerable to losses during storms than more dense, uniform beds, which is likely to be related to dense patches having self-protective properties which make them more stable (Borum *et al.*, 2004).

They provide physical structure on a somewhat structureless sediment which enhances biodiversity as well as primary and secondary production (Duffy, 2006), provide vital habitat for protected species such as seahorses, particularly the long-snouted seahorse (Garrick-Maidment *et al*., 2010; Jackson *et al*., 2013), and provide vital nursery habitats for commercial fish species (Unsworth *et al*., 2018). In the United Kingdom (UK) this includes species such as pollack, sole, mullet, plaice, skates and rays (Ashley *et al*., 2020).

Ecosystem services from seagrass

Natural England has produced a list of marine natural capital indicators and the associated ecosystem services (Lusardi *et al*., 2018). In order to assess the natural capital of seagrass beds within the target SACs, a series of ecosystem service flow indicators have been identified based on a combination of the ecosystem services, service flows, and benefits provided by Natural England and the findings of a literature review which preceded this report. The key ecosystem services from seagrasses are listed here, which are limited to the most important (short-listed) services identified by Natural England:

- **Water quality** - Clean water, also underpinning eg sustainable ecosystems, cultural services, health benefits.
- **Wild animals, plants, algae & outputs** - Products from the sea eg fish, shellfish & seaweed for food, fertiliser, angling bait, medicines. Quality of fish & shellfish (age/length profile; % affected)

- **Maintenance of nursery populations & habitats** - Biodiversity, in and of itself, and underpinning all other services such as recreation (including wildlife watching), tourism, research and education, food from wild populations & aquaculture, climate regulation.
- **Climate regulation** - Equitable climate eg reduced risk of drought, flood & extreme weather events, lower summer temperatures, reduced health & safety risks, reduced flood risk, protection of infrastructure/lack of transport disruption.
- **Cultural services** - Health and wellbeing benefits, including sense of place, spirituality, inspiration, physical and mental wellbeing.

Currently there are not sufficient data on the provision of cultural ecosystem services from seagrass and therefore this service is not considered in more detail within this report.

This list does not include other (long list) ecosystem services that seagrasses provide, such as mass stabilisation or flood protection. The presence of seagrass beds can provide a degree of coastal protection through the attenuation of wave transmission onshore (Duarte *et al.,* 2013). The degree at which wave attenuation occurs depends on leaf length and the density of seagrass (Fonseca and Cabalan, 1992; Chen *et al.*, 2007; Hansen and Reidenbach, 2012) and the effectiveness can vary spatially and temporally.

Seagrass quantity and quality

Seagrass quantity: location

The area of seagrass cover per 3.5ha hexagon for the Isles of Scilly Complex SAC is illustrated in Figure 3, which is derived from the most recent spatial data collected in 2011. The darker hexagons have a higher seagrass cover. Figure 3 illustrates that there are some areas of high seagrass cover within the SAC particularly around Little Arthur and Higher Town Bay, The lighter green areas indicating patchier, and potentially more fragmented beds. A decline in the area of seagrass within the SAC has been recorded (Bull and Kenyon, 2019), with the greatest declines recorded in the seagrass beds at Old Grimsby Harbour.

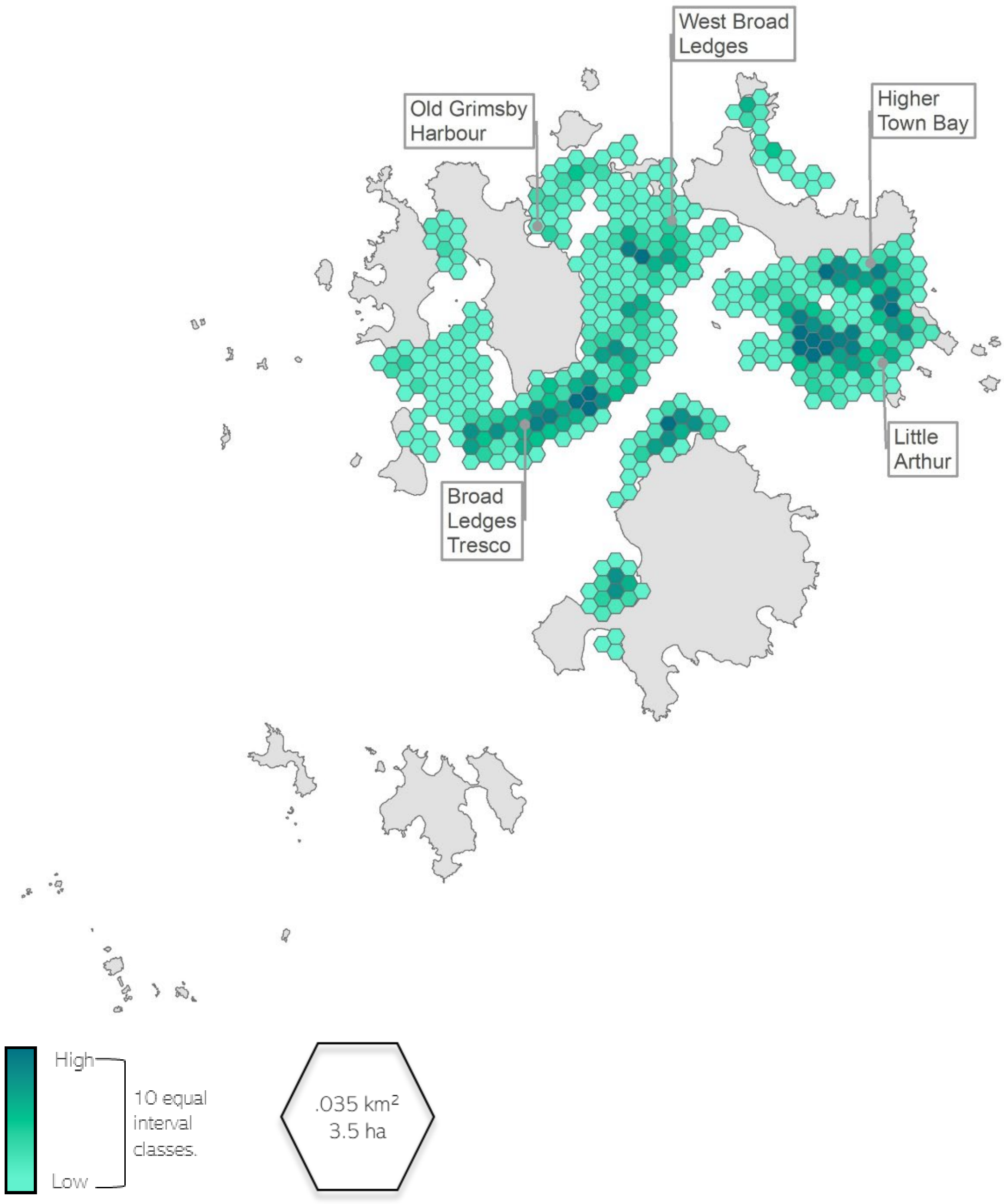


Figure 3: Area of seagrass within the Isles of Scilly SAC. The map shows areas of seagrass around and between the larger and more northerly islands. The darkest patches, indicating high seagrass cover are around Little Arthur, Higher Town Bay and Broad Ledges Tresco. Data source code 1.

Map key: Shading shows area (m^2) of seagrass cover, symbolised by 10 equal interval classes based on the range of values across the Isles of Scilly Complex SAC. Darker hexagons indicate areas of highest seagrass cover. Each hexagon represents 3.5ha.

All maps are © Natural England, 2021. Data sources and attributions for each map are listed in section [Dataset sources].

Seagrass can be found to depths of up to around 10m (Jackson *et al.,* 2013). Figure 4 illustrates the approximate depth within this SAC. While the depth may be appropriate, seagrass beds are also limited by current velocities (up to approx. 1.5 m/s) and salinity (Borum *et al*., 2004).

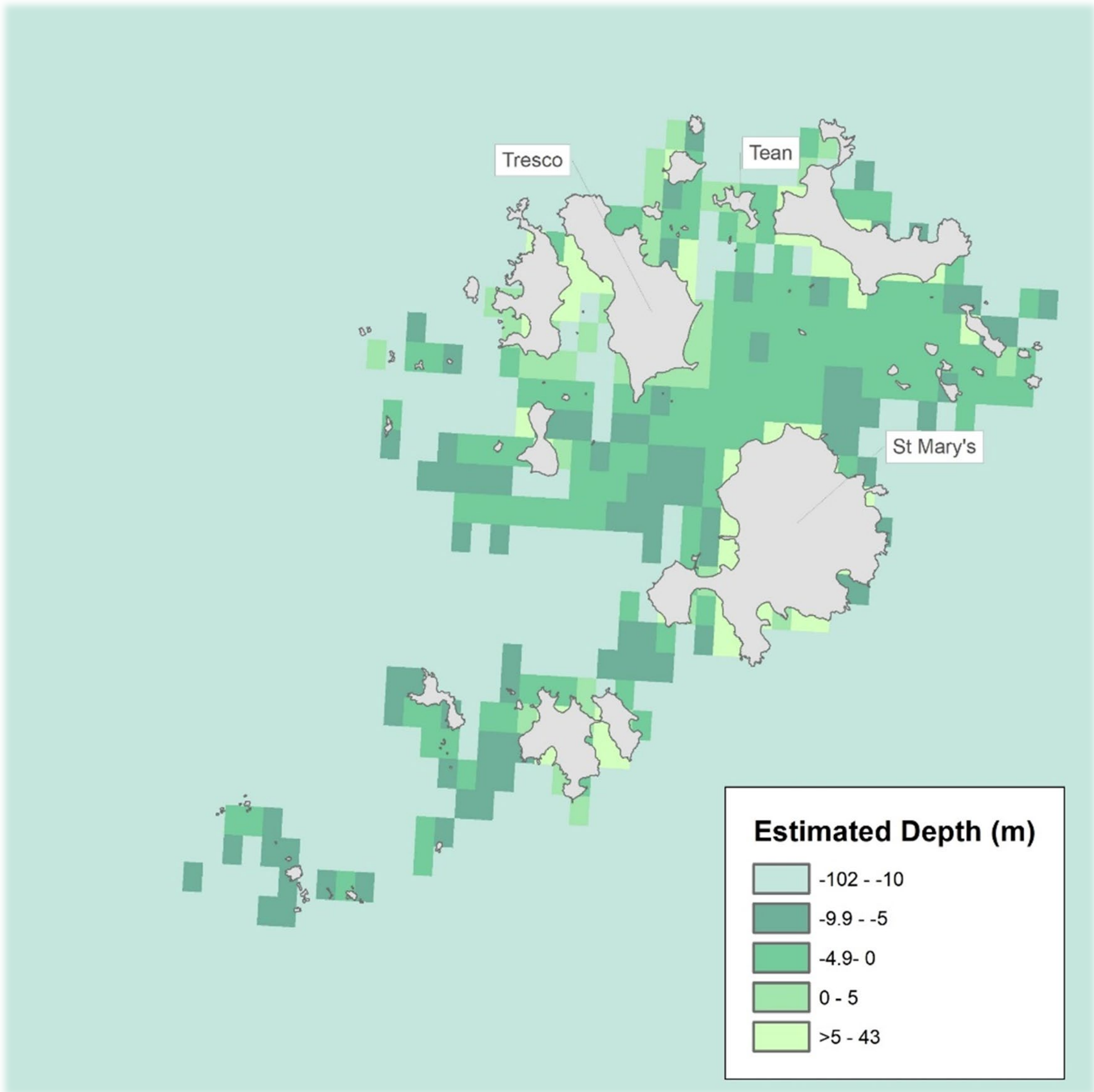


Figure 4: Approximate depth within the Isles of Scilly Complex SAC (negative values indicate estimates are below sea level). The map shows shallower depths around the coastlines and between the islands and deeper water further from the coast. Data source code 2.

The GEBCO Grid should NOT be used for navigation or for any other purpose involving safety at sea. GEBCO's global elevation models are generated by the assimilation of heterogeneous data types, assuming all of them to be referred to Mean Sea Level.

All maps are © Natural England, 2021. Data sources and attributions for each map are listed in section Dataset sources.

Seagrass quality: what are the quality indicators?

Direct indicators of seagrass quality are derived from data relating to the plants themselves, (ie, shoot density, leaf length, % cover and the presence of wasting disease)(Wood and Lavery, 2001; Ruiz and Romero, 2003). These direct indicators are used to inform local scale habitat assessments, such as the SAC condition assessments which are undertaken every six years. Ratios of leaf nutrient concentrations can provide further direct indicators of the abiotic conditions which influence seagrass quality, including:

- Declining Carbon:Nitrogen (C:N) ratio provides an early indicator of restricted light availability (McMahon *et al*., 2013) (high light=≥20, reduced light=14-20, low light=≤14 (Jones and Unsworth, 2016))
- Carbon:Phosphorus (C:P) ratio indicates environmental P availability, <400 indicates over-enrichment of P which can impact seagrass quality (McKenzie *et al*., 2012; Jones and Unsworth, 2016)
- Nitrogen:Phosphorus (N:P) ratio provides an indicator of the balance of environmental N and P (McKenzie *et al*., 2012) (between 0-20 considered to be balanced (Jones and Unsworth, 2016)).

Indirect indicators of quality are taken from the surrounding environment and provide information about the biotic and abiotic conditions where the seagrasses are growing. For example, light availability, nutrient data (nitrogen and phosphorus) and intensity of recreation activities all provide indirect indicators of seagrass quality.

Seagrass quality: direct quality indicators

The seagrasses of the Isles of Scilly SAC are some of the best in the British Isles (Jones and Unsworth, 2016) and based on plant measurements and nutrient ratio data, which are indicative of water quality and light availability (C:N >20) they are in good ecological health, with a limited P pool (C:P >900), albeit over-enriched with N (N:P >40). However, in recent years this habitat has seen an overall decline within this SAC (Bull and Kenyon, 2019). Data from Jones and Unsworth (2016) indicates that this decline is not related to water quality or restricted light availability, therefore another factor is likely to be causing this trend (ie, recreational pressures).

Table 1 describes the direct quality indicators. Shoot density was recorded for individual seagrass beds within the SAC (Table 1a, Bull and Kenyon, 2019), whereas SAC averages for leaf length and % cover are provided (Table 1b, Jones and Unsworth, 2016). According Jones and Unsworth, (2016) the seagrasses in the Isles of Scilly had the highest observed shoot biomass and seagrass cover (91.3±2.5%), lowest shoot density (4±1.4 per 0.25m^2), longest (788±4.9mm) and widest leaves (10.7±0.5mm) of all the sites they observed. Figure 3 shows the area of seagrass within the Isles of Scilly Complex SAC.

Table 1: Direct quality indicators for seagrass within the Isles of Scilly Complex SAC (Bull and Kenyon, 2019[1]; Jones and Unsworth, 2016[2]). Number in brackets indicates reference relating to data.

a)

Seagrass bed	Shoot density per $0.0625m^2$
Broad Ledges Tresco	9.3[1]
Old Grimsby Harbour	11[1]
West Broad Ledges	11[1]
Higher Town Bay	15[1]
Little Arthur	11[1]

b)

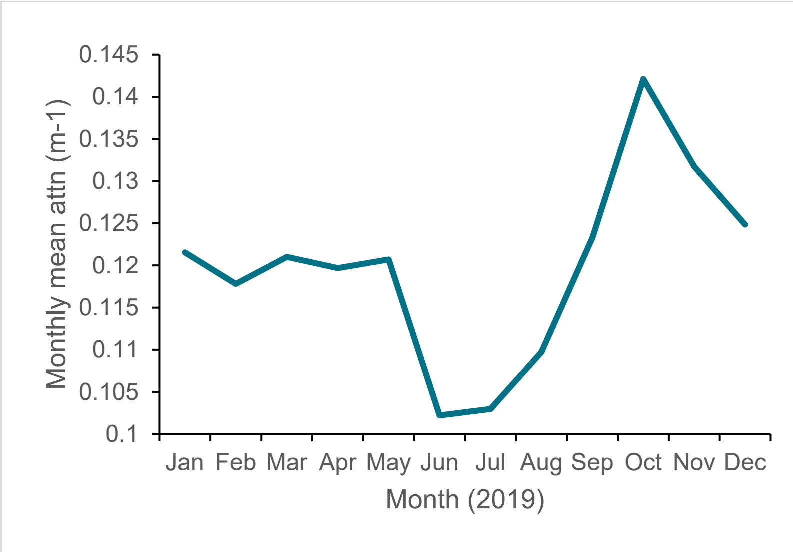
Seagrass bed	Leaf length (mm) SAC average	%cover SAC average	Area (km^2)
SAC	788±49[2]	91.3±2.5[2]	3.172

Seagrass quality: indirect quality indicator - water quality and clarity

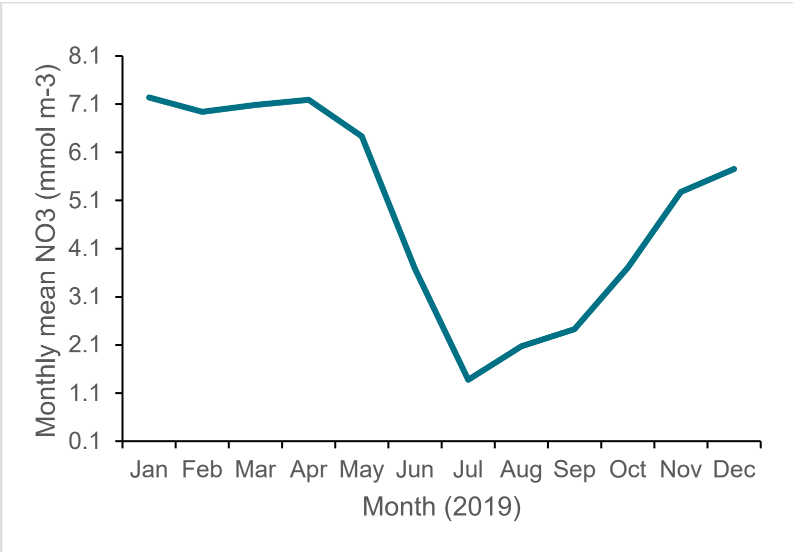
Water quality and clarity can impact seagrass health.

Nutrient loading indirectly affects seagrass by reducing light reaching the plants; increased availability of nutrients causes a shift in the dominant vegetation to faster growing species, ultimately reducing the light availability (Burkholder *et al.,* 2007). Increased turbidity and algal blooms from excessive nutrients and dredging decrease the penetration of light through the water column and inhibits photosynthesis, in turn affecting growth and reproduction (Jones *et al.,* 2000).

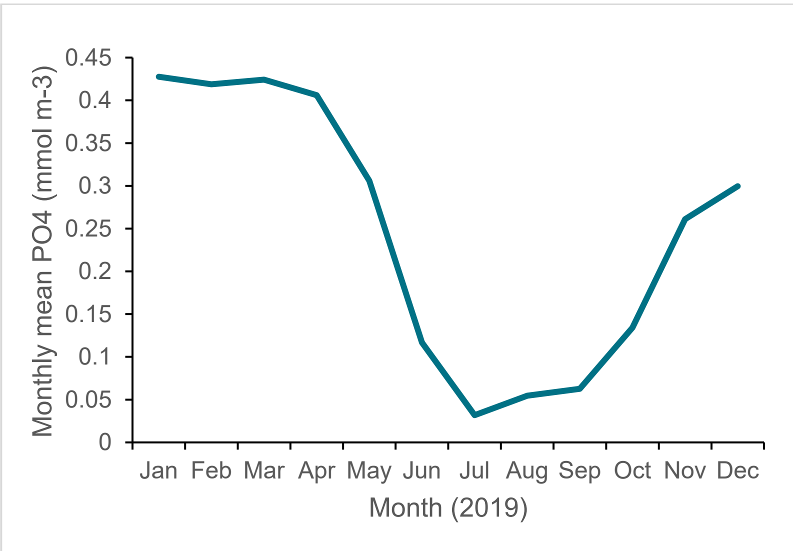
The monthly averages for modelled light attenuation co-efficient and nutrient data for the Isles of Scilly Complex SAC are presented in the graphs below (Figure 5) and give an indication of water quality and the fluctuations over the course of a year (2019). The average values from across the SAC were extracted and used in the graphs.



A)



B)



C)

Figure 5: The monthly averages for modelled light attenuation co-efficient (attn (a)) and nutrient (nitrate NO_3 (b) and phosphate PO_4 (c)) data for the Isles of Scilly Complex SAC. Data source code 4, see section Dataset sources. Graphs generated using E.U. Copernicus Marine Service Information.

Seagrass quality: indirect quality indicator – extent and intensity of recreational boating

The extent and quantity of boating activity within the Isles of Scilly Complex SAC provides an indirect indicator of seagrass quality; higher boating activity results in greater exposure to mooring and anchoring, potentially resulting in lower quality. Figure 6 illustrates the boating intensity within the SAC and in the local area taken from the Royal Yachting Association (RYA) recreational boating dataset, collected using Automatic Identification System (AIS).

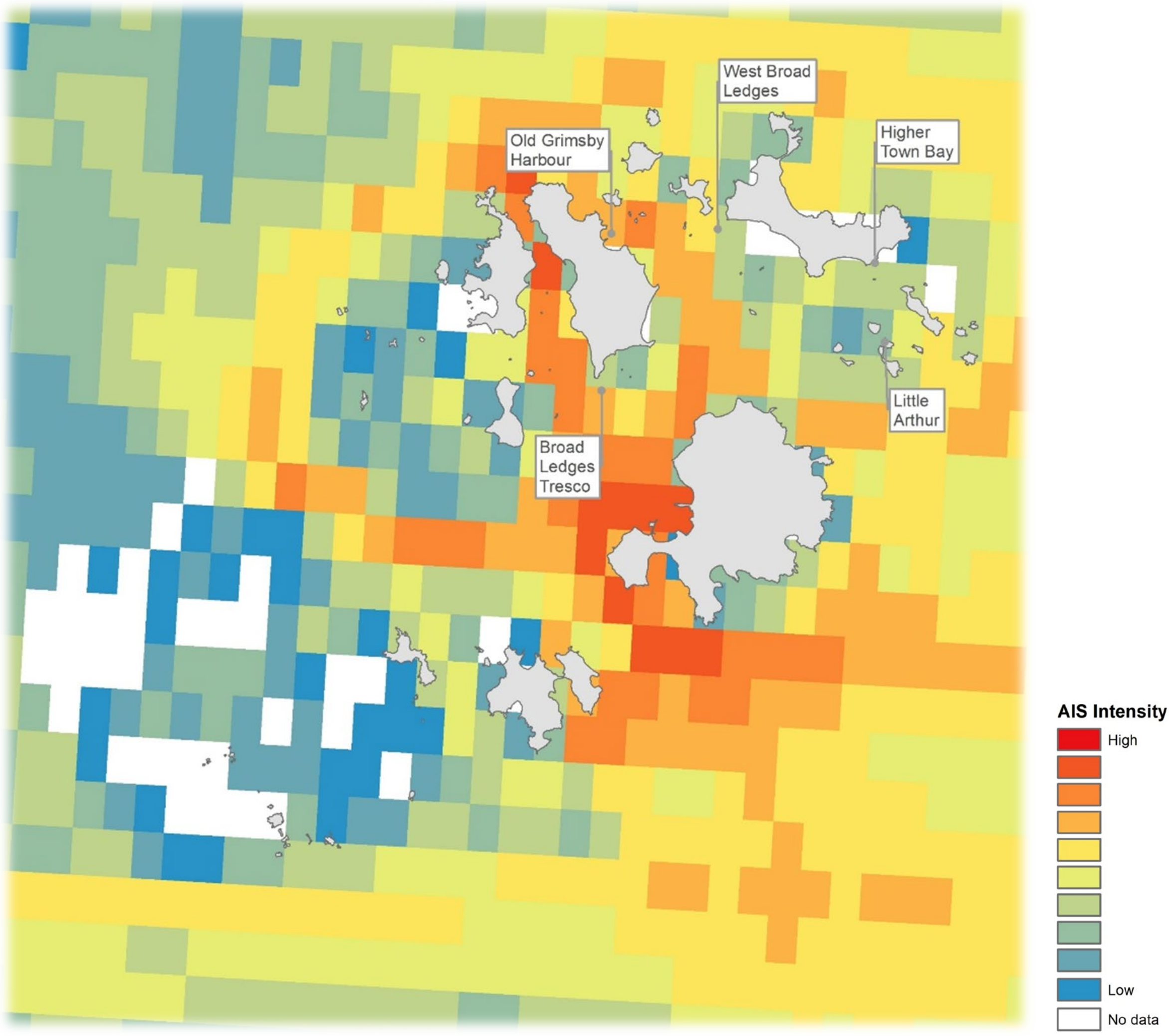


Figure 6: Recreational boating intensity within the Isles of Scilly Complex SAC (AIS = Automatic Identification System). © Data reproduced under licence from the Royal Yachting Association. Data source code 5. The map shows the most intense activity close to and between the towns of Hugh Town and New Grimsby, with lower intensity around the smaller islands to the south west.

All maps are © Natural England, 2021. Data sources and attributions for each map are listed in section [Dataset sources].

Ecosystem service flows

Ecosystem service flows: maintenance of nursery populations & habitats

Seagrass habitats provide spawning and nursery grounds for commercial and non-commercial species. Unsworth *et al*. (2018) found seagrasses provide valuable nursery habitat for 21.5% of top 25 landed species globally.

The complex vegetation provides shelter and protection from predators, and the variety of species across functional taxonomic groups utilising seagrasses, results in higher food availability (Duffey, 2006). Spawning and nursery ground data for 19 commercially or ecologically important species (Ellis *et al*., 2012) were compared to the spatial data for seagrass distribution across the SAC. Species that overlapped with the habitat distribution data are included in the relevant column in Table 2. The intensity, either high or low is also included as an indication of importance to the species. It is important to note that these data are not derived from direct species sightings within the seagrass habitat, these associations are based on spatial comparisons between datasets.

Within the Isles of Scilly Complex SAC pollack, mullet, sole, plaice, skates and rays (Ashley *et al.,* 2020) will use seagrass during juvenile stages and therefore have been included in the nursery column in Table 2. *Z. marina beds are* an important nursery habitat for Atlantic cod, although this has been established using data that were collected outside of the UK it may still be relevant within this SAC. Within the Fal and Helford general SAC description, Natural England (n.d) note that seagrass are a nursery ground for bass and cuttlefish, therefore the same association may be applicable to seagrass beds within this SAC.

Table 2: Spawning and Nursery grounds associated with seagrass beds in the Isles of Scilly Complex SAC showing association between lifecycle stage and seagrass beds (Natural England, n.d; Ellis *et al*., 2012; Lilley and Unsworth 2014; Ashley *et al.,* 2020) and intensity (Ellis *et al*., 2012). 'N' with a grey background indicates that no association was identified for this species and lifecycle stage. Data source code 6, see section Dataset sources.

Species	Spawning association	Spawning association intensity	Nursery association	Nursery association intensity
Horse mackerel	Seagrass	Low	N	N
Mackerel	Seagrass	Low	Seagrass	High
Spurdog	N	N	Seagrass	Low
Blue whiting	N	N	Seagrass	Low
European hake	N	N	Seagrass	Low
Anglefish	N	N	Seagrass	High
Common skate	N	N	Seagrass	Low
Whiting	N	N	Seagrass	Low
Cod	N	N	Seagrass	No data
Pollack	N	N	Seagrass	No data
Mullet	N	N	Seagrass	No data
Sole	N	N	Seagrass	No data
Plaice	N	N	Seagrass	No data
Skates and rays	N	N	Seagrass	No data
Bass	N	N	Seagrass	No data
Cuttlefish	N	N	Seagrass	No data

Ecosystem service flows: wild animals, plants, algae & outputs

The fish landings data for the Isles of Scilly in 2019 have been taken from the Monthly Sea Fisheries Statistics data set, 18 species of fish and shellfish were landed in the port in 2019 and one third were seagrass associated species. These species, live and landed weights, and value are described in Table 3, the species which are associated with seagrass are indicated in the "association" column (as outlined in Table 2).

The species associations presented in Table 3 are taken from multiple sources from the UK and abroad and therefore provide a general indication of the association with seagrass rather than a definitive list. Furthermore, it is not intended to attribute monetary value to seagrass within the SAC. Some entries are not identified to species level (e.g., skates and rays) so associations may not be applicable to the entire landed catch.

Table 3: Sea fisheries statistics for 2019, including species landed, weights and value for the Isles of Scilly (sorted by association with seagrass then by live weight). Species indicated have an association with seagrass habitat. (Natural England, n.d; Ellis *et al*., 2012; Lilley and Unsworth 2014; Ashley *et al.,* 2020). Dataset source code 7, see section Dataset sources.

Species	Association	Live weight (t)	Landed weight (t)	Value (£000's)
Pollack (Lythe)	Seagrass	2.64	2.16	7.30
Mullet	Seagrass	1.31	1.31	4.52
Mackerel	Seagrass	0.32	0.32	0.16
Skates and Rays	Seagrass	0.16	0.08	0.53
Plaice	Seagrass	0.11	0.10	0.71
Sole	Seagrass	0.06	0.06	0.39
Crabs	No data	48.01	46.63	163.72
Lobsters	No data	20.54	20.54	259.57
Other Shellfish	No data	2.60	2.60	69.27

Species	Association	Live weight (t)	Landed weight (t)	Value (£000’s)
Other Demersal	No data	0.16	0.16	2.06
Lemon Sole	No data	0.07	0.06	0.45
Megrim	No data	0.05	0.05	0.32
Scallops	No data	0.02	0.00	0.12
Brill	No data	0.02	0.02	0.28
Turbot	No data	0.01	0.01	0.18
Monks or Anglers	No data	0.01	0.01	0.06
Haddock	No data	0.00	0.00	0.03
Squid	No data	0.00	0.00	0.04

Ecosystem service flows: water quality

There are a number of measures of water quality which could be utilised to indicate the provision of this service within the SACs. As discussed previously the nutrient content and clarity of the water both have an impact on water quality. Seagrasses can improve the quality of water by removing detrimental anthropogenic inputs, through nutrient uptake and by depositing suspended particles within the water column (Short and Short, 1984).

The sediment accumulation rates (SAR) of seagrass have not been studied long-term (Röhr *et al*., 2016). Many of the estimates are linked to carbon sequestration rates (e.g, Miyajima *et al*., 2015). The estimate of 2 mm m^{-2} y^{-1} (Gacia and Duarte, 2001) was used here to estimate sediment accumulation rates as a proxy for the provision of this service within this SAC (Table 4). It should be noted that this estimate was based on data collected in Spain on the seagrass species *Posidonia oceanica* and therefore may not be entirely accurate for *Zostera* spp. and does not account for sediment resuspension, but provides an indicator of this ecosystem service within this SAC. Watson *et al.* (2020) provided a comprehensive summary of N and P burial rates as well as estimation of denitrification taken from a number of existing papers and these figures were used to estimate N (4.9 g N m^{-2} yr^{-1}) and P (-2.2 g P m^{-2} yr^{-1})* (Table 4). Figure 3 shows area of seagrass within the Isles of Scilly SAC, darker areas (areas of higher seagrass cover) have the potential to sequester more nitrogen (N) and accumulate more sediment, and release more phosphorous (P) than sequestered.

Table 4: Estimations of the ecosystem services provided by seagrass relating to water quality in the Isles of Scilly Complex SAC. Data source code 9, see section Dataset sources.

*** Note: There are limited studies available to provide accurate figures for P change, this figure is based on one study which actually found a seasonal net release of P from a particular seagrass bed. Future studies would be useful to confirm whether this is a common scenario for other seagrass beds.**

Ecosystem Service	Estimated total for Isles of Scilly SAC yr^{-1}
Nitrogen (N) burial (t)	16
Phosphorous (P) burial (t)*	-7
Sediment accumulation rate (m)	6346

Ecosystem service flows: climate regulation

The ability of seagrasses to stabilise and accumulate sediments results in the storage of organic carbon and the sediment is an important repository for carbon produced within the beds and elsewhere. The sediments within seagrass beds are largely anaerobic (Duarte *et al.,* 2011), meaning that material is broken down slowly and carbon can be stored indefinitely. The estimation of sequestration rates vary from 19 to 191 g C m^{-2} yr^{-1} (Watson *et al*., 2020). The long-term average carbon sequestration rate of 83 g C m^{-2} yr^{-1} presented by Duarte *et al.* (2005) has been used here to estimate the annual carbon sequestered by the seagrasses of the Isles of Scilly (Table 5) (area cover illustrated in Figure 3). Unless remobilised through either adverse weather conditions or physical disturbance these sediments will remain within the seagrass beds.

The organic carbon stored within these sediments are known as C_{stocks}. The global average of C_{stocks} in seagrass sediments is estimated to be 194.2 ± 20.2 Mg C ha which is comparable to boreal and temperate forests as well as tropical uplands (Fourqurean *et al*., 2012). The average for the seagrass beds in the south west of England is 140.98 ±73.32 Mg C ha (Green *et al*., 2018), this figure was used to estimate the C_{stocks} within the Isles of Scilly seagrass. Please note megagram (Mg) are the same unit as metric tonne (t).

Figure 3 shows area of seagrass within the Isles of Scilly Complex SAC, darker areas (areas of higher seagrass cover) have the potential to store higher C_{stocks} and sequester more carbon.

Table 5: Estimations of the ecosystem services provided by seagrass relating to climate regulation in the Isles of Scilly Complex SAC. Data source code 11, see section Dataset sources.

Ecosystem Service	Tonnes
C_{stocks}	44732
Carbon sequestered per year	263

Pressures and drivers of change

Pressures and drivers of change: recreational impacts

The close proximity to the shore and intertidal coastal zones means that seagrass beds are easily accessible by humans. This exposes them to terrestrial and marine based pressures (Cullen-Unsworth *et al*., 2013), which includes disturbances caused by boating, such as propeller damage, mooring, and anchoring (D'Avack *et al*., 2014). Mooring and anchoring causes damage to the rhizomes, shoots and leaves, while trampling also damages the roots and buries seeds, preventing germination. On the Isles of Scilly addressing the impact of mooring and anchoring on the seagrass beds is a priority.

The most commonly used mooring system is the swing mooring, This consists of a sinker block on the seafloor, and a heavy chain reaching a surface buoy, where the boat is secured (Luff *et al*., 2019). The chain moves with the changing tide and wind, which drags the chain across the surrounding seagrass beds and causes scarring. Anchoring is defined as "a device which secures a vessel to the seabed, temporarily, in order to prevent it drifting with the wind or current" (Griffiths *et al*., 2017 pp. 12). Moorings are generally a permanent feature with chronic impact (Griffiths *et al*., 2017) which makes the impact easier to quantify. Anchoring on the other hand, can occur any number of times in a seagrass bed, is highly variable spatially and temporally and is generally free, and unregulated. This variability makes the impact of anchoring difficult to measure and quantify and is therefore more of an unknown threat.

Management interventions

Advanced Mooring Systems:

Adding floats to the chains of traditional swing moorings (Stirling mooring, also known as an advanced mooring system) can prevent the chain from dragging and subsequently scarring the surrounding seagrass. Luff *et al*. (2019) assessed the impact of an advanced mooring system (Stirling mooring) compared to a traditional swing mooring, they found the average shoot density at 0.5m from the advanced mooring system sinker block was over three times higher compared to the swing mooring. They also found that blade length exceeded that of the swing mooring and the sediment grain size was smaller (meaning the finer grain was not as easily remobilized, which would impact water quality).

No Anchor Zones:

Voluntary “No Anchor Zones” can be used to discourage this anchoring over seagrass beds. Four free visitor moorings were installed outside the seagrass bed in North Haven (Skomer Marine Conservation Zone) to discourage boats from anchoring on the seagrass bed (Burton *et al.,* 2015). After the moorings were installed seagrass bed increased by 26% over 17 years (1997-2014) (Burton *et al.,* 2015). While this increase cannot be attributed to the removal of anchoring pressure alone, this figure could provide a useful estimate when calculating the potential ecosystem service benefits of “No Anchor Zones”.

Pressures and drivers of change: declining water quality and clarity

Declining water quality and clarity are the main threats to the health of seagrass habitats with nutrient loading and increased turbidity of particular concern for seagrass as they can negatively affect health and productivity (Jones *et al*., 2000; Ruiz and Romero, 2003). van Katwijk *et al*. (2016) found that in areas where seagrass restoration was attempted, 54% of loses prior to restoration were attributed to water quality deterioration.

Nutrient loading indirectly affects seagrass by reducing light reaching the plants, the increased availability of nutrients causes a shift in the dominant vegetation to faster growing species, eg opportunistic macroalgae and epiphytes, ultimately reducing the light availability (Jones and Unsworth, 2016). Jones *et al*. (2000) noted that increased turbidity and algal blooms from excessive nutrients and dredging decrease the penetration of light through the water column and inhibits photosynthesis, in turn affecting growth and reproduction. Turbidity can also reduce the oxygen availability for seagrass respiration and may result in hypoxic conditions (Mateo *et al*., 2006).

Potential

Potential: restoration potential

The Environment Agency (Environment Agency, 2020) forecasted restoration potential for seagrasses in England, Figure 7 shows the area where seagrass could colonise/recolonise based on salinity, wave exposure and bathymetry. The range of the Isles of Scilly seagrass beds are already extensive, Figure 7A shows the area for potential restoration is limited to a small area on the south east of St. Mary’s. This is a 0.16% increase on the current distribution of seagrass within the SAC (Figure 7B), the associated impact on ecosystem services are outlined in Table 6.

The strongest possibility for expansion of seagrass habitat within this SAC is to reduce fragmentation and improve connectivity within the existing beds. The light green hexagons in the current seagrass range indicate that the seagrass beds in these areas are fragmented. Fragmentation can occur in areas that are exposed to recreation boating pressures as a result of damage caused to the seagrass. Practical interventions (ie advanced mooring systems and No Anchor Zones) could reduce the impacts of recreational boating and allow the seagrass bed to recover, which would improve the connectivity between existing fragmented seagrass beds and increase the ecosystem services provided locally. The potential impacts of these interventions are illustrated on the following pages.

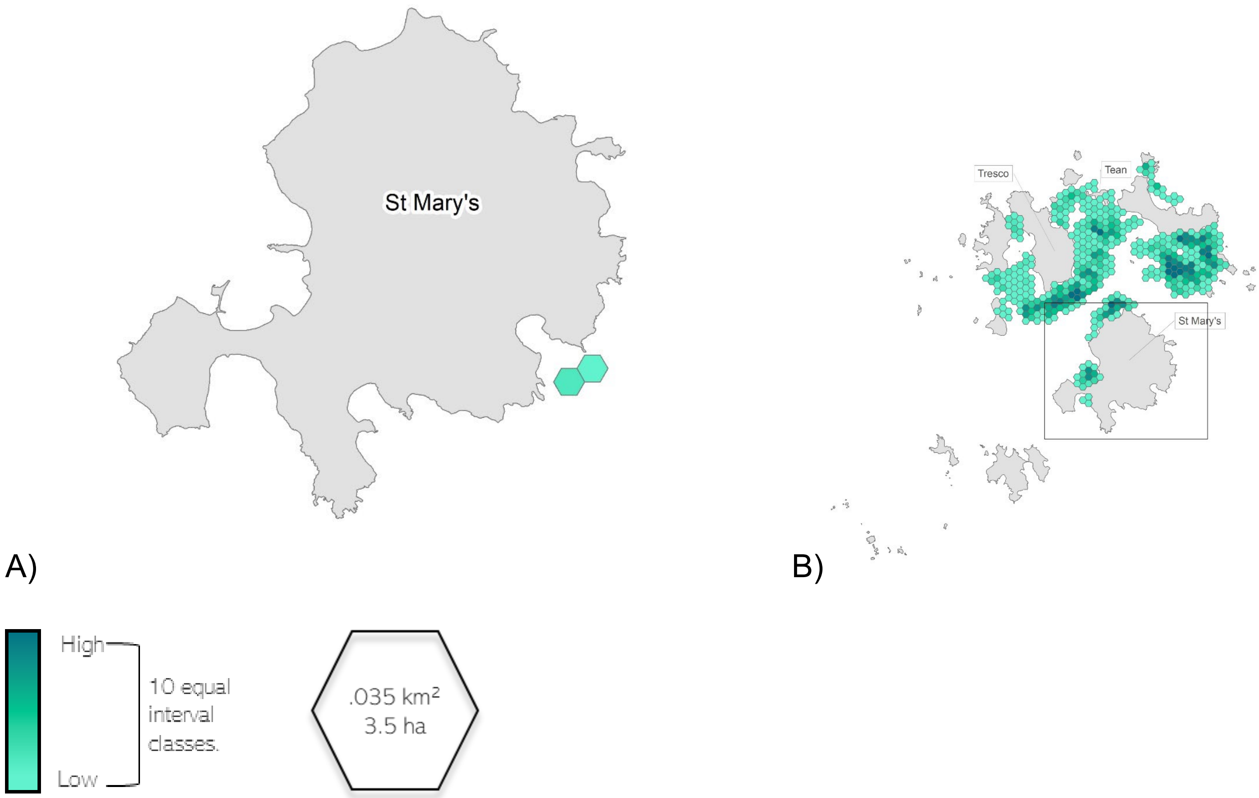


Figure 7: (A) Forecasted locations for seagrass restoration (zoomed to St Mary's), alongside (B) current distribution within the SAC. Darker hexagons indicate higher potential seagrass cover. The map shows areas of potential to the south east of St Mary's. Dataset source code 12 for A and 13 for B.

Map key: Shading shows potential area (m^2) of seagrass cover, symbolised by 10 equal interval classes based on the range of values across the Isles of Scilly Complex SAC. Darker hexagons indicate higher potential seagrass cover. Each hexagon represents 3.5ha.

Table 6: Changes in ecosystem services based on an area increase of 0.16%. Data source code 14, see section Dataset sources.

*** Note: There are limited studies available to provide accurate figures for P change, this figure is based on one study which actually found a seasonal net release of P from a particular seagrass bed. Future studies would be useful to confirm whether this is a common scenario for other seagrass beds.**

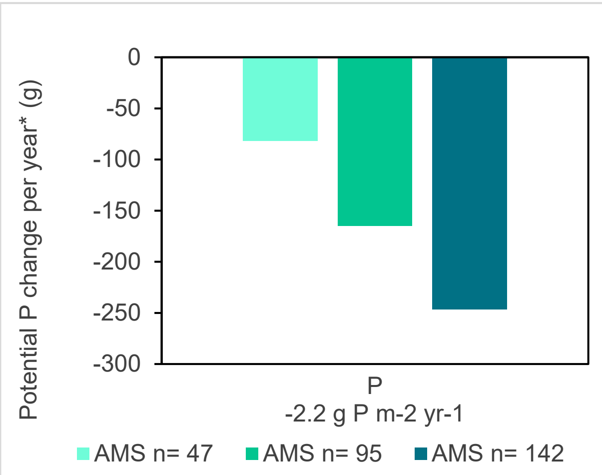
Ecosystem services Broad service in **bold** (see section Ecosystem services from seagrass) followed by specific service	**Current estimated total for the SAC yr^{-1}**	**Potential estimated total for the SAC yr^{-1}**
Area (km^2)	3.172	3.178
Climate regulation Carbon sequestration (t) (83 g C m^{-2} yr^{-1})	263	264
Water quality Nitrogen burial (N) (t) (4.9 g N m^{-2} yr^{-1})	16	16
Water quality Phosphorous burial (P) (t) (-2.2 g P m^{-2} yr^{-1})*	-7	-7
Water quality Sediment accumulation (m) (2 mm m^{-2} y^{-1})	6346	6356

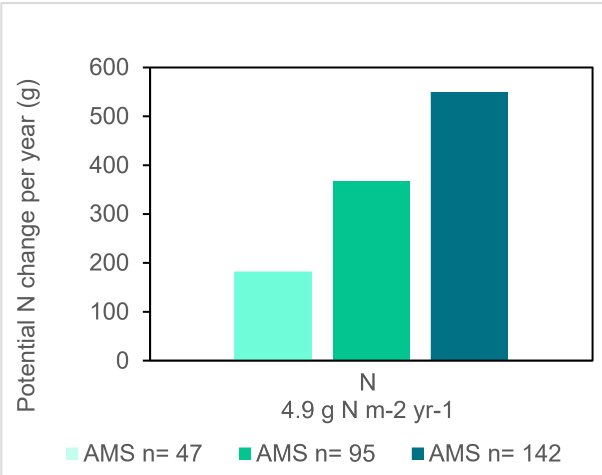
Potential: mooring

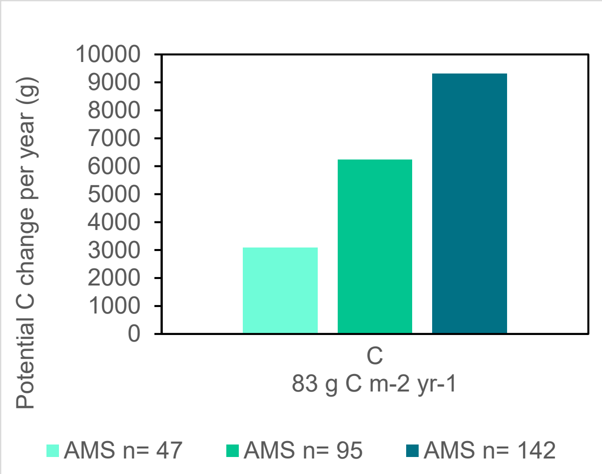
A swing mooring is used to secure boats to a fixed point and consists of a buoy attached by a chain to an anchoring point placed on the seabed. When a mooring is placed in seagrass beds the movement of the chain, caused by the changing tides can scour the seagrass and can leave scars. Within the Isles of Scilly Complex SAC the average scar is 147.13m^{2,} (the area between the center of the mooring and where the seagrass reached ≥ 10%)(Unsworth *et al*., 2017); potentially bigger than the boats that use the mooring.

Mooring scars don't just cause seagrass beds to become fragmented; they also impact the total ecosystem services provided. At St. Mary's there are 142 moorings, based on the estimate above this equates to an estimated 20892m^2 of damage to the seagrass in this one area. While there are also moorings located at Old Grimsby Harbour (Bull and Kenyon, 2019) the number which overlap with the seagrass bed is not known.

Luff *et al.* (2019) found that shoot density was significantly higher in the area surrounding the sinker block (0.5m from the sinker) of an advanced mooring system compared to a traditional swing mooring. Based on this estimation, each swing mooring replaced with an advanced mooring system could increased the area of the seagrass bed at St Mary's by 0.79m^2, which translates into an increase in shoot density from 64 m^{-2} (swing mooring) to 221 m^{-2} (advanced mooring system). Based on the assumption that this increase in shoot density is sufficient to provide an increase in the associated ecosystem services, estimations of increased ecosystem service provision are illustrated in these graphs (Figure 8). These estimates provide broad indication of the potential for increased benefits locally rather than precise figures. The numbers presented are based on scenarios of replacing 47, 95 and 142 swing moorings with advanced mooring systems.







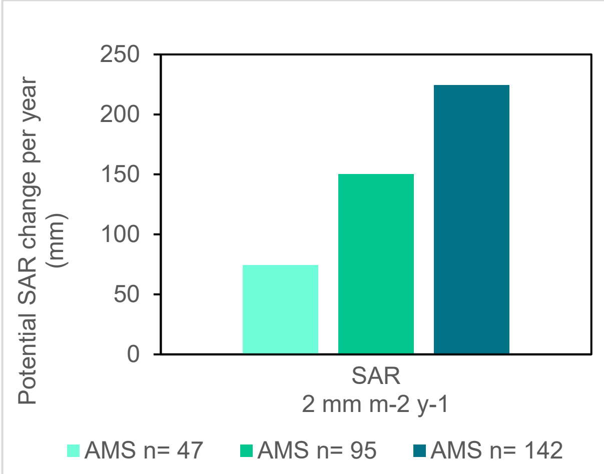


Figure 8: Potential change in ecosystem services based on replacing 47 (left-hand bar), 95 (middle bar) and 142 (right-hand bar) swing moorings with advanced mooring systems (AMS). N=Nitrogen, P=Phosphorous, C=Carbon, SAR=Sediment Accumulation Rate.

*** Note: There are limited studies available to provide accurate figures for P change, this graph is based on one study which actually found a seasonal net release of P from a particular seagrass bed. Future studies would be useful to confirm whether this is a common scenario for other seagrass beds.**

Potential: anchoring

On the Isles of Scilly, anchoring does not occur in any fixed location, although there are popular anchoring areas, often these are chosen as they provide shelter depending on the wind direction. When a boat sets an anchor on a seagrass bed the process can damage the seagrass and the surrounding sediment. The amount of damage can depend on the type and size of the anchor. Unlike mooring this pressure is not consistent and can vary between locations and seasons, which makes the impacts of anchoring difficult to quantify. Typically a single anchoring event can cause a scar between 1-4m^2 (Collins *et al.*, 2010), and uproot between 1.8 and 5.5 shoots each time (Milazzo *et al.*, 2004).

Anchoring can cause seagrass beds to become fragmented, which reduces the distribution of the habitat and the provision of ecosystem services. In some areas No Anchor Zones have been established to reduce this impact, and after their implementation as much as 26% increase in seagrass area over a 17 year period could be observed (Burton *et al.*, 2015), increasing the ecosystem services provided to the local area.

An estimation of the difference in the extent of seagrass habitat now, and in the future (2038) if anchoring pressure were removed entirely is illustrated in Figure 9, which is based on a 26% increase. On the following page the potential increase ecosystem services are described in Table 7 and the current distributions is illustrated for comparison. These estimations are based on the anchoring pressure being consistent over the entire SAC, which is unrealistic, however, this offers an indication of the potential were this pressure to be removed entirely.

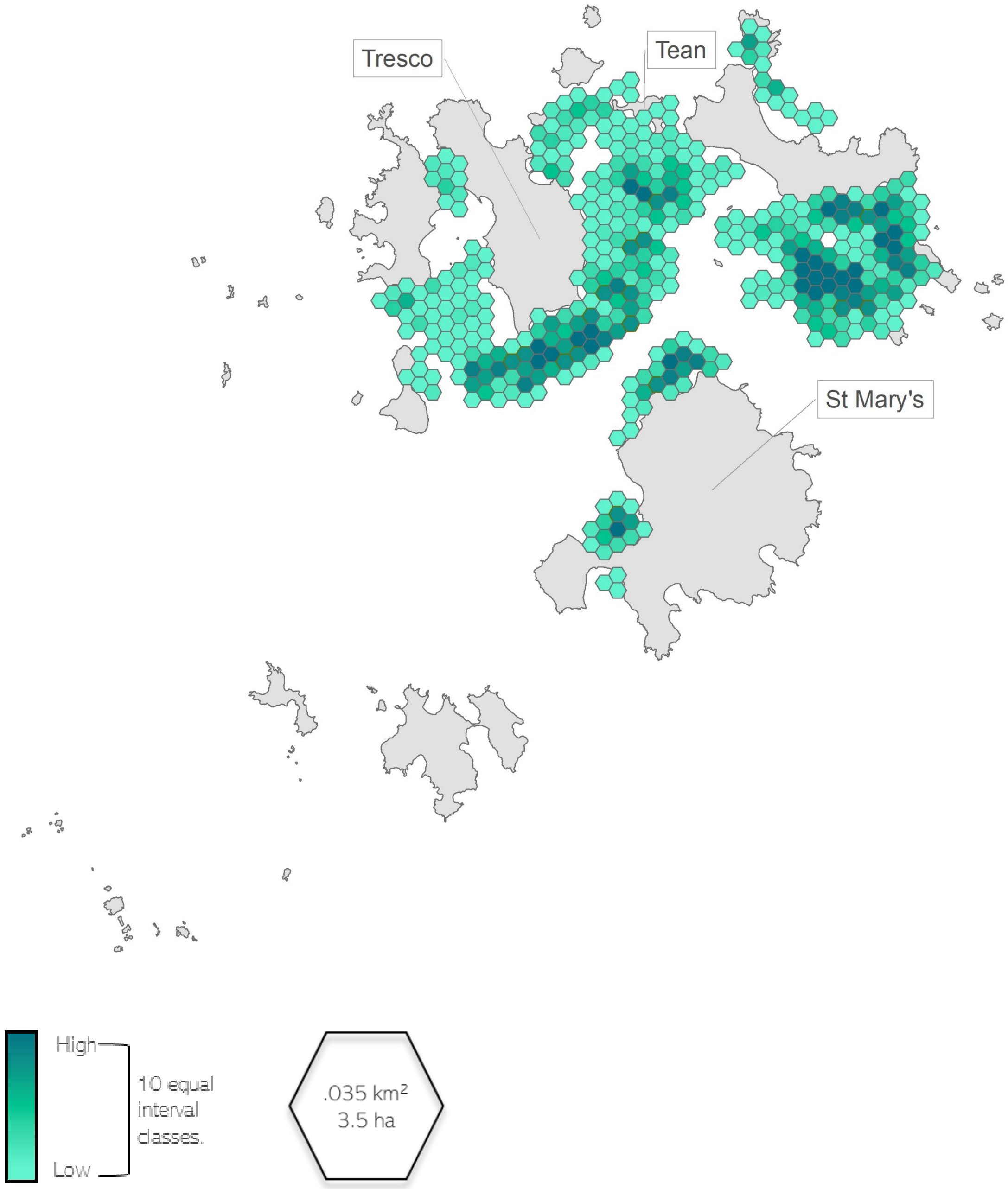


Figure 9: Potential seagrass distribution if anchoring pressure was removed entirely. This is based on an estimated increase in area of 26% over 17 years. Data source code 15. The map shows areas of seagrass in the same locations as Figure 3 but with increases in seagrass cover, shown by darker shading particularly in the centres of the larger areas of seagrass.

Table 7: Changes services provided by seagrass based on a 26% increase. Data source code 16, see section Dataset sources.

*** Note: There are limited studies available to provide accurate figures for P change, this figure is based on one study which actually found a seasonal net release of P from a particular seagrass bed. Future studies would be useful to confirm whether this is a common scenario for other seagrass beds.**

Ecosystem service Broad service in **bold** (see section Ecosystem services from seagrass) followed by specific service	**Current estimated total for Isles of Scilly SAC yr^{-1}**	**Potential estimated total for Isles of Scilly SAC yr^{-1}**
Area (km^2)	3.172	3.99
Climate regulation Carbon (C) sequestration (t)	263	331
Water quality Nitrogen (N) burial (t)	16	20
Water quality Phosphorous (P) burial (t)*	-7	-9
Water quality Sediment accumulation	6346	7982

More about ReMEDIES

This report provides supporting evidence for the ReMEDIES Project, it underpins the strategies for raising local awareness of seagrass habitat and provides context for the value of seagrass in terms of ecosystems services and its sensitivity to recreational pressures within the SAC.

Across all the targeted ReMEDIES SACS, the project aims to:

- To improve 24 205 ha of Habitats Directive habitat types Sandbanks which are slightly covered by sea water all the time, Estuaries and Large shallow inlets and bays across 5 Natura 2000 sites (SACs) towards favourable conservation status.
- 60% increase in boaters awareness of Annex 1 habitats and their locations through attendance at 10 workshops with 300 people.
- Nearly 2000 recreational users (boaters, Royal Yachting Association instructors, charter vessel skippers and bait collectors/walkers) trained in developing management options.
- Removal of 60 traditional moorings and concrete blocks, and installation of 76 eco-moorings; 150 stakeholders attending 3 annual eco-mooring workshops.
- Successful seagrass cultivation system in place, 10 000 plants suitable for transplanting produced, and seagrass beds increased by up to 8 ha.
- Fifteen workshops held and six voluntary codes of conduct in place.
- Up to 100 m fencing and signage in place to reduce disturbance.
- Networking with stakeholders at 30 other relevant seabed sites.
- Create 3.95 FTE job opportunities.

For more information on the ReMEDIES project please visit: The project - Save Our Seabed.

References

Literature cited

Ashley, M., Rees, S., Mullier, T., Reed, B., Cartwright, A., Holmes, L., Shee (2020) *Isles of Scilly natural capital asset and risk register to inform management of Isles of Scilly fisheries resources*. A report by research staff the Marine Institute at the University of Plymouth.

Borum, J., Duarte, C., Krause-Jensen, D., Greve, T. eds. (2004) *European seagrasses: An introduction to monitoring and management.* The M&MS project.

Bull, J., Kenyon, E. (2019) *Isles of Scilly eelgrass bed voluntary monitoring programme 2019 Annual Survey*. Natural England.

Burkholder, J., Tomasko, D., Touchette, B. (2007) Seagrasses and eutrophication. *The Journal of Experimental Marine Biology and Ecology*. **350**, 46–72.

Burton, M., Lock, K., Clabburn, P., Griffiths, J., Newman, P. (2015) *Skomer Marine Conservation Zone. Distribution & abundance of* Zostera marina *in North Haven 2014.* NRW Evidence Report No 68.

Chen, S., Sanford, L., Koch, E., Shi, F., North, E. (2007) A nearshore model to investigate the effects of seagrass bed geometry on wave attenuation and suspended sediment transport. *Estuaries and Coasts*. **30**(2), 296–310.

Collins, K., Suonpää, A., Mallinson, J. (2010) The impacts of anchoring and mooring in seagrass, Studland Bay, Dorset, UK. *Underwater Technology*. **29**(3), 117–123.

Cullen-Unsworth, L., Mtwana, L., Paddock, J., Baker, S., McKenzie, L., Unsworth, R. (2013) Seagrass meadows globally as a coupled social – ecological system: Implications for human wellbeing. *Marine Pollution Bulletin*. [online]. Available from: http://dx.doi.org/10.1016/j.marpolbul.2013.06.001.

D'Avack, E., Tillin, H., Jackson, E., Tyler-Walters, H. (2014) *Assessing the sensitivity of seagrass bed biotopes to pressures associated with marine activities*. JNCC Report No:505: Peterborough, Joint Nature Conservation Committee.

Duarte, C., Kennedy, H., Marbà, N., Hendriks, I. (2011) Assessing the capacity of seagrass meadows for carbon burial: Current limitations and future strategies. *Ocean and Coastal Management*, 1–7. [online]. Available from: http://dx.doi.org/10.1016/j.ocecoaman.2011.09.001.

Duarte, C., Losada, I., Hendriks, I., Mazarrasa, I., Marbà, N. (2013) The role of coastal plant communities for climate change mitigation and adaptation. *Nature Climate Change*. **3**(11), 961–968.

Duarte, C., Middelburg, J., Caraco, N. (2005) Major role of marine vegetation on the oceanic carbon cycle. *Biogeosciences*. **2**, 1–8.

Duffy, J. (2006) Biodiversity and the functioning of seagrass ecosystems. *Marine Ecology Progress Series*. **311**, 233–250.

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

Environment Agency (2020) Seagrass restoration potential. [online]. Available from: https://data.gov.uk/dataset/5b943c08-288f-4d47-a924-a51adda6d288/seagrass-potential#licence-info.

Fonseca, M., Cabalan, A. (1992) A preliminary evaluation of wave attenuation by four species of seagrass. *Estuarine, Coastal and Shelf Science*. **35**, 565–576.

Fourqurean, J., Duarte, C., Kennedy, H., Marbà, N., Holmer, M., Mateo, M.A., Apostolaki, E., Kendrick, G., Krause-Jensen, D., McGlathery, K., Serrano, O. (2012) Seagrass ecosystems as a globally significant carbon stock. *Nature Geoscience*. **5**(7), 505–509.

Friedlingstein, P., Jones, M., O'Sullivan, M., Andrew, R., Hauck, J., Peters, G., Peters, W., Pongratz, J., Sitch, S., Le Quéré, C., Bakker, D., Canadell, J., Ciais, P., Jackson, R., Anthoni, P., Barbero, L., Bastos, A., Bastrikov, V., Becker, M., Bopp, L., Buitenhuis, E., Chandra, N., Chevallier, F., Chini, L., Currie, K., Feely, R., Gehlen, M., Gilfillan, D., Gkritzalis, T., Goll, D., Gruber, N., Gutekunst, S., Harris, I., Haverd, V., Houghton, R., Hurtt, G., Ilyina, T., Jain, A., Joetzjer, E., Kaplan, J., Kato, E., Klein Goldewijk, K., Korsbakken, J., Landschützer, P., Lauvset, S., Lefèvre, N., Lenton, A., Lienert, S., Lombardozzi, D., Marland, G., McGuire, P., Melton, J., Metzl, N., Munro, D., Nabel, J., Nakaoka, S.-I., Neill, C., Omar, A., Ono, T., Peregon, A., Pierrot, D., Poulter, B., Rehder, G., Resplandy, L., Robertson, E., Rödenbeck, C., Séférian, R., Schwinger, J., Smith, N., Tans, P., Tian, H., Tilbrook, B., Tubiello, F., van der Werf, G., Wiltshire, A., Zaehle, S. (2019) Global carbon budget 2019. *Earth Syst. Sci. Data*. **11**(4), 1783–1838.

Gacia, E., Duarte, C. (2001) Sediment retention by a Mediterranean *Posidonia oceanica* meadow: The balance between deposition and resuspension. *Estuarine, Coastal and Shelf Science*. **52**, 505–514.

Garrick-Maidment, N., Trewhella, S., Hatcher, J., Collins, K., Mallinson, J. (2010) Seahorse tagging project, Studland Bay, Dorset, UK. *Marine Biodiversity Records*. **3**(e73), 1–4.

Green, A., Chadwick, M., Jones, P. (2018) Variability of UK seagrass sediment carbon: Implications for blue carbon estimates and marine conservation management. *PLoS ONE*. **13**(9), 1–18.

Griffiths, C., Langmead, O., Readman, J., Tillin, H. (2017) *Anchoring and mooring impacts in English and Welsh Marine Protected Areas: Reviewing sensitivity, activity, risk and management*. A report to Defra Impacts Evidence Group.

Guiry, M., Guiry, G. (2020) *Zostera marina* var. angustifolia Hornemann 1816. *AlgaeBase*. [online]. Available from: https://www.algaebase.org/search/species/detail/?species_id=140442&sk=40&from=results [Accessed October 6, 2020].

Hansen, J., Reidenbach, M. (2012) Wave and tidally driven flows in eelgrass beds and their effect on sediment suspension. *Marine Ecology Progress Series*. **448**, 271–287.

Jackson, E., Griffiths, C., Durkin, O. (2013) *A guide to assessing and managing anthropogenic impact on marine angiosperm habitat*. Natural England Commissioned Report 111.

Jones, B., Unsworth, R. (2016) The perilous state of seagrass in the British Isles. *Royal Society Open Science*. **3**(150596).

Jones, L., Hiscock, K., Connor, D. (2000) *Marine habitat reviews. A summary of ecological requirements and sensitivity characteristics for the conservation and management of marine SACs*. Peterborough, Joint Nature Conservation Committee. UK Marine SACs Project report.

Lilley, R., Unsworth, R. (2014) Atlantic cod (*Gadus morhua*) benefits from the availability of seagrass (*Zostera marina*) nursery habitat. *Global Ecology and Conservation*. **2**, 367–377.

Luff, A., Sheehan, E., Parry, M., Higgs, N. (2019) A simple mooring modification reduces impacts on seagrass meadows. *Scientific Reports*. **9**(20062).

Lusardi, J., Rice, P., Waters, R., Craven, J. (2018) *Natural capital indicators: for defining and measuring change in natural capital*. Natural England Research Report 076.

Marine Life Information Network (2022) Habitat list. Available from https://www.marlin.ac.uk/habitats (accessed 04/04/2022)

Mateo, M., Cebrian, J., Dunton, K., Mutchler, T. (2006) Carbon Flux in Seagrass Ecosystems. In A. Larkum, R. Orth, & C. Duarte, eds. *Seagrasses: Biology, Ecology and Conservation*. Netherlands: Springer, pp. 159–192.

McKenzie, L., Collier, C., Waycott, M., Unsworth, R., Yoshida, R., Smith, N. (2012) Monitoring inshore seagrasses of the GBR and responses to water quality. In *12th International Coral Reef Symposium*. Cairns, pp. 9–13.

McMahon, K., Collier, C., Lavery, P.S. (2013) Identifying robust bioindicators of light stress in seagrasses: A meta-analysis. *Ecological Indicators*. **30**, 7–15.

Milazzo, M., Badalamenti, F., National, I., Ceccherelli, G., Chemello, R. (2004) Boat anchoring on *Posidonia oceanica* beds in a marine protected area (Italy, western Mediterranean): effect of anchor types in different anchoring stages. *Journal of Experimental Marine Biology and Ecology*. **299**, 51–62.

Miyajima, T., Hori, M., Hamaguchi, M., Shimabukuro, H., Adachi, H., Yamano, H., Nakaoka, M. (2015) Geographic variability in organic carbon stock and accumulation rate in sediments of East and Southeast Asian seagrass meadows. *Global Biogeochemical Cycles*. **29**, 397–415.

Natural Capital Committee (2017) How to do it: a natural capital workbook. [online]. Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/608852/ncc-natural-capital-workbook.pdf.

Natural England (n.d) Conservation advice for Marine Protected Areas Fal and Helford SAC. [online]. Available from: https://designatedsites.naturalengland.org.uk/Marine/MarineSiteDetail.aspx?SiteCode=UK0013112&SiteName=fal&SiteNameDisplay=Fal%20and%20Helford%20SAC&countyCode=&responsiblePerson=&SeaArea=&IFCAArea=&NumMarineSeasonality=&HasCA=1].

Röhr, M.E., Boström, C., Canal-vergés, P., Holmer, M. (2016) Blue carbon stocks in Baltic Sea eelgrass (*Zostera marina*) meadows. *Biogeosciences*. **13**(22), 6139–6153.

Royal Yachting Association (2019) *UK Coastal Atlas of Recreational Boating 2.1: User Guide*.

Ruiz, J., Romero, J. (2003) Effects of disturbances caused by coastal constructions on spatial structure, growth dynamics and photosynthesis of the seagrass *Posidonia oceanica*. *Marine Pollution Bulletin*. **46**, 1523–1533.

Short, F., Short, C. (1984) The seagrass filter: purification of estuarine and coastal waters. In V. Kennedy, ed. *The estuary as a filter*. Orlando: Academic Press, pp. 395–143.

Sunderland, T., Waters, R., Marsh, D., Hudson, C., Lusardi, J. (2019) *Accounting for National Nature Reserves: A natural capital account of the National Nature Reserves managed by Natural England*. Natural England Research Report 078.

Touchette, B., Burkholder, J. (2000) Review of nitrogen and phosphorus metabolism in seagrasses. *Journal of Experimental Marine Biology and Ecology*. **250**, 133–167.

Tyler-Walters, H. and d'Avack, E.A.S. (2015) Ruppia maritima in reduced salinity infralittoral muddy sand. In Tyler-Walters H. and Hiscock K. (eds) Marine Life Information Network: Biology and Sensitivity Key Information Reviews, [on-line]. Plymouth: Marine Biological Association of the United Kingdom. Available from: https://www.marlin.ac.uk/habitat/detail/266 (accessed 04/04/2022)

Unsworth, R., Nordlund, L., Cullen-Unsworth, L. (2018) Seagrass meadows support global fisheries. *Conservation Letters*. **e12566**.

Unsworth, R., Williams, B., Jones, B., Cullen-Unsworth, L. (2017) Rocking the boat: Damage to eelgrass by swinging boat moorings. *Frontiers in Plant Science*. **8**(1309).

van Katwijk, M., Thorhaug, A., Marba, N., Orth, R., Duarte, C., Kendrick, G., Althuizen, I., Balestri, E., Bernard, G., Cambridge, M., Cunha, A., Durance, C., Giesen, W., Han, Q., Hosokawa, S., Hiswara, W., Komatsu, T., Lardicci, C., Kun-Seop, L., Meinesz, A., Nakaoka, M., O'Brien, K., Paling, E., Pickerell, C., Ransijn, A., Verduin, J. (2016) Global analysis of seagrass restoration: the importance of large-scale planting. *Journal of Applied Ecology*. **53**, 567–578.

Watson, S., Preston, J., Beaumont, N., Watson, G. (2020) Assessing the natural capital value of water quality and climate regulation in temperate marine systems using a EUNIS biotope classification approach. *Science of the Total Environment*. **744**(140688).

Wigley, S., Paling, N., Rice, P., Lord, A., Lusardi, J. (2020) *National natural capital atlas: Mapping indicators*. Natural England Commissioned Report Number 285.

Wood, N., Lavery, P. (2001) Monitoring seagrass ecosystem health — the role of perception in defining health and Indicators. *Ecosystem Health*. **6**(2), 134–148.

Dataset sources

Numbers in brackets after each source show the maps/indicators the dataset was used to create.

CEFAS

Spawning and Nursery Grounds Layers for Selected Fish in UK Waters in 2010. Contains public sector information licensed under the Open Government Licence v3. http://data.cefas.co.uk/#/View/153. **(6)**

Copernicus Marine Service

NORTHWESTSHELF_ANALYSIS_FORECAST_BIO_004_002_b. Graphs generated using E.U. Copernicus Marine Service Information available at https://resources.marine.copernicus.eu/?option=com_csw&view=details&product_id=NORTHWESTSHELF_ANALYSIS_FORECAST_BIO_004_002_b. **(4)**

Environment Agency

Seagrass Restoration Potential. Contains public sector information licensed under the Open Government Licence v3.0. https://data.gov.uk/dataset/5b943c08-288f-4d47-a924-a51adda6d288/seagrass-potential. **(12, 14)**

GEBCO

Gridded Bathymetry Data. GEBCO Compilation Group (2020) GEBCO 2020 Grid (doi:10.5285/a29c5465-b138-234de053-6c86abc040b9). **(2)**

Marine Management Organisation

Monthly Sea Fisheries Statistics December 2019. Contains public sector information licensed under the Open Government Licence v3. https://www.gov.uk/government/statistics/monthly-sea-fisheries-statistics-december-2019. **(7)**

Natural England

Marine Evidence Database. © Natural England [2021] Extract from original data source: Jackson, E.L., Higgs, S., Allsop, T., Cawthray, A., Evans, J. and Langmead, O. (2011) Isles of Scilly Seagrass Mapping. Natural England Commissioned Reports, Number 087 © Crown copyright and database right [2021]. Ordnance Survey licence 100022021. **(1, 3, 8, 9, 10, 11, 13, 14, 15, 16, 17)**

Office for National Statistics

Countries (December 2017) Full Clipped Boundaries in Great Britain. Contains public sector information licensed under the Open Government Licence v3.0. https://data.gov.uk/dataset/3fd8d2d2-b591-42ff-b333-c53a6a513e96/countries-december-2017-full-clipped-boundaries-in-great-Britain. **(1, 2, 3, 5, 8, 10, 12, 13, 15, 17)**

Ordnance Survey

OS Vector Map District. Contains OS data © Crown copyright and database right 2021 **(2, 8, 10, 12, 13, 15, 17)**

Royal Yachting Association

RYA recreational boating dataset. © Data reproduced under licence from the Royal Yachting Association. **(5)**