Seagrass Natural Capital Assessment: Plymouth Sound and Estuaries SAC

Using natural capital indicators to explore the distribution and condition of seagrass in the Plymouth Sound and Estuaries Special Area of Conservation (SAC) and the ecosystem services seagrass provides to society

Accessible version

Second edition October 2022

Natural England Commissioned Report NECR420

www.gov.uk/natural-england

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ISBN 978-1-78354-912-2

Catalogue code: NECR420

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Keywords

Marine, natural capital, seagrass, Special Area of Conservation, Plymouth Sound and Estuaries

Acknowledgements

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

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.

Working in partnership with:

Citation

HOWARD-WILLIAMS, E. 2022. Seagrass Natural Capital Assessment: The Plymouth Sound and Estuaries SAC. NECR420. 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 Plymouth Sound and Estuaries 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 Plymouth Sound and Estuaries 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 led 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 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 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.

Using Natural England's natural capital indicators this document illustrates the state of the seagrass within the Plymouth Sound and Estuaries SAC and the ecosystems services they provide. Habitat suitability data illustrates the potential area of seagrass distribution were pressures to be removed/reduced. Data from previous seagrass studies illustrates the potential for increased ecosystems services within the Plymouth Sound and Estuaries SAC.

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.

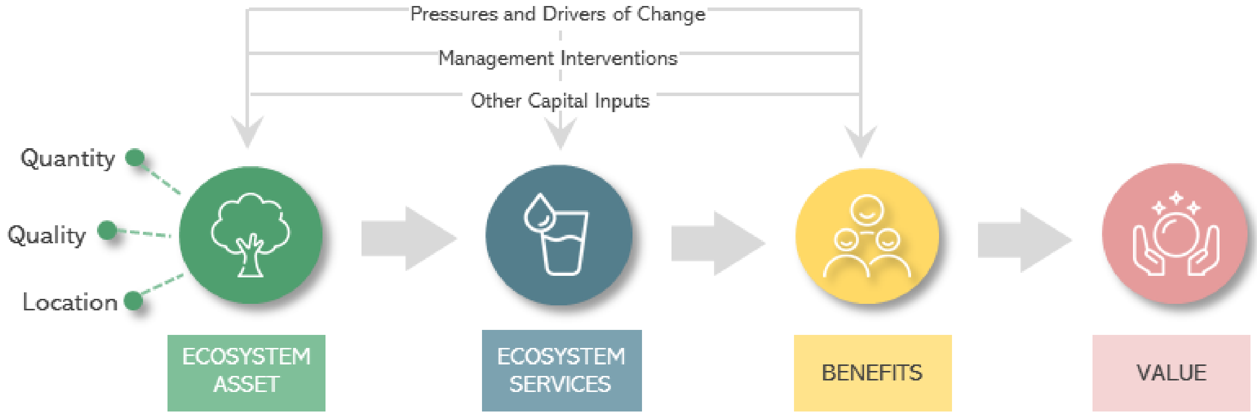

Figure 1: Generalised natural capital logic chain (Wigley et al., 2020).

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.

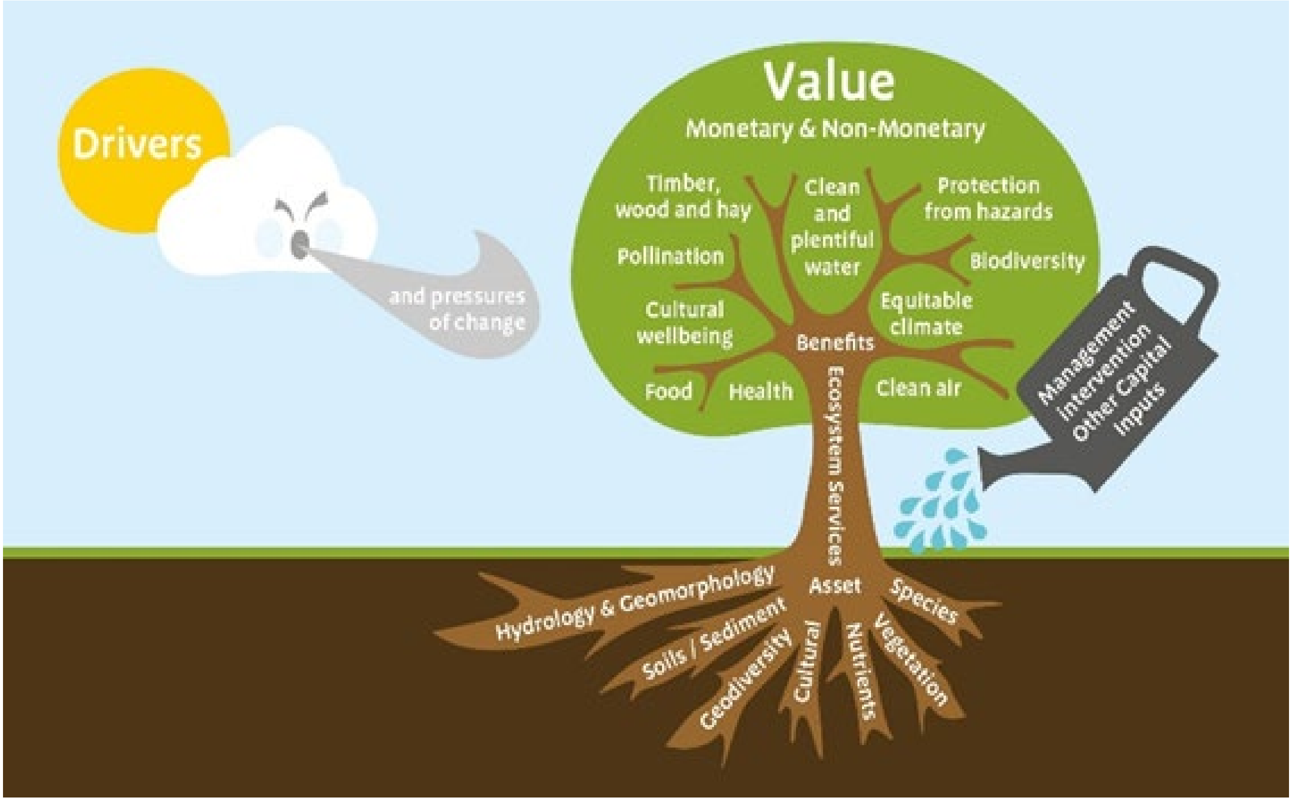

Figure 2: Natural capital attributes from Sunderland et al. (2019). Image created by Countryscape 2019.

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 Plymouth Sound and Estuaries 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 ecosystem assets are 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 Plymouth Sound and Estuaries SAC is illustrated in Figure 3, which is derived from the most recent spatial data collected between 2010 and 2016. These data indicate there are some areas of high seagrass cover, with the lighter green areas indicating smaller, and potentially more fragmented areas.

The subtidal and intertidal seagrass beds in the Plymouth Sound and Estuaries SAC are in unfavourable unknown condition. Recreational pressure within the SAC is a primary reason for the adverse condition of the subtidal seagrass beds (Natural England, 2018a). Water quality (nutrient enrichment and presence of TBT) are of concern for the intertidal seagrass beds within the SAC (Natural England, 2018b).

The most recent survey undertaken in 2018 indicates that all the subtidal seagrass beds have declined in extent and abundance apart from Cawsand Bay since 2012 (Bunker and Green, 2018). Although the confidence in these comparisons is low due to changes in methodologies between the 2012 and 2018 surveys, poor sea conditions and equipment failures encountered in 2012.

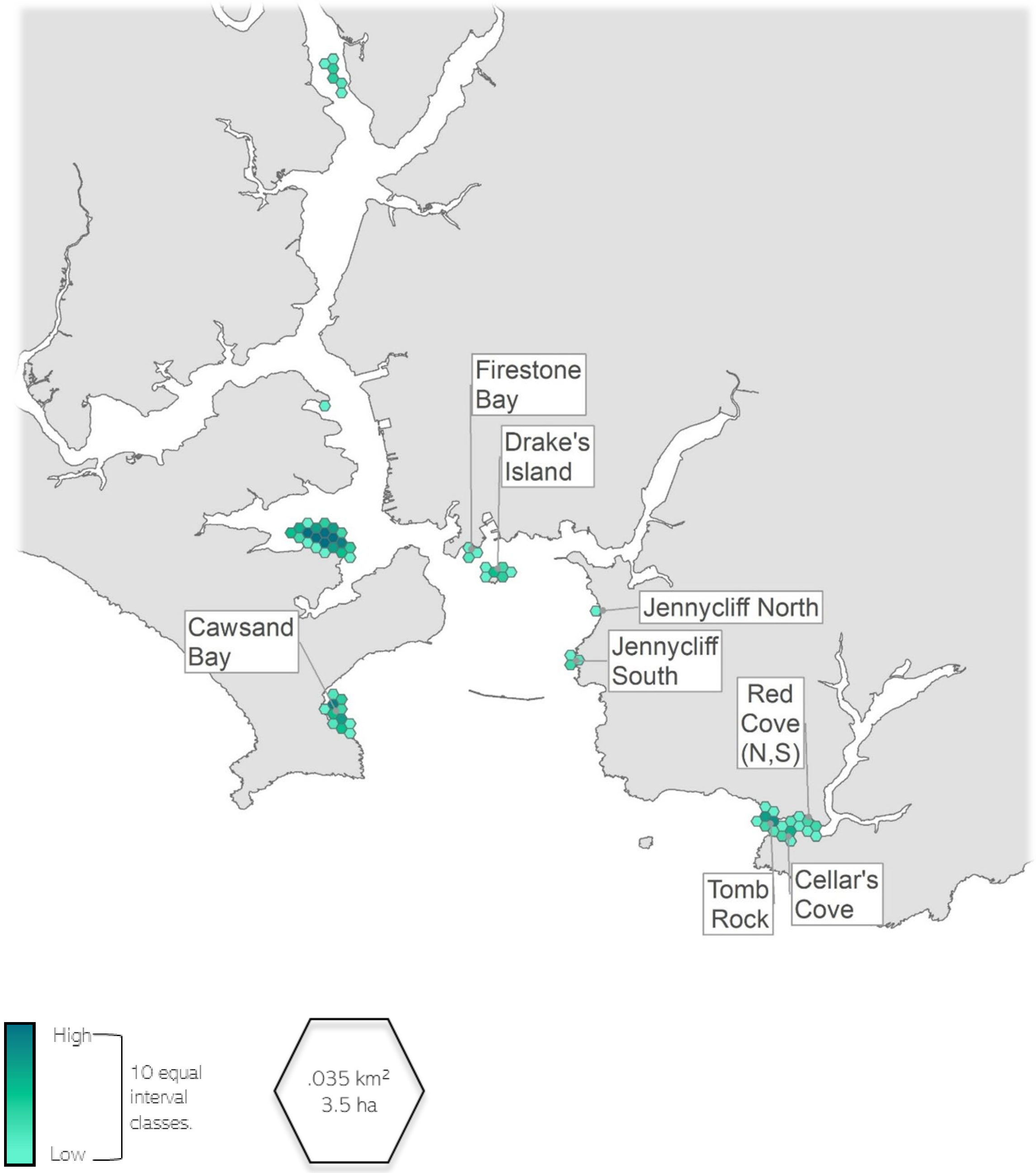

Figure 3: Area of seagrass within the Plymouth Sound and Estuaries SAC. The map shows larger areas of seagrass at Cawsand Bay, Tomb Rock, Cellar's Cove and Red Cove, and to the west of Cremyll. Smaller seagrass beds are at Jennycliff, Drake's Island, Firestone Bay and further north in the estuary, close to Cargreen. 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 Plymouth Sounds and Estuaries 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).

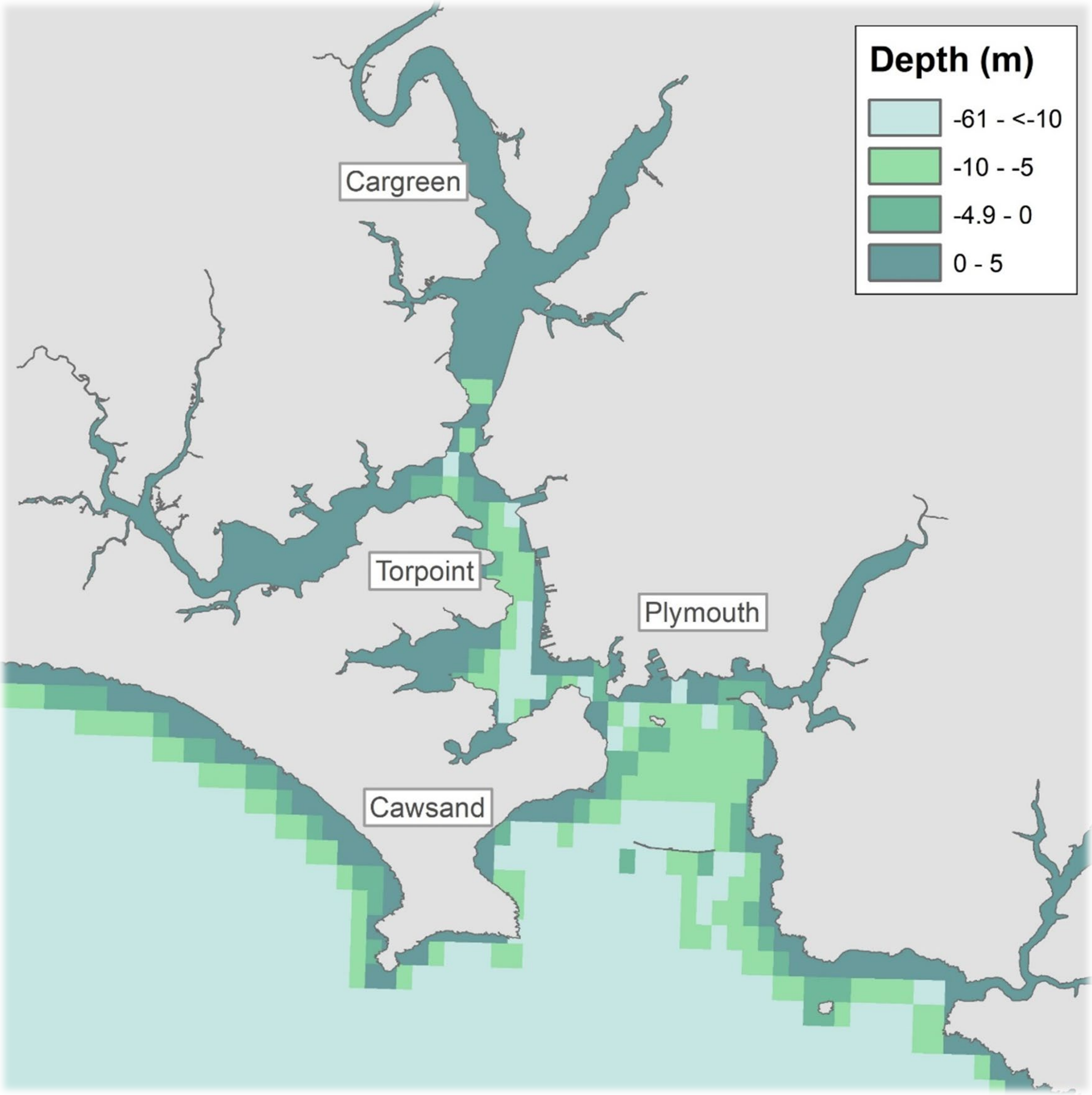

Figure 4: Approximate depth within the Plymouth Sounds and Estuaries SAC (negative values indicate estimates are below sea level). The map shows shallower depths around the coastline and in the inner parts of the estuary and deeper water further from the coast. Data source code 2.

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.

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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.

Indirect indicators of quality are taken from the surrounding environment and provide information about the biotic and abiotic conditions where 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 average shoot density per bed across the Plymouth Sound and Estuaries SAC ranges from 64-119 per m^2 (Bunker and Green, 2018). The highest shoot density was recorded in the Red Cove South bed. Based on drop-down video surveys percentage cover was highest in the Cellar's Cove bed (69%) and lowest at Jennycliff North (6%). If the percent cover at Jennycliff North were to drop below 5% it would no longer be considered a seagrass bed (Tullrot, 2009). Table 1 shows data on the direct quality indicators for the different seagrass bed and Figure 3 shows the area of seagrass within the Plymouth Sound and Estuaries SAC.

Table 1: Direct quality indicators for seagrass within the Plymouth Sound and Estuaries SAC. DDV = drop down video surveys. *Eastern part only (Bunker and Green, 2018). 'N' with a grey background indicates no data collected at named seagrass bed.

Seagrass bed	Average shoot density m^2	Average plant length (cm)	% infected leaves	Average % cover DDV
Drake's Island	64	80	53	66
Cawsand Bay	86	54	41	59
Cellar's Cove	112	52	53	69
Red Cove South	119	56	29	55
Red Cove North	N	N	N	46*
Tomb Rock	N	N	N	11
Jennycliff North	N	N	N	6
Jennycliff South	N	N	N	14
Firestone Bay	N	N	N	17

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 nutrient and light attenuation co-efficient data for the Plymouth Sound and Estuaries SAC are presented in the graphs below and give an indication of water quality and the fluctuations over the course of a year (2019). The extent of these data did not reach the SAC boundary, therefore, the closest modelled values at 10m are presented here.

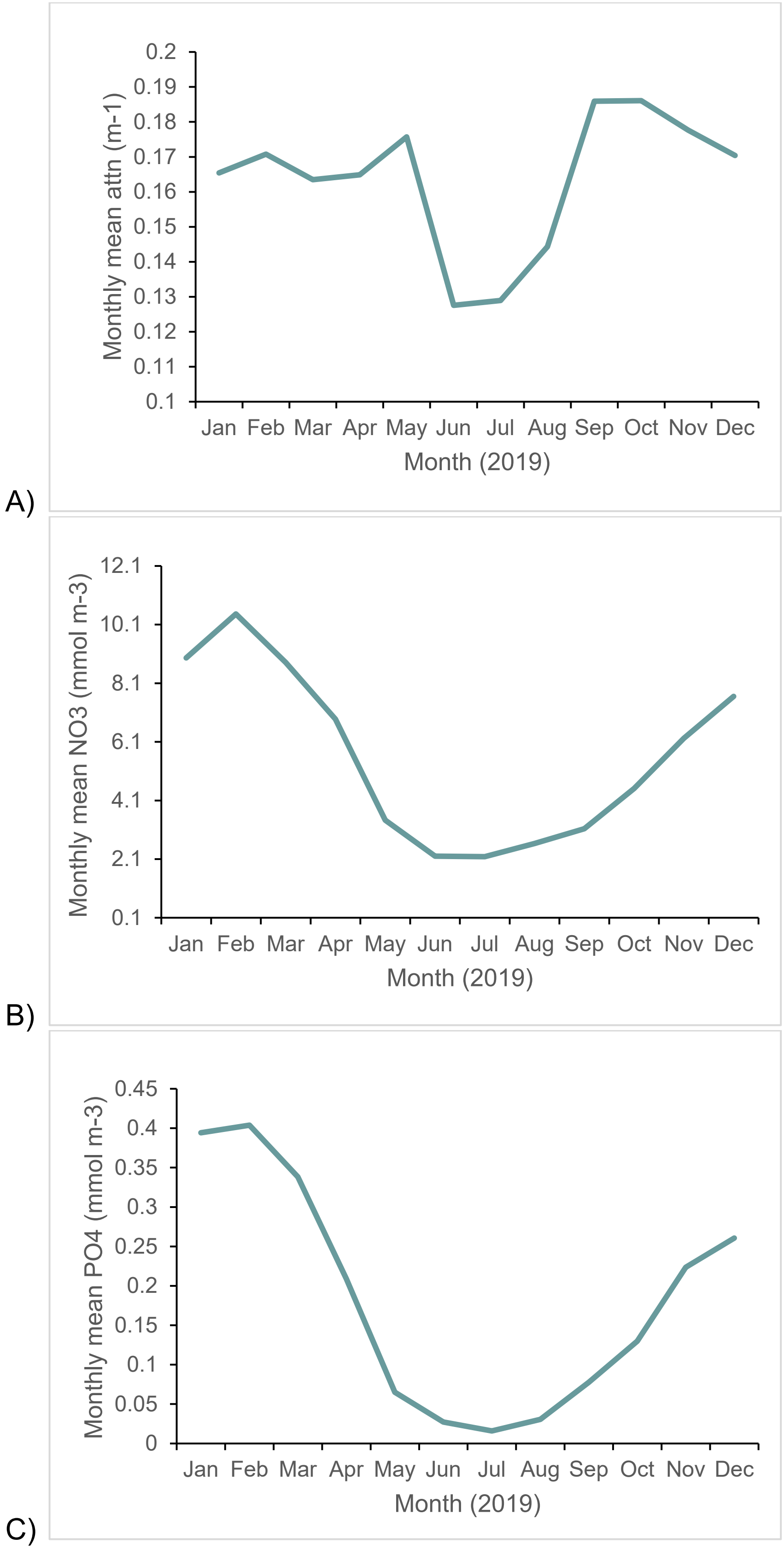

Figure 5: The monthly averages for modelled light attenuation co-efficient (attn (a)) and nutrient (nitrate NO_3 (b) and phosphate PO_4 (c)) data for the Plymouth Sound and Estuaries SAC. Data source code 4, see section Dataset sources. Graphs generated using E.U. Copernicus Marine Service Information.

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

The extent and quantity of boating activity within the Plymouth Sound and Estuaries 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 taken from the Royal Yachting Association (RYA) recreational boating dataset. and in the local area, collected using Automatic Identification System (AIS). Figure 6 also shows the general boating areas as the RYA acknowledge that close inshore areas and many estuaries are frequented by vessels that are small, and may not carry AIS transponders (RYA, 2019).

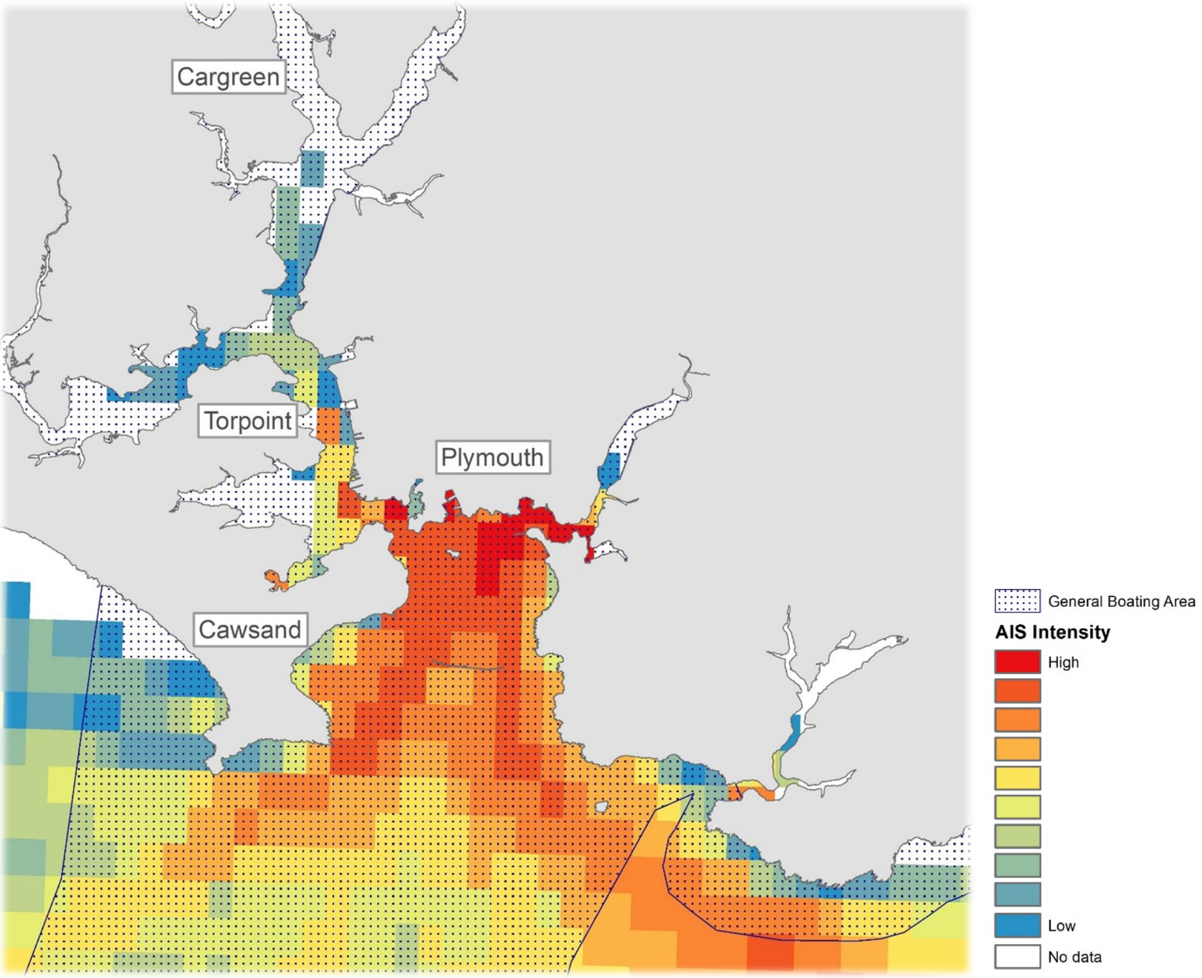

Figure 6: Recreational boating intensity within the Plymouth Sound and Estuaries SAC (AIS = Automatic Identification System). © Data reproduced under licence from the Royal Yachting Association. Data source code 5.

The map shows the most intense activity to the south of the city of Plymouth, with high intensity also extending out from the Plymouth area to the south-east and 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.

Additional evidence of species that utilise seagrass as nursery grounds from outside the SAC includes pollack, mullet, sole, plaice, skates and rays within the Isle of Scilly SAC (Ashley *et al*., 2020), bass and cuttlefish in the Fal and Helford SAC (Natural England, n.d) and Atlantic cod (these data were collected outside of the UK) (Lilley and Unsworth 2014). As some of the species presented in Table 2 do not directly link to the Plymouth Sound and Estuaries SAC, they provide a broad indication of the species associated with seagrass rather than a definitive list.

Table 2: Spawning and Nursery grounds associated with seagrass beds in the Plymouth Sounds and Estuaries 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
Sandeel	Seagrass	Low	N	N
Sole	Seagrass	Low	N	N
Spurdog	N	N	Seagrass	Low
Mackerel	N	N	Seagrass	High
Anglerfish	N	N	Seagrass	High
Whiting	N	N	Seagrass	Low
Cod	N	N	Seagrass	
Pollack	N	N	Seagrass	
Mullet	N	N	Seagrass	
Sole	N	N	Seagrass	
Plaice	N	N	Seagrass	
Skates and rays	N	N	Seagrass	
Bass	N	N	Seagrass	
Mackerel	N	N	Seagrass	
Cuttlefish	N	N	Seagrass	

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

The fish landings data for the ports within the Plymouth Sound and Estuaries SAC have been taken from the Monthly Sea Fisheries Statistics 2019 data set. Species with landed weights of over 80 tonnes or which have an association with seagrass have been included in Table 3 (Natural England, n.d; Ellis *et al*., 2012; Lilley and Unsworth 2014; Ashley *et al*., 2020). The species which are associated with seagrass are indicated in the “association” column (as outlined in Table 2). Thirty-five species of fish and shellfish were landed in the ports in 2019, 10 were associated with seagrass, which equates to 29% of the landed species. 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 (eg, 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 Plymouth Sound and Estuaries SAC (sorted by association with seagrass and live weight). (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)
Cuttlefish	Seagrass	670.33	670.33	1676.79
Mackerel	Seagrass	255.42	255.35	284.38
Plaice	Seagrass	179.22	188.00	463.93
Sole	Seagrass	109.62	113.79	1412.48
Whiting	Seagrass	85.56	100.66	152.33
Pollack	Seagrass	71.42	83.15	245.94
Skates and Rays	Seagrass	39.76	57.24	78.26
Bass	Seagrass	32.63	32.66	393.71
Mullet	Seagrass	10.73	10.77	72.74
Cod	Seagrass	3.86	4.47	16.52
Herring		2157.34	2157.27	949.21
Horse Mackerel		1932.53	1932.53	1511.37
Scallops		1330.15	1331.85	2803.03
Sardines		817.73	817.73	332.54
Crabs		378.76	391.61	918.63
Monks or Anglers		113.74	330.20	882.24

Species	Association	Live weight (t)	Landed weight (t)	Value (£000’s)
Lemon Sole		137.71	144.51	671.55
Other Demersal		136.98	144.23	305.75
Gurnard		82.41	82.27	136.35

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 Plymouth Sound and Estuaries 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 Plymouth Sound and Estuaries 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 Plymouth Sound and Estuaries SAC yr^{-1}
Nitrogen (N) burial (t)	3
Phosphorous (P) burial (t)*	-2
Sediment accumulation rate (m)	1407

The bacterial filtration ability of a mixed seagrass bed was assessed by Lamb *et al*. (2017) on the midshelf of the Spermonde Archipelago, Indonesia. They observed a 50% reduction in the relative abundance of harmful bacteria when seagrass beds were present compared to when they were not, although the authors noted that the mechanism for this was not fully understood. Data on the presence and abundance of bacteria within the SAC could provide an indication of seagrasses' contribution to the localised water quality.

Figure 7 illustrates shellfish harvesting areas according to the extent of contamination with *E. coli* in the flesh of the shellfish within the Plymouth Sound and Estuaries SAC. These maps provide an indication of the levels of bacteria within the SAC. A single area can have multiple classifications depending on species, these are illustrated in Figure 7. The classification categories are described below (Food Standards Agency, 2020):

- Class A (80% of samples ≤ 230 *E. coli*/100g; all samples must be less than 700 E. coli/100g) - molluscs can be harvested for direct human consumption
- Class B (90% of samples must be ≤ 4600 *E. coli*/100g; all samples must be less than 46000 *E. coli*/100g) - molluscs can be sold for human consumption:
    - after purification in an approved plant, or
    - after re-laying in an approved Class A re-laying area, or
    - after an EC-approved heat treatment process
- Class C (≤ 46000 *E. coli*/100g) - molluscs can be sold for human consumption only after re-laying for at least two months in an approved re-laying area followed, where necessary, by treatment in a purification center, or after an EC-approved heat treatment process
- Prohibited (>46000 *E. coli*/100g) – molluscs can not be sold for human consumption

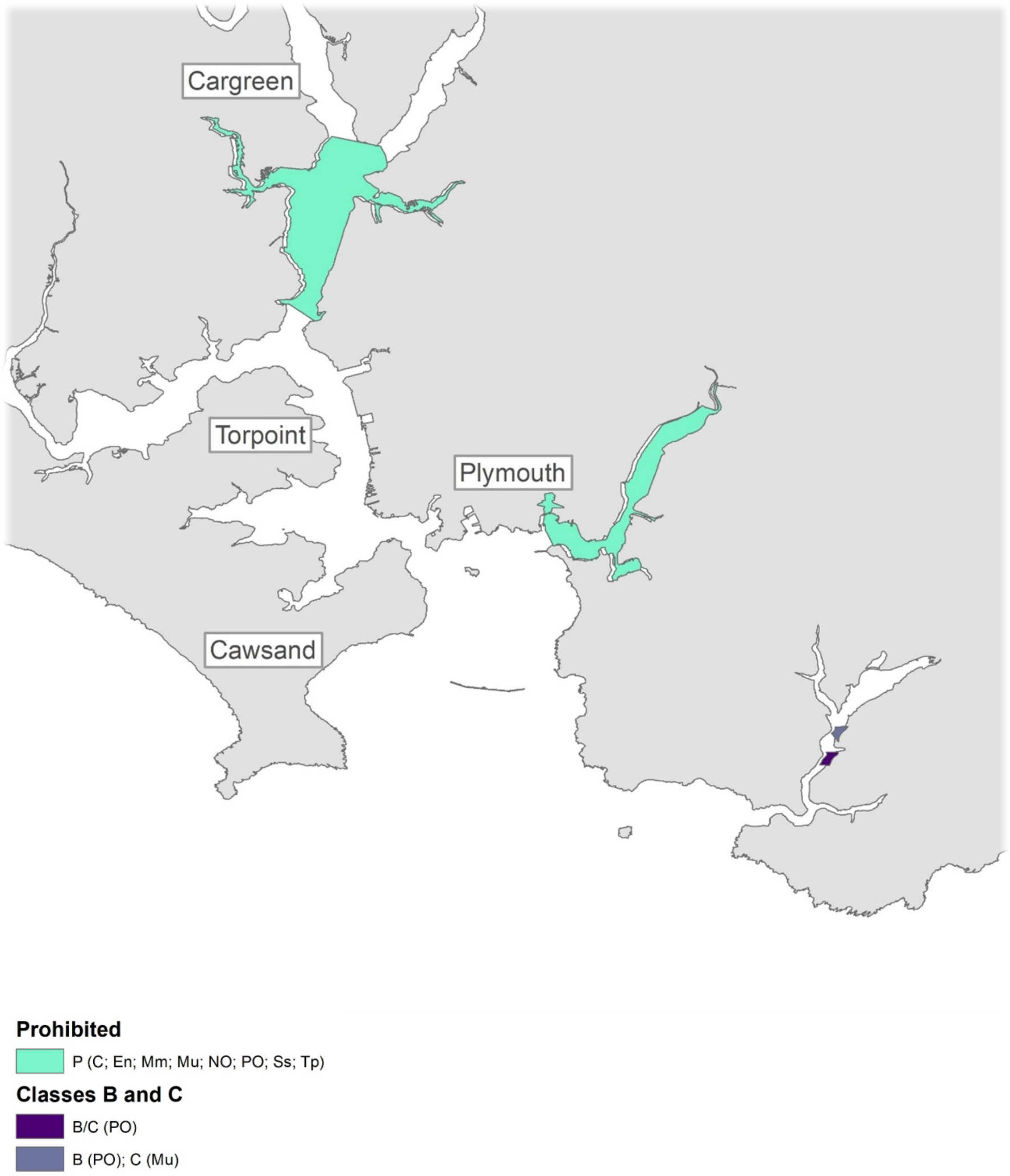

Figure 7: Shellfish classifications within the Plymouth Sound and Estuaries SAC. Each area may have multiple classifications, see legend for classes and species. Data source code 10.

The map shows areas classed as Prohibited for multiple species on the Tamar Estuary to the south of Cargreen and north of Saltash, and the Plym Estuary to the west of Plymouth. On the Yealm Estuary, there is a small area of Seasonal classes B and C for Pacific Oysters and a small area classed as Class B for Pacific Oyster and Class C for Mussels.

Classification: B=Class B; C=Class C; B/C=Seasonal classes B and C; P=Prohibited. Species: C=Cockles; En=Ensis spp.; Mm=M mercenaria; Mu=Mussel; NO=Native Oyster; PO=Pacific Oyster; Ss=S solida; Tp=Tape spp..

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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 varies 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 in the Plymouth Sound and Estuaries SAC (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), however, in the Plymouth Sound and Estuaries SAC the C_{stocks} for individual seagrass beds was estimated by Green *et al.* (2018), the individual bed estimations derived from these figures are detailed in Table 5. The southwest average was used where beds were not specified in Green *et al*. (2018). Please note megagram (Mg) is the same unit as metric tonne (t).

Figure 3 shows area of seagrass within the Plymouth Sound and Estuaries SAC, darker areas (areas of higher seagrass cover) have the potential to store higher C_{stocks} and sequester more carbon. C_{stocks} are dependent on the estimations for individual seagrass beds.

Table 5 (a & b): Estimations of the C_{stocks} per bed and the estimated carbon sequestration per year by seagrass relating to climate regulation in the Plymouth Sound and Estuaries SAC. Data source code 11, see section Dataset sources.

a)

Seagrass Bed	Area (ha)	Estimated t C ha	Estimated C_{stocks} (t)
Cawsand bay	11.92	140.24	1672
Firestone Bay	0.76	136.62	104
Drake's Island	3.84	380.07	1461
Jennycliff (North and South)	1.6	130.25	208
Yealm	5.55	117.97	655
Tomb Rock	6.58	98.01	645
Remaining areas	40.07	140.98	5649
SAC total	**70.33**		**10394**

b)

Ecosystem Service	Estimated total for Plymouth Sound and Estuaries SAC yr^{-1} (t)
Carbon sequestered	**58**

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). When mooring and anchoring occur on seagrass beds it causes damage to the rhizomes, shoots and leaves of seagrass. Trampling also damages the roots and buries seeds, preventing germination. Within the Plymouth Sound and Estuaries SAC 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, which 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 seagrass 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 remobilised, which would impact water quality).

No Anchor Zones:

Voluntary “No Anchor Zones” can be used to discourage 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, the 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 keys 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 forecasted restoration potential for seagrasses in England (Environment Agency, 2020). Figure 8 shows the area where seagrass could colonise/recolonise based on salinity, wave exposure and bathymetry. The Environment Agency note that forecasted locations should be considered as an initial aid to identifying sites and should not always be assumed to be precise at the local level. The University of Exeter has carried out high resolution habitat suitability mapping to identify sites for seagrass restoration using a number of environmental variables and available data in the Plymouth Sound and Estuaries SAC. Figure 8 illustrates a potential area of around 10 km^2 (not including the current area within the SAC). The associated impact on ecosystem services are outlined in Table 6 (these estimates are based on the entire area of the forecasted potential). However, without addressing the causes of decline within seagrass beds, range expansion would be unlikely.

Fragmentation can occur in areas that are exposed to recreational 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.

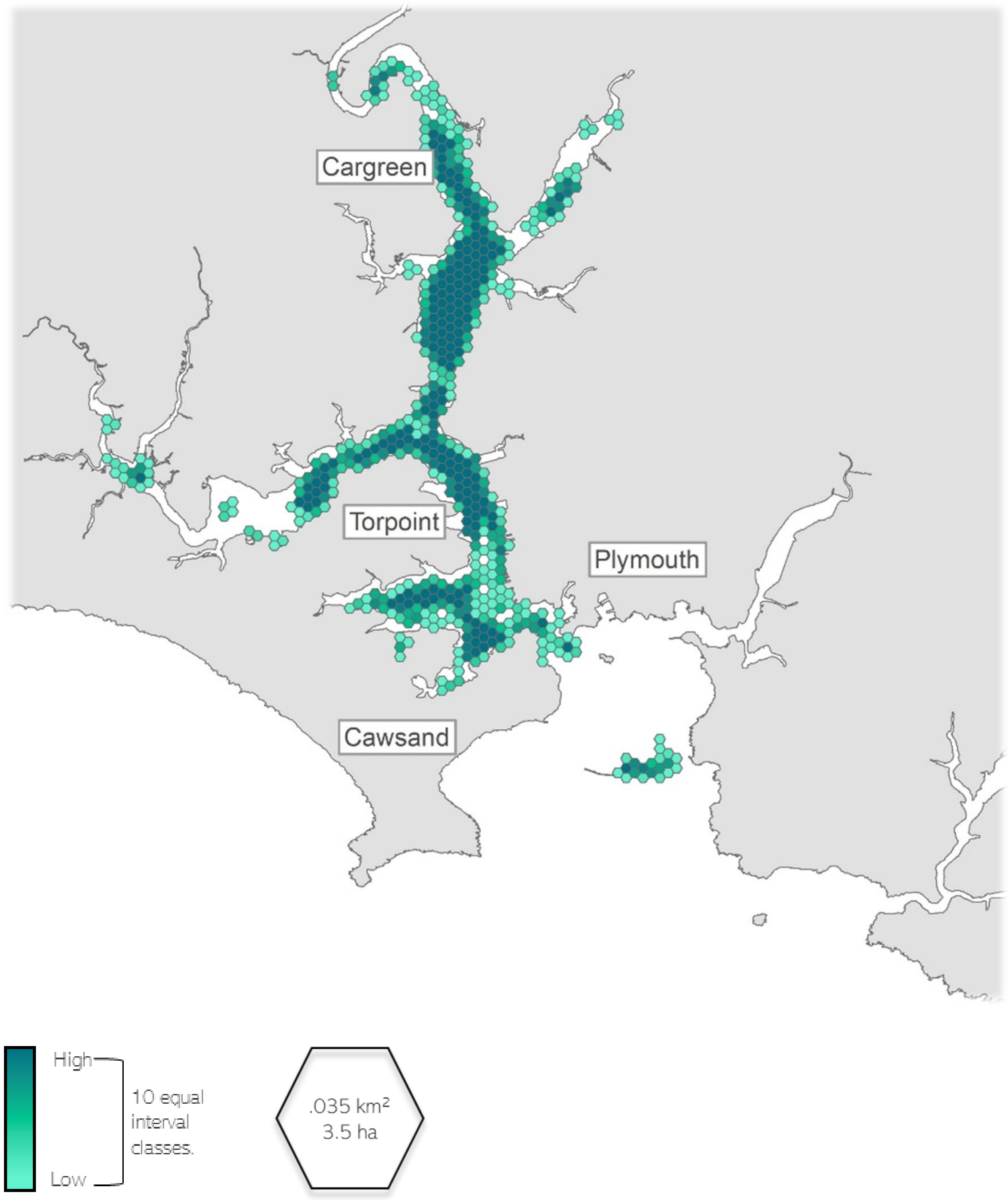

Figure 8: Forecasted locations for seagrass restoration. Darker hexagons indicate higher potential seagrass cover. The map shows areas of potential around the breakwater and in the parts of the estuary leading to the Rivers Tamar, Tavy and Lynher, with the darkest shading in the centres of the patches. Data source code 14.

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 Plymouth Sound and Estuaries SAC. Darker hexagons indicate higher potential seagrass cover. Each hexagon represents 3.5ha.

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Table 6: Changes in ecosystem services based on an area increase of 0.16%. Data source code 13, 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 Plymouth Sound and Estuaries SAC yr^{-1}**	**Potential estimated total for the Plymouth Sound and Estuaries SAC yr^{-1}**
Area (km^2)	0.7	10.21
Climate regulation Carbon sequestration (t) (83 g C m^{-2} yr^{-1})	58	848
Water quality Nitrogen burial (N) (t) (4.9 g N m^{-2} yr^{-1})	3	50
Water quality Phosphorous burial (P) (t) (-2.2 g P m^{-2} yr^{-1})*	-2	-22
Water quality Sediment accumulation (m) (2 mm m^{-2} y^{-1})	1407	20427

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 Plymouth Sound and Estuaries SAC the average scar (the area between the center of the mooring and where the seagrass reached ≥ 10%) (Unsworth *et al*., 2017) size is 122m^2.

Five advanced mooring systems are installed in the seagrass bed at Cawsands. Here there are at least eight swing moorings in the seagrass bed. There is one swing mooring known to overlap in the seagrass in the Yealm. There is limited information about the moorings in the remainder of the seagrass beds in the SAC and it is possible there are more. The average scar (the area between the center of the mooring and where the seagrass reached ≥ 10%)(Unsworth *et al*., 2017) size is 122m^2. The total area of mooring scars in the SAC is estimated to be 1098m^2. The average size of mooring scars has been calculated using bed specific estimates from Unsworth *et al*. (2017).

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 increase the area of the seagrass beds in the SAC 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 9). 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 3, 6 and 9 swing moorings with advanced mooring systems.

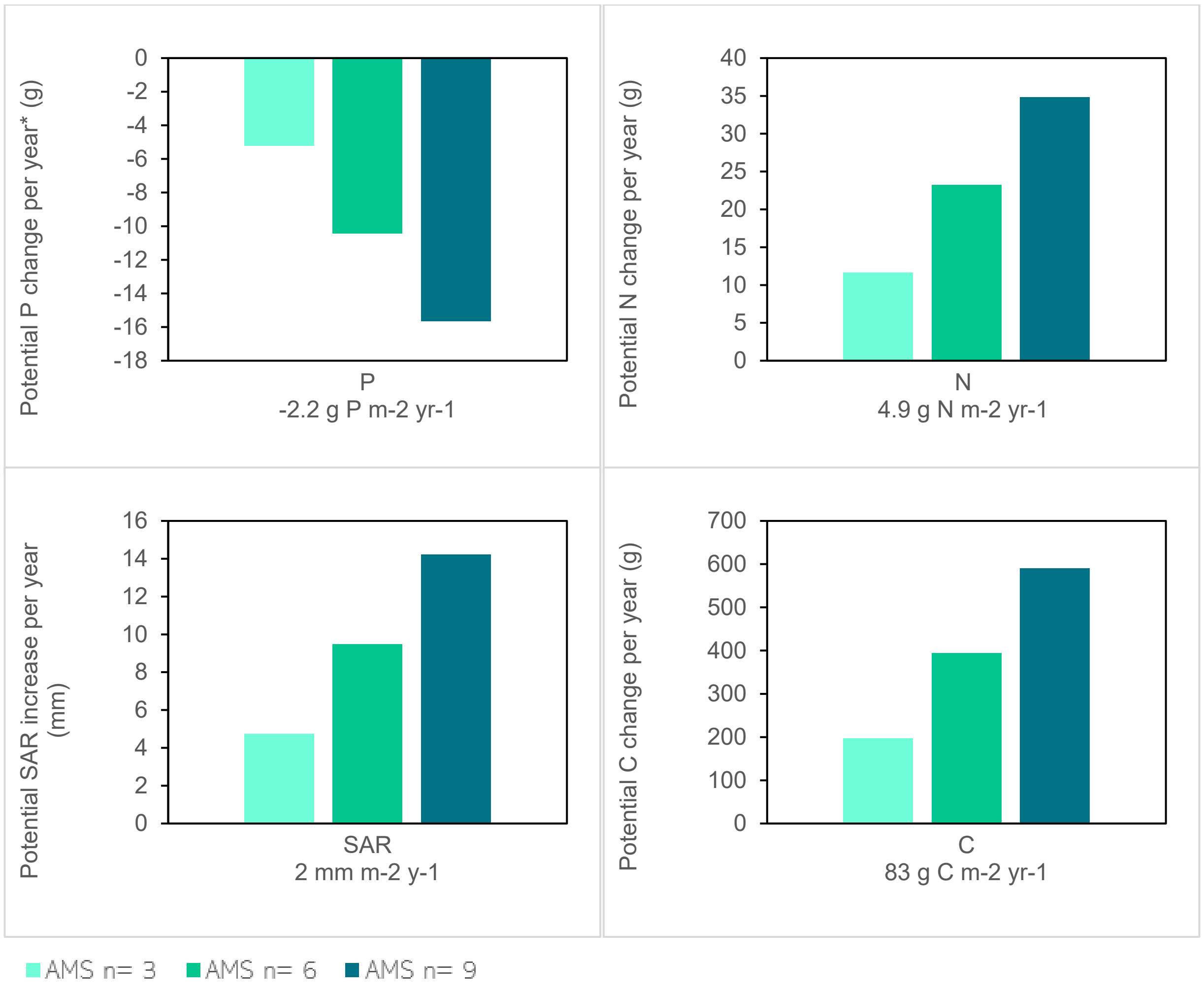

Figure 9: Potential change in ecosystem services based on replacing 3 (left-hand bar), 6 (middle bar) and 9 (right-hand bar) swing moorings with advanced mooring systems (AMS). N=Nitrogen, P=Phosphorous, C=Carbon, SAR=Sediment Accumulation Rate.

*** 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

Within the Plymouth Sound and Estuaries SAC, 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 cause damage to the plants 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 in seagrass 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 the river Helford a No Anchor Zone was established to reduce this impact. In other areas where anchoring was discouraged in seagrass, the seagrass cover increased by 26% over a 17 year period (1997-2014) (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 (as shown in Figure 3), and in the future (2038), based on a 26% increase if anchoring pressure were removed entirely across the SAC is illustrated in Figure 10. The potential change in ecosystem services are outlined in Table 7. 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.

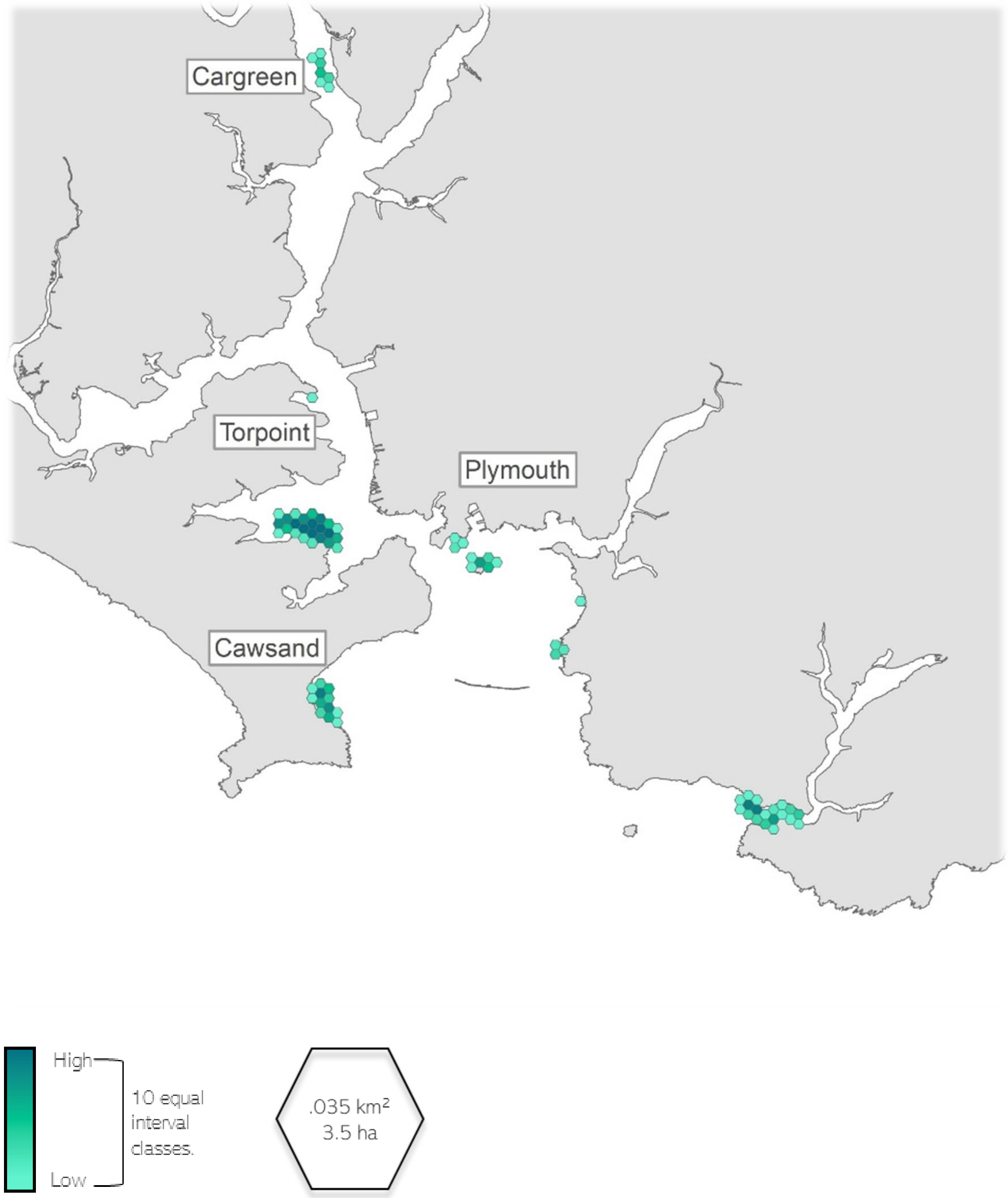

Figure 10: Potential seagrass distribution if anchoring pressure was removed entirely. This is based on an estimated increase in area of 26% over 17 years. Data source code 15. The map shows areas of seagrass in the same locations as Figure 3 but with increases in seagrass cover, shown by extensions to the size of several of the larger areas of seagrass.

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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 Plymouth Sound and Estuaries SAC yr^{-1}**	**Potential estimated total for Plymouth Sound and Estuaries SAC yr^{-1}**
Area (km^2)	0.7	0.89
Climate regulation Carbon sequestration (t) (83 g C m^{-2} yr^{-1})	58	74
Water quality Nitrogen burial (N) (t) (4.9 g N m^{-2} yr^{-1})	3	4
Water quality Phosphorous burial (P) (t) (-2.2 g P m^{-2} yr^{-1})*	-2	-2
Water quality Sediment accumulation (m) (2 mm m^{-2} y^{-1})	1407	1773

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.

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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**)

Shellfish Classification Zones of England and Wales. Contains public sector information licensed under the Open Government Licence v3. http://data.cefas.co.uk/#/View/79. (**10**)

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. (**13, 14**)

GEBCO

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

Marine Management Organisation

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Natural England

Marine Evidence Database. © Natural England [2021] Extract from original data source; 2010 NE Tamar Tavy & St John's Lake SSSIs Littoral Biotope Survey and Condition Assessment Ecospan (was M_00308); 2016 EA Tamar Estuary Intertidal Seagrass Survey; Plymouth Sound and Estuaries SAC Seagrass Condition Assessment 2012. © Crown copyright and database right [2021]. Ordnance Survey licence 100022021. (**1, 3, 8, 9, 11, 12, 13, 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, 14, 15, 17**)

Ordnance Survey

OS Vector Map District. Contains OS data © Crown copyright and database right 2021. (**2, 5, 8, 10, 14, 15, 17**)

Royal Yachting Association

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