Seagrass Natural Capital Assessment: The Essex Estuaries SAC

Second edition May 2022

Natural England Commissioned Report NECR417

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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.

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Working in partnership with:

Citation

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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 Essex 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 Essex 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.

The Essex Estuaries SAC

SEAGRASS natural capital assessment

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

LIFE Recreation ReMEDIES (LIFE18 NAT/UK/000039) is financially supported by LIFE, a financial instrument of the European Commission.

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ReMEDIES Project Overview

Reducing and **M**itigating **E**rosion and **D**isturbance **I**mpacts aff**E**cting the **S**eabed

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 Essex Estuaries SAC and the ecosystem services they provide. 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 Essex Estuaries SAC.

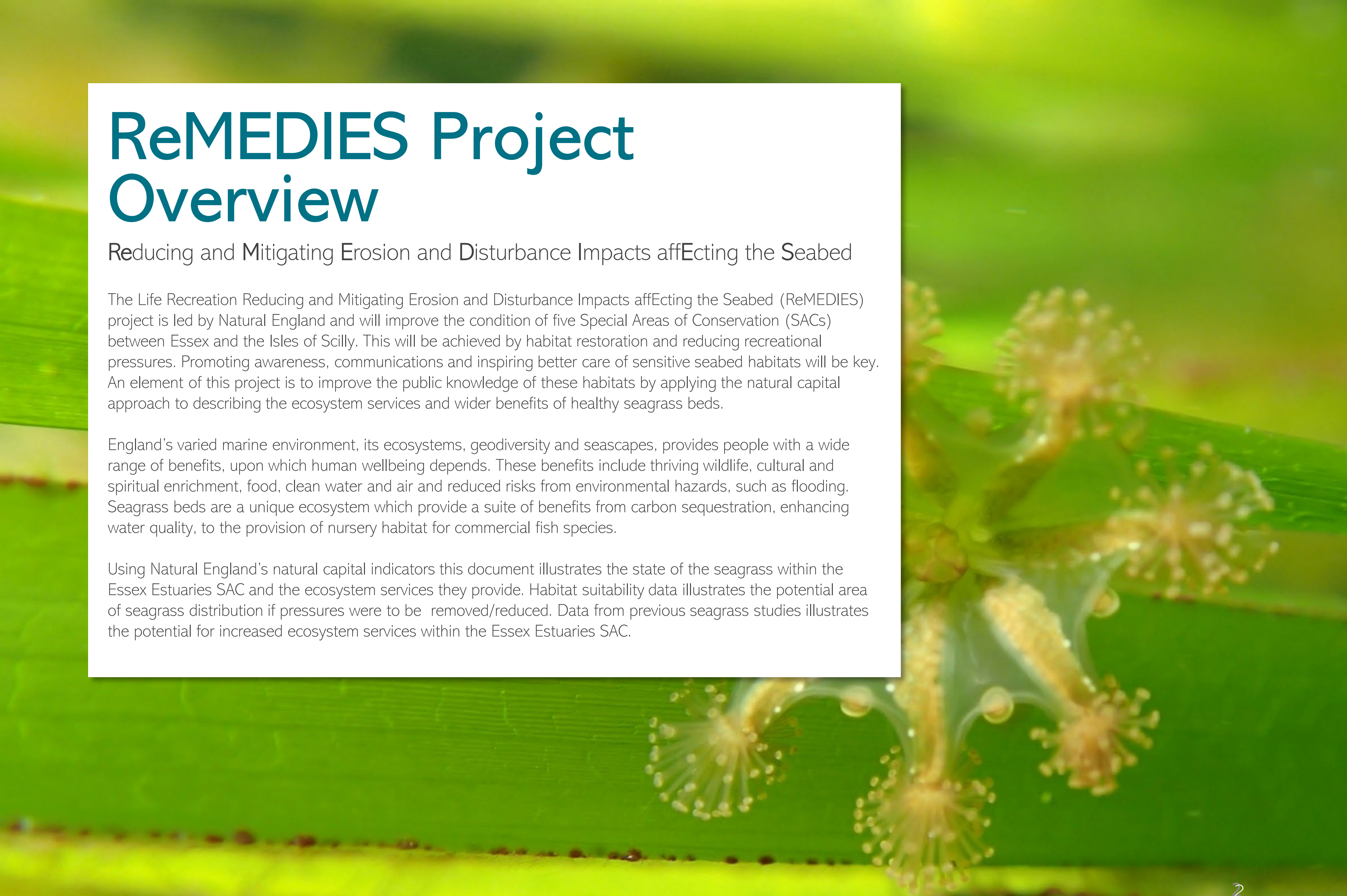


Photo: *Haliclystus* sp. or a Kaleidoscope jellyfish on *Zostera marina* (on the Isles of Scilly). Copyright H Selley. Reproduced with permission.

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 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.

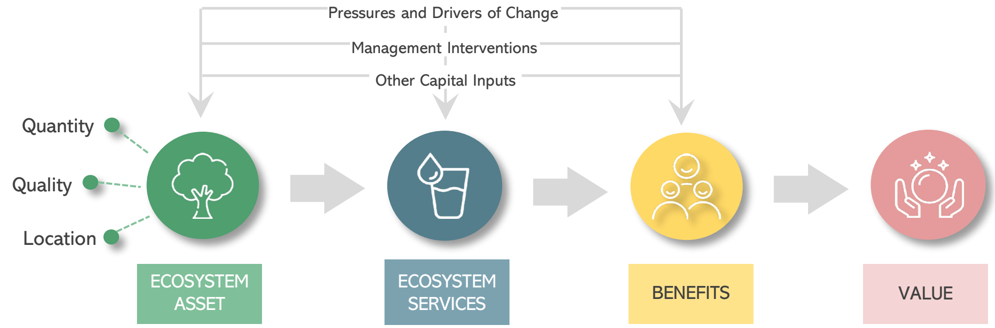


Figure 1: Generalised natural capital logic chain (Wigley et al., 2020).

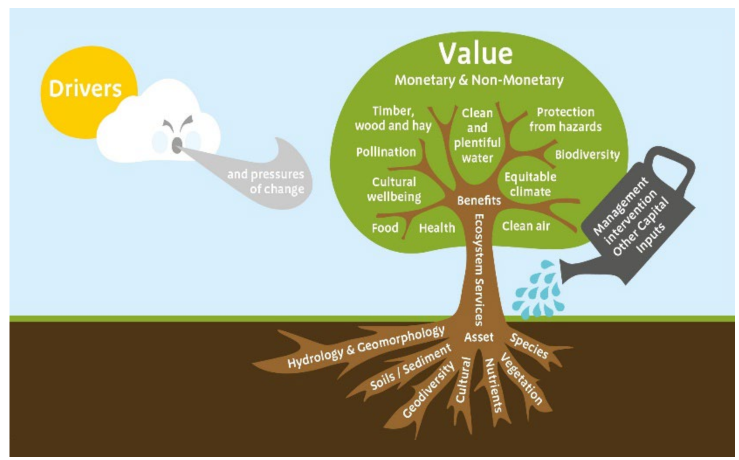


Figure 2: Natural Capital attributes: Sunderland et al. (2019). Image created by Countryscape 2019.

Measuring our natural capital

In 2018, Natural England published 'Natural Capital Indicators: for defining and measuring change in natural capital'. 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 Logic chain showing the characteristics that link marine assets to the ecosystem service; Provisioning: wild animals, plants and algae and their outputs. <u>Short-list indicators are underlined</u>. Quantity – 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)
<u>-Sediment biota</u>

Nutrient (& chemical) status:
-Nutrient status of sediment & seawater (N, P, Si)
<u>-Chemical status of sediment & sea water: toxic contaminants</u>
<u>-pH</u>
<u>-Dissolved oxygen</u>
<u>-Bacterial and viral water quality</u>

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

Habitat & Species (including algae; plankton, invertebrates; fish; birds; mammals)
-Abundance (no.)
-Biomass (kg)
<u>-Net productivity by species (kcal/ha/yr)</u>
-Productivity: biomass ratios
-Species diversity (diversity indices)
<u>-Number of trophic levels & community composition in each level</u>
-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 Essex 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.

Datasets used to create maps and tables numbered in pink are identified on page 30

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).

Photo: A sea hare (*Aplysia punctata*) in seagrass meadow at Chesil and the Fleet SAC. Copyright Keith Hiscock (cropped). Reproduced with permission.

Ecosystem Asset: 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. 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.

Ecosystem services from seagrass

Ecosystem services that are considered in more detail within this report are underlined.

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.

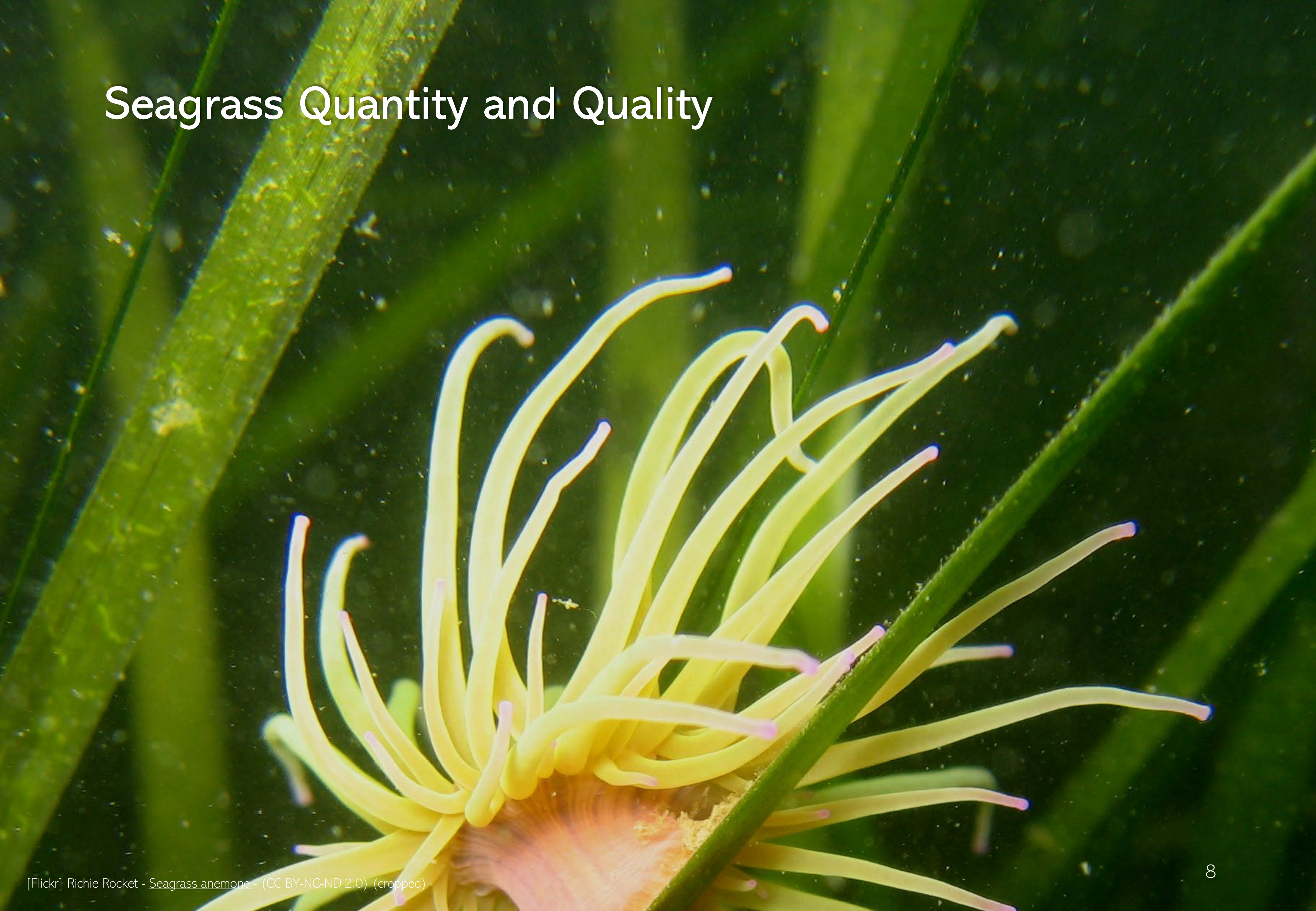
Climate regulation

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 cultural ecosystem service provision by seagrass and therefore this service is not considered in more detail within this report.*

Seagrass Quantity and Quality



[Flickr] Richie Rocket - Seagrass anemone - (CC BY-NC-ND 2.0) (cropped)

Seagrass Quantity:
Location

Map key:
Area (m²) of seagrass cover: Symbolised based on the range of values across the Essex Estuaries SAC

High
Low
10 equal interval classes.

.10 km^2
10 ha

Note: All maps are © Natural England, 2021. Data sources and attributions for each map are listed on page 30.

The area of seagrass cover per 10ha hexagon for the Essex Estuaries SAC is illustrated in this map, which is derived from data collected between 2008-2016. These data indicate there are some areas of high seagrass cover, with the lighter green areas indicating smaller, and potentially more fragmented areas.

Jackson *et al.* (2016) surveyed seagrass beds within the Essex Estuaries SAC. Of the seven sites surveyed, seagrass was only found in two (Shoeburyness and St Lawrence) and they were found to be patchier than in previous surveys undertaken in 2012 by the Environment Agency. Two species of seagrass were recorded during the surveys, *Z. marina* (Shoeburyness) and *Z. noltii* (Shoeburyness and St Lawrence). Jackson *et al.* (2016) concluded that all the seagrasses in the Essex Estuaries SAC are in unfavourable condition, with a decline in all the previous sites.

1. Area of seagrass within the Essex Estuaries SAC. Darker hexagons indicate areas of highest seagrass cover.

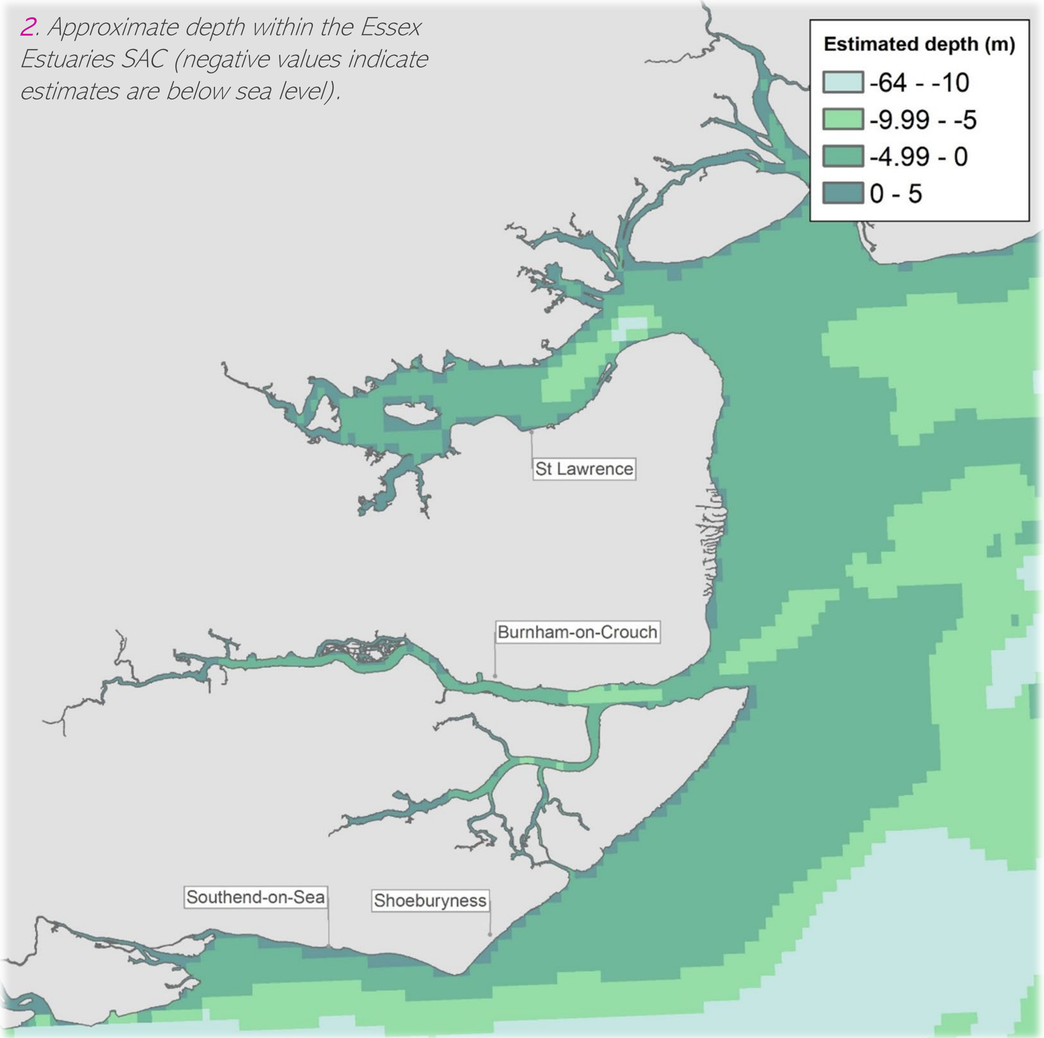
**Please note: seagrass data used to create this map are not openly available.*

Seagrass Quantity:
Location

Note: All maps are © Natural England, 2021. Data sources and attributions for each map are listed on page 30.

Seagrasses can be found to depths of up to around 10m (Jackson *et al.*, 2013), This map 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).

[Flickr] Stephengg - Blackwater estuary at Maldon, low tide - (CC BY-NC-ND 2.0)



2. Approximate depth within the Essex Estuaries SAC (negative values indicate estimates are below sea level).

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.

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.

These direct and indirect quality indicators are described on the following pages.

Photo: Long snouted seahorse (*Hippocampus guttulatus*) grasps seagrass blade. Copyright Keith Hiscock. Reproduced with permission.

Seagrass Quality:
Direct Quality Indicators

Map key:
Area (m^2) of seagrass cover: Symbolised based on the range of values across the Essex Estuaries SAC

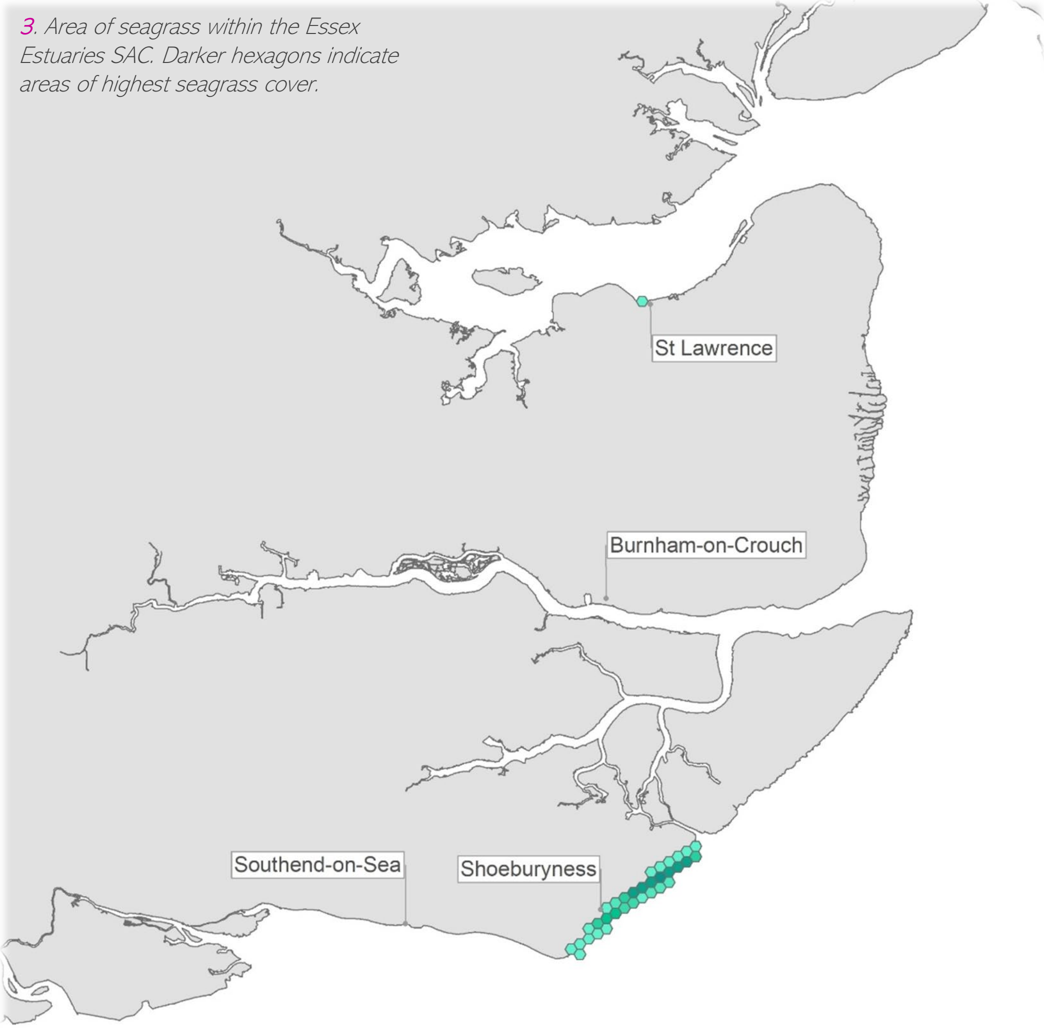
High
Low
10 equal interval classes.

.10 km^2
10 ha

Note: All maps are © Natural England, 2021. Data sources and attributions for each map are listed on page 30.

The mean shoot density for *Z. noltii* was 54 (Shoeburyness) and 88 (St Lawrence) per m^2, and 63 per m^2 for *Z. marina* (Jackson *et al.*, 2016). The mean leaf length and % cover was higher for *Z. marina* (18cm and 48% respectively) compared to *Z. noltii* (8-15cm and 38-42% respectively). The observed leaf lengths of *Z. marina* were lower than reported by other studies and may suggest constricted growth due to reduced light availability (Jackson *et al.*, 2016). Jones and Unsworth (2016) found there were indicators of light limitation at seagrass beds at Southend-on-Sea (11km from Shoeburyness) which would support this theory.


Photo: Snake locks in seagrass. Copyright Fiona Crouch. Reproduced with permission.



3. Area of seagrass within the Essex Estuaries SAC. Darker hexagons indicate areas of highest seagrass cover.

**Please note: seagrass data used to create this map are not openly available.*

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 Essex Estuaries SAC are presented in the graphs below (Figure 3) 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.

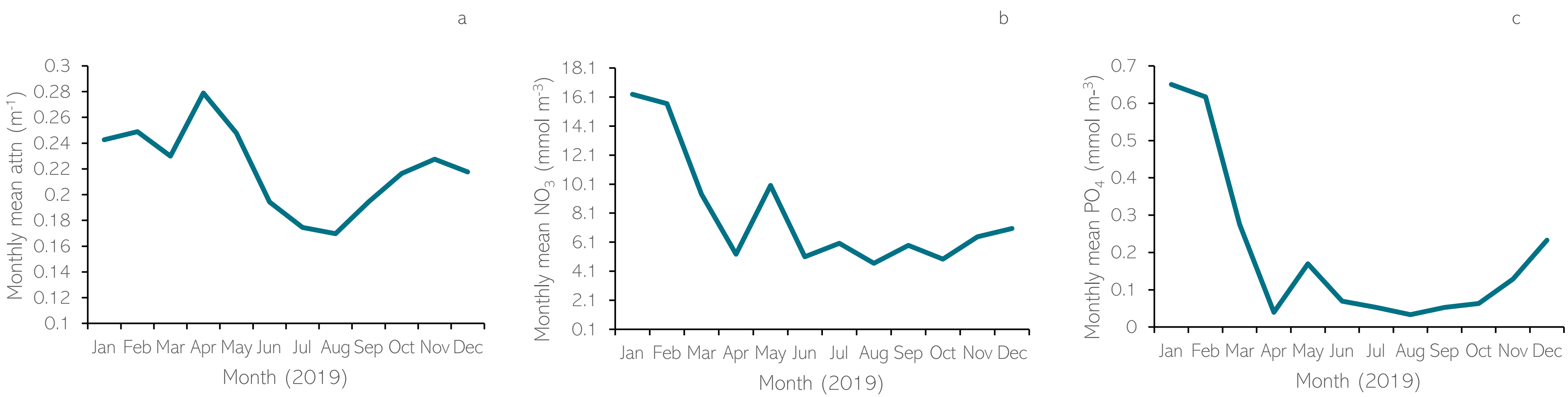


Figure 3 - The monthly averages for modelled light attenuation co-efficient (attn (a)) and nutrient (nitrate NO_3 (b) and phosphate PO_4 (c)) data for the Essex Estuaries SAC (4).

Graphs generated using E.U. Copernicus Marine Service Information

Ecosystem Service Flows

[Flickr] Susannah Anderson - Eggs on Eelgrass - (CC BY-NC-ND 2.0)

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 the 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 1. The intensity, either high (H) or low (L) 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 Isles of Scilly Complex 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 1 do not directly link to the Essex Estuaries SAC, they provide a broad indication of the species associated with seagrass rather than a definitive list.

Table 1 – Spawning and Nursery grounds associated with seagrass beds in Essex Estuaries SAC (5). ● = association between lifecycle stage and seagrass beds (Natural England, n.d; Ellis *et al.*, 2012; Lilley and Unsworth 2014; Ashley *et al.*, 2020). Intensity: High = H; Low = L (Ellis *et al.*, 2012). ▢ = No association identified for this species and lifecycle stage.

Species	Spawning	Intensity	Nursery	Intensity
Sole	●	H	●	H
Cod	●	L	●	L
Sandeel	●	L		
Herring			●	H
Mackerel			●	L
Plaice			●	L
Thornback ray			●	L
Tope shark			●	L
Whiting			●	L
Pollack			●	
Mullet			●	
Skates and Rays			●	
Bass			●	
Cuttlefish			●	

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

The fish landings data for the ports within the Essex 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 2 (Natural England, n.d; Ellis *et al.*, 2012; Lilley and Unsworth 2014; Ashley *et al.*, 2020). Species highlighted are associated with seagrass (outlined on the previous page). Twenty-two species of fish and shellfish were landed in the ports in 2019, nine were associated with seagrass, which equates to around 40% of the landed species. The species associations presented in this table 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.

Seagrass (*Zostera marina*) bed at Carricknath, Cornwall.

Table 2 – Sea fisheries statistics for 2019 (6), including, species landed, weights and value for the Essex 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).

Species	Live weight (t)	Landed weight (t)	Value (£000's)
Skates and Rays	44.13	37.56	50.64
Sole	21.02	20.23	141.17
Bass	3.16	3.15	19.58
Herring	1.89	1.89	2.33
Mullet	0.84	0.84	1.26
Cod	0.64	0.55	1.21
Whiting	0.18	0.16	0.15
Plaice	0.06	0.05	0.09
Cuttlefish	0.01	0.01	0.03
Other Shellfish	14.95	14.95	57.71
Cockles	11.00	11.00	4.48
Whelks	2.91	2.91	3.75
Other Demersal	1.86	1.64	2.25
Other Pelagic	1.41	1.41	0.62

Ecosystem service flows:
Water Quality

Map key:
Area (m^2) of seagrass cover: Symbolised based on the range of values across the Essex Estuaries SAC

High
Low
10 equal interval classes.

.10 km^2
10 ha

Note: All maps are © Natural England, 2021. Data sources and attributions for each map are listed on page 30.

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 SAR as a proxy for the provision of this service within this SAC (Table 3). 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 3).

Table 3 – Estimations of the ecosystem services provided by seagrass relating to water quality in the Essex Estuaries SAC (7).

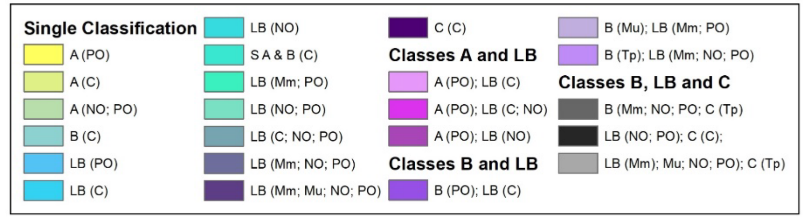
Ecosystem Service	Estimated total for Essex Estuaries SAC yr^{-1}
Nitrogen (N) burial (t)	4
Phosphorous (P) burial (t)*	-2
Sediment accumulation rate (m)	1598

* 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.

8. Area of seagrass within the Essex Estuaries SAC. Darker areas have the potential to sequester more nitrogen (N) and accumulate more sediment, and release more phosphorous (P) than sequestered.

Please note: seagrass data used to create this map are not openly available.

Ecosystem service flows:
Water Quality

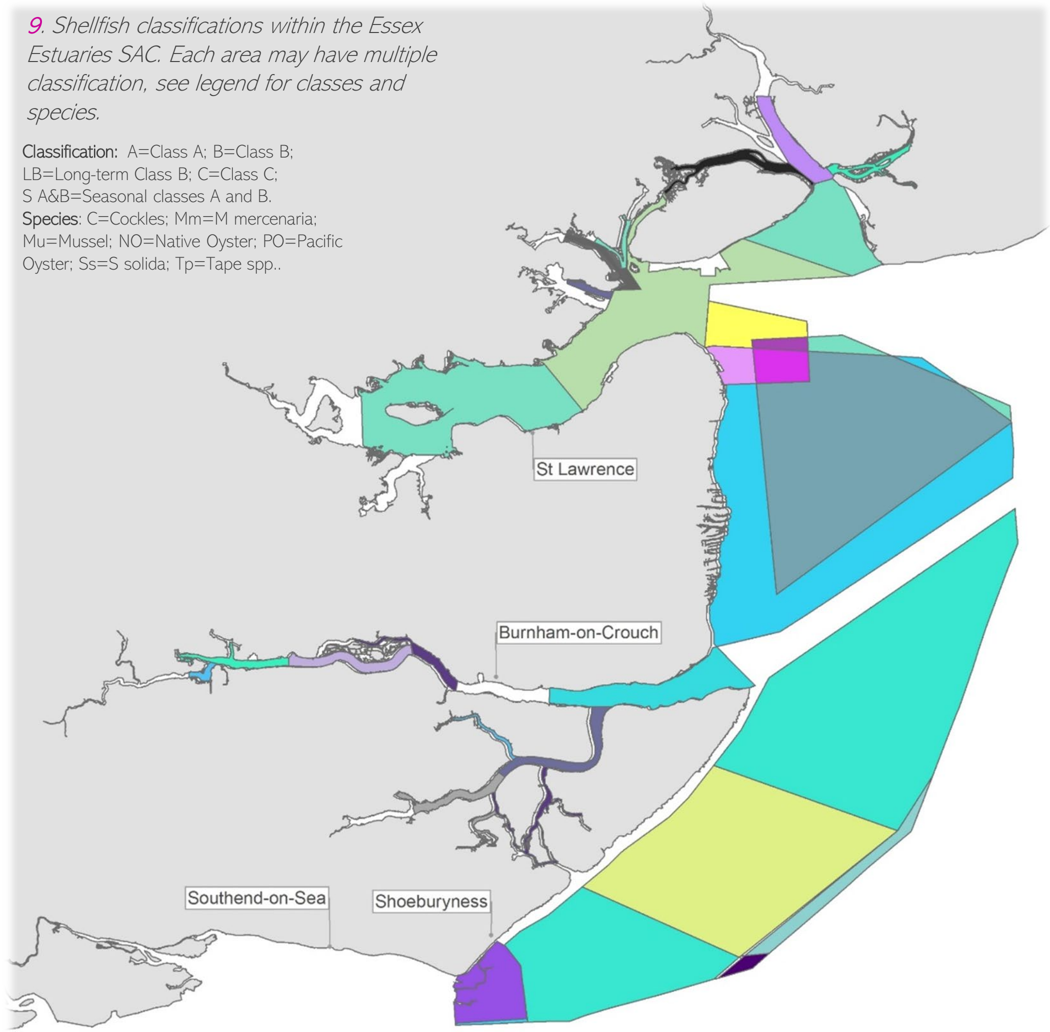


 Data sources and attributions for each map are listed on page 30.

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.

This map illustrates shellfish harvesting areas according to the extent of contamination with *E. coli* in the flesh of the shellfish within the Essex 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 this map. The classification categories are described below (Food Standards Agency):

- 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.



9. Shellfish classifications within the Essex Estuaries SAC. Each area may have multiple classification, see legend for classes and species.

Classification: A=Class A; B=Class B; LB=Long-term Class B; C=Class C; S A&B=Seasonal classes A and B.
Species: C=Cockles; Mm=M mercenaria; Mu=Mussel; NO=Native Oyster; PO=Pacific Oyster; Ss=S solida; Tp=Tape spp..

**Small areas of duplicate classification were identified and removed, as were areas less than 0.33km².*

Ecosystem service flows:
Climate regulation

Map key:
Area (m^2) of seagrass cover: Symbolised based on the range of values across the Essex Estuaries SAC

High
Low
10 equal interval classes.

.10 km^2
10 ha

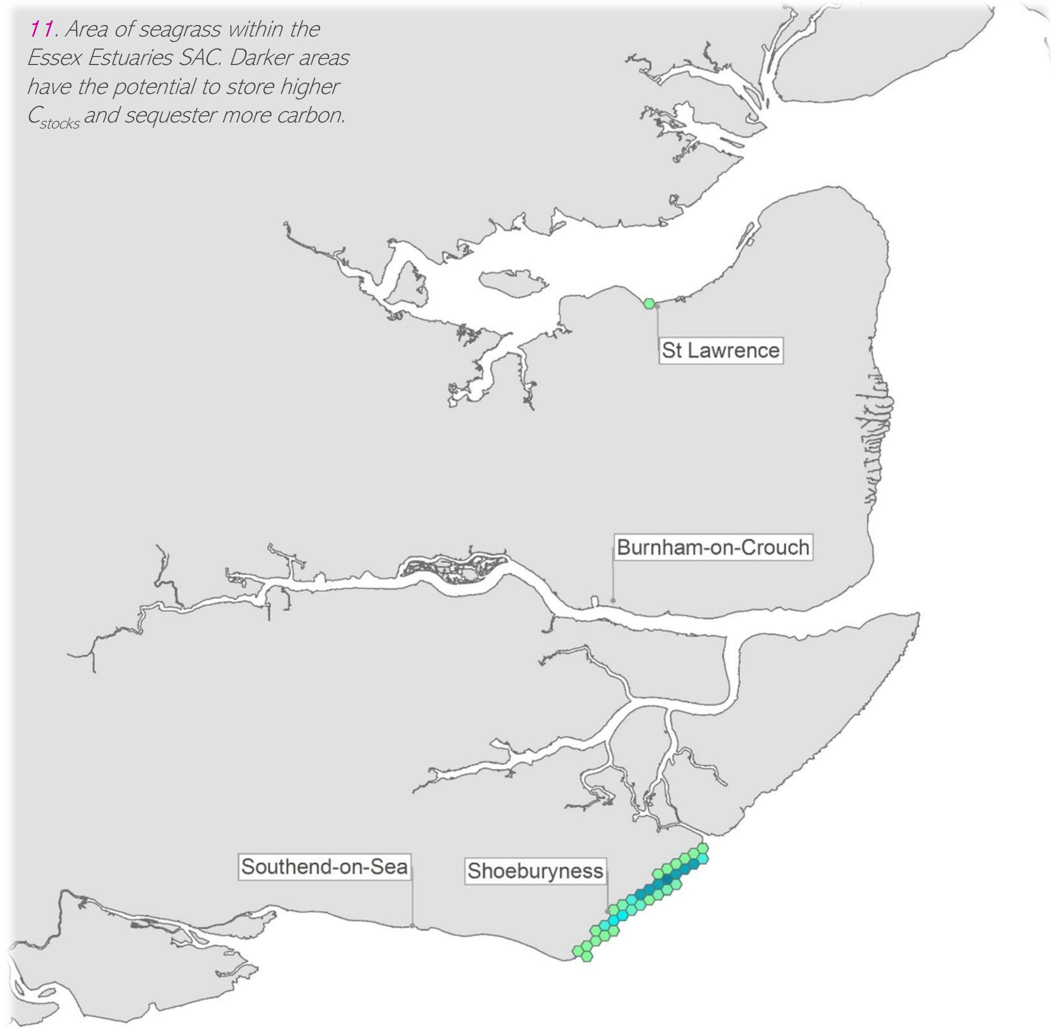
Note: All maps are © Natural England, 2021. Data sources and attributions for each map are listed on page 30.

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 rate 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 Essex Estuaries SAC (Table 4) (area cover illustrated in this map). 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 (megagram (Mg) is the same unit as tonne (t)) 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 seagrass beds in the Essex Estuaries SAC.

Table 4 – Estimations of the C_{stocks} per bed and the estimated carbon sequestration per year by seagrass relating to climate regulation in the Essex Estuaries SAC (10).

Ecosystem Service	Estimated total for Essex Estuaries SAC yr^{-1} (t)
Carbon sequestration	66
C_{stocks}	11262



11. Area of seagrass within the Essex Estuaries SAC. Darker areas have the potential to store higher C_{stocks} and sequester more carbon.

Please note: seagrass data used to create this map are not openly available.

Pressures and Drivers of Change

[Flickr] Bay Photographic – Old Leigh Dinghies (CC BY 2.0) (cropped)

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 Essex Estuaries SAC addressing the impact of trampling is a priority. No specific data on the extent of trampling in the Essex Estuaries SAC has been identified, however, Jackson *et al.* (2016) observed trampling by walkers, horse riders, dogs, kite surfers and boats launching in the Essex Estuaries SAC.

Management Interventions

Restricting access to the intertidal seagrass was proposed by Travaille, Salinas-de-León and Bell (2015) as an effective management tool where there is an increased potential for this pressure. They suggested that specific access routes could be implemented which concentrates activity to a specific location. Eckrich and Holmquist (2000) also concluded that concentrating activities may be a good solution. Alternatively, voluntary No Access Zones in combination with educational tools could be an option to discouraged trampling on the intertidal seagrass within the SAC. No data on the effectiveness of these management suggestions were identified.

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 habitat. 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).

Photo: Stalked Jellyfish. Copyright Fiona Crouch. Reproduced with permission.

Potential

[Flickr] Paul - Scilly Sunset - (CC BY-NC-ND 2.0)

Potential:
Restoration Potential

Map key:
Potential area (m^2) of seagrass cover: Symbolised based on the range of values across the Essex Estuaries SAC

High
Low
10 equal interval classes.

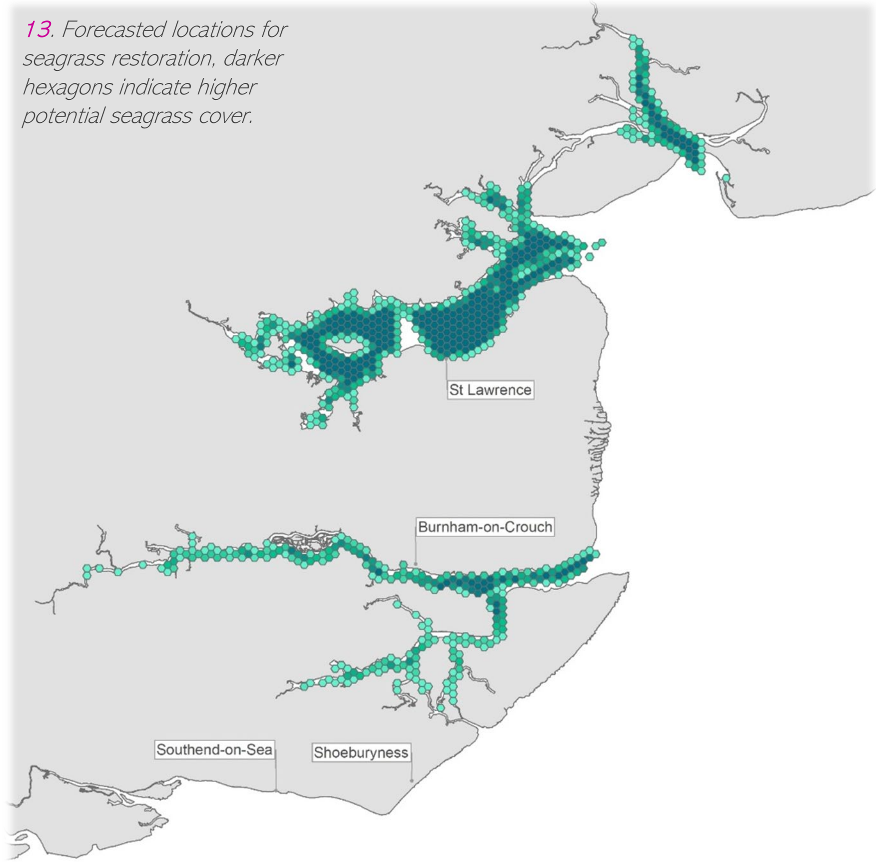
.10 km^2
10 ha

The Environment Agency forecasted restoration potential for seagrasses in England (Environment Agency, 2020), this map 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. This map illustrates the potential area identified by the Environment Agency of around 41 km^2 (not including the current area within the SAC). However, without addressing the causes of decline within seagrass beds, range expansion would be unlikely. The associated impact on ecosystem services are outlined in Table 5.

Fragmentation can occur in areas that are exposed to trampling by walkers, horse riders, dogs, kite surfers and boats launching, which results in causing damage to the seagrass. Practical interventions such restricting access to the intertidal seagrass could reduce the impacts of trampling and allow the seagrass bed to recover, which could improve the connectivity between existing fragmented seagrass beds and increase the ecosystem services provided locally. Trampling is discussed further on the following page.

Table 5 - Changes in ecosystem services based on an area increase taken from the Environment Agency (2020) seagrass potential dataset (12).

Ecosystem services Broad service in **bold** (see page 7) followed by specific service	Current estimated total for Essex Estuaries SAC yr^{-1}	Potential estimated total for Essex Estuaries SAC yr^{-1}
Area (km^2)	0.8	41.49
Climate regulation Carbon sequestration (t) (83 g C m^{-2} yr^{-1})	66	3444
Water quality Nitrogen burial (N) (t) (4.9 g N m^{-2} yr^{-1})	4	203
Water quality Phosphorous burial (P) (t) (-2.2 g P m^{-2} yr^{-1})*	-2	-91
Water quality Sediment accumulation (m) (2 mm m^{-2} y^{-1})	1598	82980



13. Forecasted locations for seagrass restoration, darker hexagons indicate higher potential seagrass cover.

* 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.

Potential:
Trampling

There are limited data on the impacts of trampling on seagrass globally, and as far as can be determined, there are no UK based studies. Trampling of intertidal seagrass beds is an issue in the Essex Estuaries SAC. Eckrich and Holmquist (2000) investigated the effects of trampling of seagrass in Puerto Rico, they observed an overall decrease in biomass with increased trampling pressure and time. Specifically a reduction in seagrass *Thalassia testudinum* rhizome biomass, leaf area index, short-shoot density, canopy height and standing crop. In Willapa bay, Washington, trampling has a greater impact in soft substrata (Major *et al.*, 2004) and shallower water, as there is less buoyancy (Eckrich and Holmquist, 2000). Garmendia *et al.* (2017) found that in Spain, under heavy trampling conditions *Z. noltii* shoot density reduce by 23%, whereas under light trampling there was no difference from the control (no trampling pressure).

Travaille, Salinas-de-León and Bell (2015) observed a significant reduction in blade length (mm) and shoot count (per 100cm^2) between highly impacted areas (trampled) compared to the control. These results correspond with Eckrich and Holmquist (2000), where percent cover reduced by an estimated 22%* when compared to the control group. An increase in bare sand was also observed and would suggest there was a corresponding reduction in the associated ecosystem services. Under the no trampling scenario the seagrass cover increased by an estimated 5%[1] over 4 months (Eckrich and Holmquist, 2000). The impacted seagrass was found to only moderately recover from trampling after seven months if the pressure has ceased entirely. Estimated average increases included leaf area index ↑ 0.5* (m^2/m^2), short shoot density ↑ 125* (m^{-2}) and canopy height ↑ 6mm* (Eckrich and Holmquist 2000). Suggesting that even low levels of trampling have potentially long-lasting impacts on seagrass beds (Travaille, Salinas-de-León and Bell, 2015). Data on trampling within this SAC were not identified, although Jackson *et al.* (2016) observed trampling by walkers, horse riders, dogs, kite surfers and boats launching within this SAC. As a result of limited data specifically related to the impact of reducing trampling, estimations of the potential for the provision of ecosystem services were not attempted.


Photo: Seagrass. Copyright Fiona Crouch. Reproduced with permission.

*Please note that this figure is based on estimates taken from graphical representation of the results not the actual figures.

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:

1.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.
2. 60% increase in boaters awareness of Annex 1 habitats and their locations through attendance at 10 workshops with 300 people.
3. Nearly 2000 recreational users (boaters, Royal Yachting Association instructors, charter vessel skippers and bait collectors/walkers) trained in developing management options.
4. Removal of 60 traditional moorings and concrete blocks, and installation of 76 eco-moorings; 150 stakeholders attending 3 annual eco-mooring workshops.
5. Successful seagrass cultivation system in place, 10 000 plants suitable for transplanting produced, and seagrass beds increased by up to 8 ha.
6. Fifteen workshops held and six voluntary codes of conduct in place.
7. Up to 100 m fencing and signage in place to reduce disturbance.
8. Networking with stakeholders at 30 other relevant seabed sites.
9. Create 3.95 FTE job opportunities.

For more information on the ReMEDIES project please visit:

https://saveourseabed.co.uk/the-project/

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.
- Burkholder, J., Tomasko, D., Touchette, B. (2007) Seagrasses and eutrophication. *The Journal of Experimental Marine Biology and Ecology*. **350**, 46–72.
- 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.
- 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.
- Eckrich, C., Holmquist, J. (2000) Trampling in a seagrass assemblage: direct effects, response of associated fauna, and the role of substrate characteristics. *Marine Ecology Progress Series*. **201**, 199–209.
- 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.
- Foods Standards Agency (2020) Shellfish classification. [online]. Available from: https://www.food.gov.uk/business-guidance/shellfish-classification.
- 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.
- Garmendia, J., Valle, M., Borja, A., Chust, G., Lee, D., Rodríguez, G., Franco, J. (2017) Effect of trampling and digging from shellfishing on *Zostera noltei* (Zosteraceae) intertidal seagrass beds. *Sci. Mar.*. **81**(1).
- 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.
- 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].

Literature cited:

- 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., Cousens, S., Bridger, D., Nancollas, S., Sheehan, E. (2016) Conservation inaction in action for Essex seagrass meadows? *Regional Studies in Marine Science*. 8, 141–150.
- 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.
- Lamb, J., van de Water, J., Bourne, D., Altier, C., Hein, M., Fiorenza, E., Abu, N., Jompa, J., Harvell, C. (2017) Seagrass ecosystems reduce exposure to bacterial pathogens of humans, fishes and invertebrates. *Science*. 355(6326), 731–733.
- 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.
- 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.
- Major, W., Grue, C., Grassley, J., Conquest, L. (2004) Non-target Impacts to eelgrass from treatments to control spartina in Willapa Bay, Washington. *Journal of Aquatic Plant Management*. 42, 11–17.
- 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.
- 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.
- 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.
- Travaille, K., Salinas-de-León, P., Bell, J. (2015) Indication of visitor trampling impacts on intertidal seagrass beds in a New Zealand marine reserve. *Ocean and Coastal Management*. 114, 145–150.
- 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.

Literature cited:

- 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.

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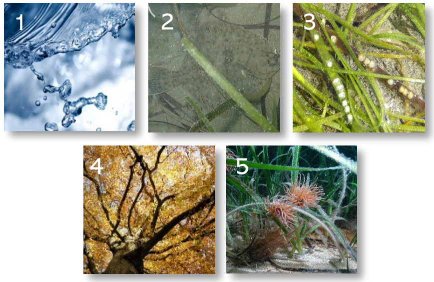
Most photo attributions are given as text on the photo itself, but the following sources were used for the ecosystem services photos on page 7.



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Dataset Sources:

Numbers in pink show which 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. (5)
- 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. (9)

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, 13)

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. (6)

Natural England

- Marine Evidence Database. © Natural England [2021] Extract from original data source: 2007 to date, Environment Agency National Seagrass Data; 2014 RP7123 Intertidal Seagrass survey Marine Institute University of Plymouth Essex Estuary SAC © Crown copyright and database right [2021]. Ordnance Survey licence 100022021. (1, 3, 7, 8, 10, 11, 12)

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, 8, 9, 11, 13)

Ordnance Survey

- OS Vector Map District. Contains OS data © Crown copyright and database right 2021. (1, 2, 3, 8, 9, 11, 13)