Solent Maritime SAC: Subtidal Seagrass Condition Monitoring

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Further information

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Foreword

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.

Executive summary

In June 2021 a new cycle of monitoring the subtidal seagrass (*Zostera marina*) beds in the Solent Maritime Special Area of Conservation (SAC) commenced. Selected sites were surveyed previously in 2018 and 2020 by the Environment Agency to record the seagrass extent and percent cover. Natural England led the 2021 *in situ* survey programme following the methods developed for surveying seagrass beds in Torbay. The data collected will allow the condition of the subtidal seagrass beds to be assessed against some of the targets for this feature of the SAC.

This is an EU LIFE Recreation ReMEDIES Project: Reducing and Mitigating Erosion and Disturbance Impacts affecting the Seabed. EU project number: LIFE 18 NAT/UK/000039.

The ReMEDIES survey programme (including the EA 2018 and 2020 surveys) was designed primarily to monitor the subtidal seagrass bed feature of the SAC. Both the extent and distribution of the beds and the ecological structure and function of the beds and their associated biological communities have conservation targets to be restored from their present unfavourable or unknown conditions.

The 2021 survey, the subject of this report, collected data to contribute to the assessment of the structure and function of the seagrass beds, specifically density and overall health. There was no quantitative collection of associated species data or further assessment of extent and distribution.

The survey also aimed to provide data to support the assessment of the spiny (long-snouted) seahorse attribute:

- Quality and quantity of the habitat available, with the same targets as above for the seagrass bed attribute.
- Population size and age / sex ratios with the target to enable the population to thrive by maintaining these parameters.

The data collected since 2018 provide the first step toward recording statistically robust and repeatable monitoring data against which future data can be compared. Historical data available from a variety of different survey programmes and organisations recorded prior to these surveys only permit qualitative comparisons and are discussed in this report.

At seven sites across four different seagrass beds, divers used a 0.25 m^2 quadrat to measure attributes of the seagrass beds (density, % cover, % algae) and 0.0625 m^2 quadrats to sample shoots for assessment of length, disease and epiphytes. Each survey station was defined as a circular area of 30 m radius with randomly generated, pre-determined survey points within it. The monitoring sites were selected using the EA 2018 and 2020 survey data of bed extent and percent cover to select areas known to support seagrass beds.

The following key findings were determined:

- **The mean percentage seagrass cover across all sites was 48.5%**, ranging from 26.2% at ‘Cowes Harbour’ to 69.4% at ‘Yarmouth Harbour’.
- **The mean shoot density for all sites combined was 209 shoots per m^2**. The density was lowest at the ‘Cowes Harbour’ site and highest at the ‘Yarmouth Harbour’ site, with 59 and 343 shoots per m^2 respectively.
- Algal cover in each seagrass bed ranged between 4.2% at ‘Cowes Harbour’ and 48.3% at ‘Yarmouth 3’. **The mean percentage algal cover across all sites was 21.3%.**
- ‘Yarmouth Harbour’ and ‘Cowes Harbour’ had the greatest range of leaf lengths, with some leaves exceeding 80 cm and both sites with mean lengths >40 cm.
- The **overall mean leaf length** for the seagrass within the Solent Maritime SAC was **34.3 cm** (±15.8 stdev). Mean leaf lengths from seagrass in Priory Bay on the Isle of Wight were reported as 29.6 cm in June 2013 (Jones and Unsworth, 2016), which are comparable to the overall SAC mean of 34.3 cm in the present study.
- The mean shoot **infection scores for presence of** *Labyrinthula zosterae* **were low** (<1.2) for all the sites and ranged from 0 – 3.4.
- Overall mean **epiphyte cover scores** per shoot were lowest at the Yarmouth and Osborne Bay sites, ranging between 0.7 and 1.1. The mean scores were highest at the two Beaulieu sites and at Cowes Harbour where they ranged between 1.6 and 2.0. The overall mean epiphyte cover score for the seagrass in the SAC was 1.1 (±0.7 stdev).
- In 2021, overall, 5.2% of the *Z. marina* plants were flowering at the time of survey.
- Non-native species were not observed in high abundances during the survey
- One short-snouted seahorse *Hippocampus hippocampus* was recorded.

Further data analysis showed that:

- Validation of the survey design through post-survey power analyses showed sampling effort in the field should be maintained and the method has high power (>0.9) to detect increasing or decreasing trends in density over a decadal period.
- Post-dive shoot processing should be reduced considerably by processing a random selection of five shoots per quadrat, rather than the entire sample. This would still provide representative samples for leaf length, infection and epiphytic growth whilst reducing post-dive workload and financial cost significantly.
- None of the data from previous surveys available were suitable for statistical comparison with those collected during the 2021 monitoring survey due to variation in the techniques, survey effort, spatial scale, seasons and different project aims.

The following recommendations were made for future surveys:

- Whilst changes in shoot density can be informative about the state of seagrass within a bed, it does not provide information on the expansion or contraction of the overall bed. Bed boundary / area cover data, such as that collected by EA in 2018 and 2020, coupled with the shoot density data would provide a statistically powerful method for detecting change.
- Aerial surveys (drones) could be used to monitor anchor / mooring damage within the seagrass bed, or part thereof, if water clarity is sufficient.
- Assigning divers to specifically collect data on the seagrass bed biological communities will enhance our understanding of the diversity within the Solent Maritime SAC and enable quantification and statistical analysis of the data.

Content

1 Introduction

1.1 Site overview and designated features

The Solent Maritime Special Area of Conservation (SAC) was designated on 1st April 2005 and is part of the Solent European Marine Site (EMS) and overall MPA network. The habitats below are listed Annex I habitats for which the site was designated (under the EC Habitats Directive):

Annex I habitats that are a primary reason for site selection:

- Estuaries
- Spartina swards (*Spartinion maritimae*)
- Atlantic salt meadows (*Glauco-Puccinellietalia maritimae*)

Annex I habitats present as a qualifying feature for site selection:

- Sandbanks which are slightly covered by sea water all the time
- Mudflats and sandflats not covered by seawater at low tide
- Coastal lagoons
- Annual vegetation of drift lines
- Perennial vegetation of stony banks
- *Salicornia* and other annuals colonising mud and sand
- Shifting dunes along the shoreline with *Ammophila arenaria* (‘White dunes’)

Annex II species present as a qualifying feature for site selection:

- Desmoulin’s whorl snail, *Vertigo moulinsiana*

The Solent Maritime SAC is a complex site which encompasses a major estuarine system and fully marine habitats with an unusual tidal regime which includes double tides and long periods of slack water at both high and low tide. The SAC includes one of the only major, sheltered channels in Europe, lying between a substantial island (the Isle of Wight) and the mainland. Sediment habitats within the site include subtidal sandbanks and extensive areas of intertidal mudflats and sandflats, which often support eelgrass (*Zostera* species). The subtidal seagrass beds are a sub-feature of the Annex I habitat ‘Sandbanks which are slightly covered by sea water all the time.’

For full site details please see: [Solent Maritime SAC - UK0030059]

1.2 *Zostera* beds

OSPAR (2009) states that to "qualify as a Zostera 'bed', plant densities should provide at least 5% cover (although when Zostera densities are this low, expert judgement should be sought to define the bed). More typically, however, Zostera plant densities provide greater than 30% cover."

The following information is extracted from OSPAR (2009) and provides further context to our understanding of *Zostera marina* beds.

1.2.1 Zostera marina beds

EUNIS Code: A2.611, A5.533 and A5.545
National Marine Habitat Classification for UK & Ireland code: LS.LMP.LSgr and SS.SMP.SSgr

Zostera marina forms dense beds, with trailing leaves up to 1 m long (up to 2 m in Western Europe (Brittany France) in sheltered bays and lagoons from the lower shore to about 5 m depth, occasionally down to 10 m (in Sweden and Norway) if water is very clear, typically on sand and sandy mud (occasionally with a mixture of gravel). Where their geographical range overlaps, such as the Solent in the UK, *Z. marina* transitions up the shore to *Z. noltei*.

Zostera beds were added to the OSPAR List of threatened and/or declining species and habitats (OSPAR agreement 2008-6). In 2009 it was recognised that seagrass beds were in decline in OSPAR Regions II & III and under threat in all areas where they occur.

There was mass dieback of *Z. marina* throughout Western Europe and elsewhere during the 1920s and mid-1930s due to a wasting disease called Labyrinthula zosterae. More recently (1990s), declines have also been reported in the Wadden Sea and the UK for both *Z. marina* and *Z. noltei*; affected areas are slow to recover.

Seagrass stabilises the substratum and provides shelter and a substrate for many species. Where the habitat is well-developed the leaves may be colonised by diatoms, algae, stalked jellyfish, hydroids, bryozoans and anemones. The infauna are generally similar to species occurring in shallow areas in a variety of substrata (e.g. amphipods, polychaete worms, bivalves and echinoderms), and can be rich within the bed. The shelter provided by seagrass beds makes them important nursery areas for fish and cephalopods. The diversity of the species will depend on environmental factors such as exposure and density of the microhabitats, but it is potentially highest in the perennial, fully marine, subtidal communities and may be lowest in intertidal, estuarine, annual beds.

Seagrass beds are very productive and often contain a large biomass. Living seagrass is a major food source for wildfowl, particularly Brent geese and widgeon but also for mute and whooper. Only about 5% of seagrass production is thought to be consumed directly.

The focus of the 2021 survey was to ascertain the condition of the subtidal *Zostera marina* beds, under the EU LIFE Recreation ReMEDIES (Reducing and Mitigating Erosion and Disturbance Impacts affecting the Seabed, LIFE18 NAT/UK/000039) Project.

1.3 LIFE Recreation ReMEDIES Project

LIFE Recreation ReMEDIES is a four-year project running from July 2019 to Oct 2023, with a potential extension to 2024. It aims to improve the condition of marine habitats of European importance in five key Special Areas of Conservation (SACs) in the UK, including the Solent Maritime SAC. The project aims to reduce and protect against recreational pressures to 1,285 ha. of England's most important and at-risk seagrass beds by using best practice management techniques such as advanced mooring systems, voluntary codes, targeted training, behavioural change, and managing access. The project will also demonstrate habitat restoration and management techniques, including seagrass restoration, and promote awareness and actively inspire better care of Annex 1 habitats to maximise the longevity and sustainability of project actions.

Natural England is the lead partner, and is working with the Marine Conservation Society, Ocean Conservation Trust, Plymouth City Council/TECF and the Royal Yachting Association. The project is financially supported by LIFE, a financial instrument of the European Commission.

Further detail on the LIFE Recreation ReMEDIES project is available at https://saveourseabed.co.uk/ .

1.4 Survey areas

Four subtidal seagrass beds within the SAC were selected to be part of a long-term site monitoring plan for the ReMEDIES project that commenced in 2018.

The condition monitoring programme aims to look for long-term trends from a selection of sites across a broad spatial scale within the Solent Maritime SAC. The sites selected were:

- **Yarmouth** - acts as one of the gateways to the Island with one of the main ferry services operating from its harbour (Figure 1).
- **Cowes** - a busy industrial, commercial and recreational sailing site with seagrass beds located adjacent to the breakwater (Figure 2).
- **Osborne Bay** - has an extensive seagrass bed stretching 5.5 km to Fishbourne, the seabed is a mixture of mud and sand (Figure 2).
- **Beaulieu** - a tidal river, navigable by small raft with a marina at Bucklers Hard. The seagrass beds are situated at the mouth of the river, ~1 km from Gull Island (Figure 3).

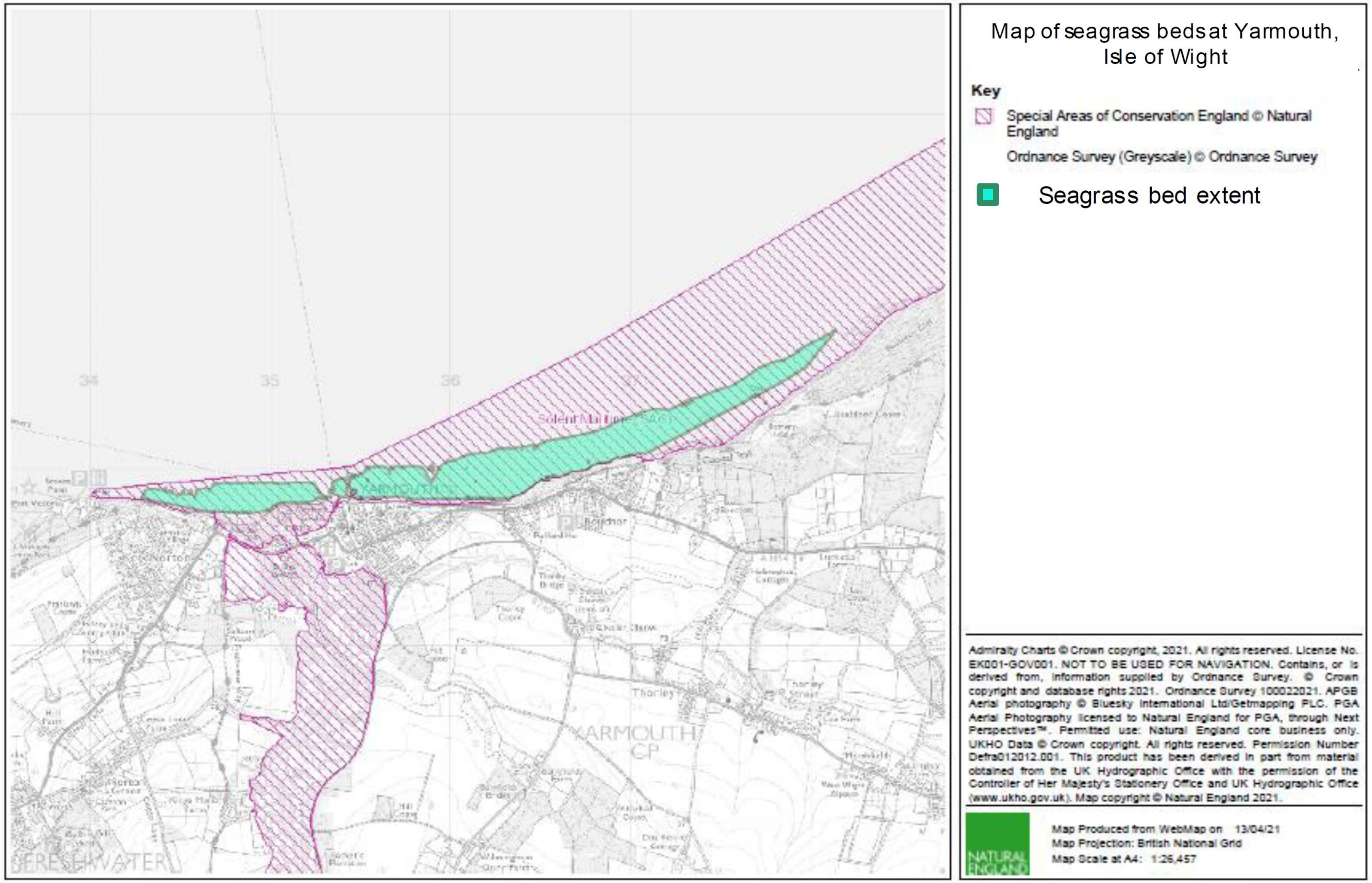

Figure 1. Extent of seagrass beds at Yarmouth, Isle of Wight in the Solent Maritime SAC (Green, 2019).

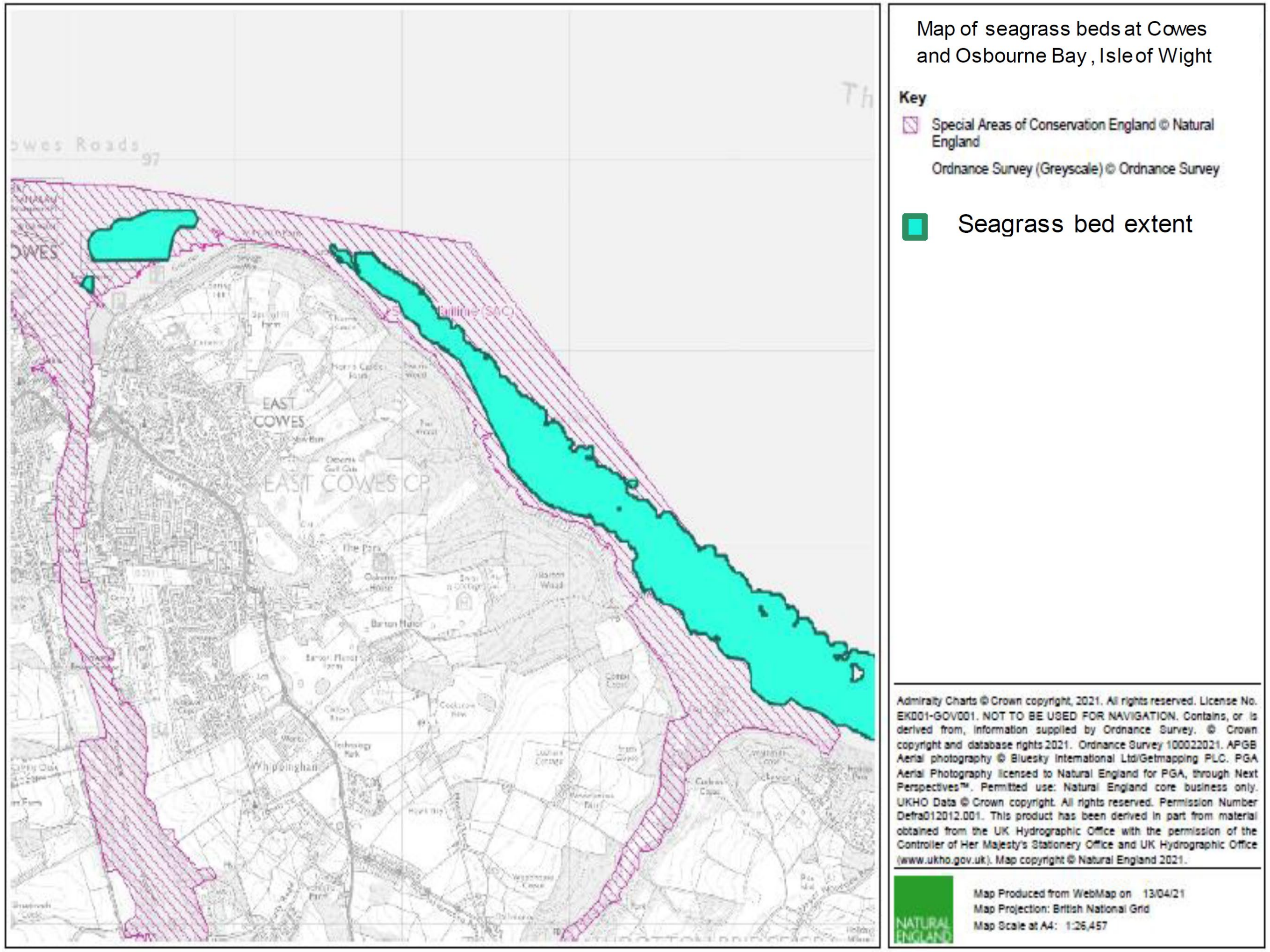

Figure 2. Extent of seagrass beds at Cowes (top left) and Osborne Bay (right hand side), Isle of Wight in the Solent Maritime SAC (Kenworthy, 2021).

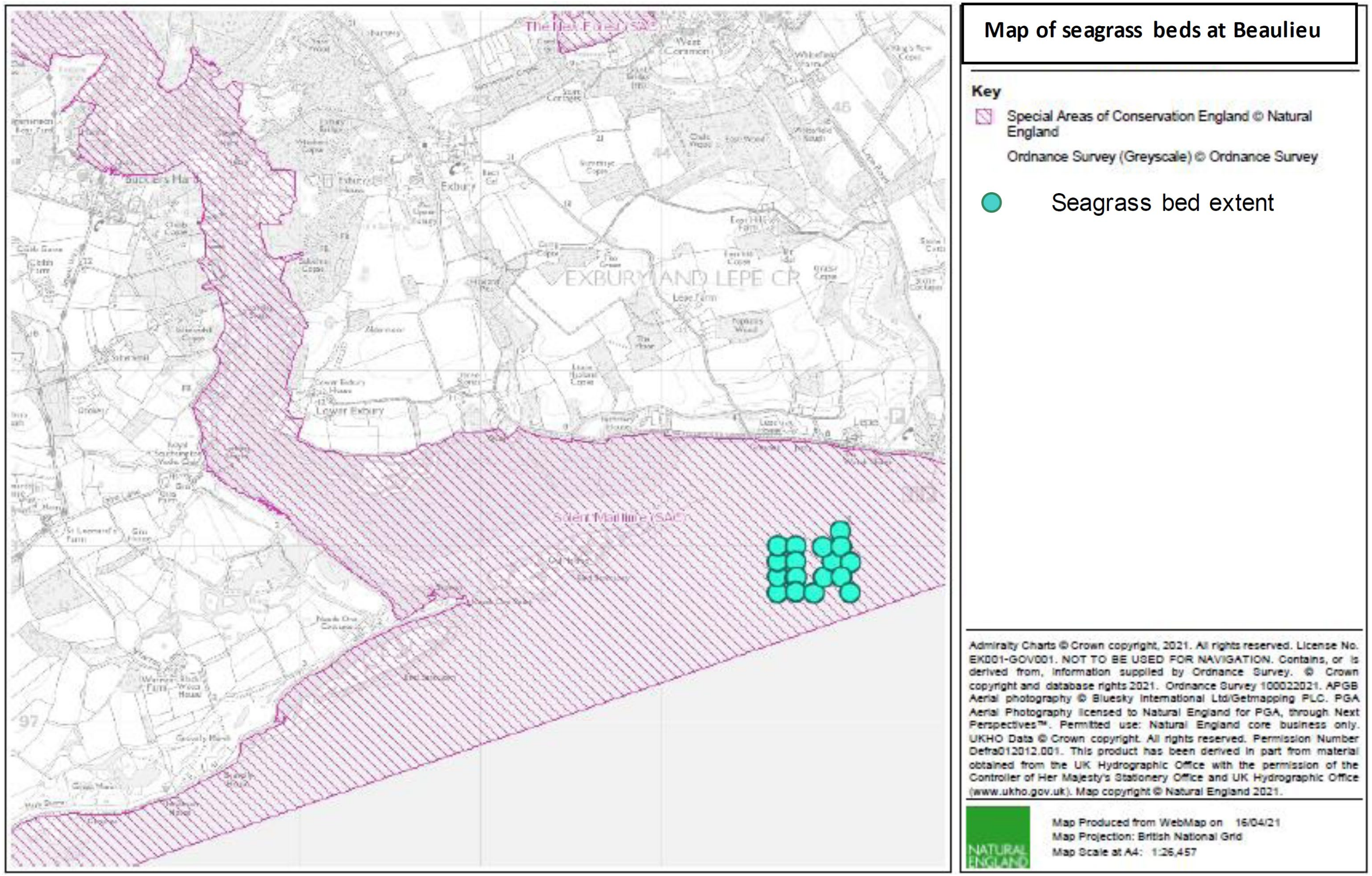

Figure 3. Extent of seagrass beds at the Beaulieu River mouth within the Solent Maritime SAC (Green, 2019).

1.5 Aims and Objectives

An ecological survey using scientific divers was planned from 14th – 18th June 2021 to collect high-quality data and inform a condition assessment of subtidal seagrass feature of the Solent Maritime SAC.

The data collected could then be compared with drop-down video data / echosounder data collected by the Environment Agency in 2018 and 2020 (Green, 2019; Kenworthy, 2021).

1.5.1 Aims

The 2021 project aimed to achieve the following:

- Acquire high-quality data of suitable resolution to allow key attributes to be assessed according to Common Standards Monitoring guidance for seagrass features.
- Produce a follow up report for seagrass in the sites to provide supplementary evidence to the baseline to inform condition.
- Compare to existing data where possible.
- Give an indication of the condition of the feature within the site to allow Natural England to undertake a formal condition assessment.

1.5.2 Objectives

The specific objectives of this project were to collect data and report on surveys to inform condition monitoring of certain attributes of the Solent Maritime SAC subtidal seagrass feature.

The attributes are:

- Extent and distribution
- Distribution: presence and spatial distribution of biological communities
- Structure: biomass
- Structure: non-native species and pathogens

For details on these attributes please refer to the Conservation Advice package for the site.

1.6 Previous surveys

Previous surveys conducted within the seagrass beds of the Solent Maritime SAC are summarised in Table 1.

Table 1. Summary of previous monitoring surveys of the Solent Maritime SAC seagrass beds and referenced in this report.

Year(s)	Methods / aims	General aims (not exhaustive)	Reference
2015	Compiled data from previous seagrass bed surveys.	Inventory of eelgrass beds in Hampshire and the Isle of Wight 2015	Marsden & Scott (2015)
2018 and 2020	Drop-camera and single beam echosounder surveys of subtidal seagrass beds. Photos were analysed for percentage cover of *Zostera marina*, macroalgae, non-native species and anthropogenic impacts such as litter. Aims - to monitor the extent and density of seagrass beds.	2018 - Survey of subtidal seagrass beds in the Solent Maritime SAC (West of Yarmouth, Yarmouth to Bouldnor and North Solent beds) and The Needles Marine Conservation Zone (Colwell Bay and Totland Bay).	Green (2019)
		2020 - Survey of subtidal seagrass beds in the Solent Maritime SAC (River Medina and Osborne Bay, Isle of Wight).	Kenworthy (2021)

2 Methods

2.1 Dive operations

The dive survey was carried out between 14th – 18th June 2021. A Lymington-based chartered hard boat, Wight Spirit, an Evolution 38S hard boat, category 2 MCA-registered vessel, acted as the diving platform. The diving work comprised a team of six divers plus one dedicated non-diving supervisor and a surface stand-by on the vessel.

All diving was carried out under the Diving at Work Regulations (1997). All health and safety matters relating to the diving undertaken was governed by this legislation, the accompanying Scientific and Archaeological Approved Code of Practice (ACOP), and the Rules and Guidance for Scientific Diving in the Statutory Nature Conservation Bodies (Holt, 2015). In accordance with these regulations all divers were qualified to HSE Pt IV or equivalent CMAS 3*.

Natural England produced and supplied a Diving Project Plan which detailed the diving operations, site-specific information, risk assessment and emergency procedures. The plan detailed the sites to be dived on each day of field work and the times of low / high water when diving operations would take place.

The scientific diving team used SCUBA diving equipment and air. Diver pairs were equipped with through-water surface-to-diver voice communications with a diver-to-surface beep return (one per buddy pair as a minimum). This communication system provided the primary communication and recall facility.

2.2 Dive survey & methodology

Seagrass beds within the Solent Maritime SAC were surveyed by divers at seven different sampling stations. A selection of sampling stations was identified prior to the survey based on a range of depths and anticipated seagrass densities, the latter based on Environment Agency (EA) echosounder and drop camera survey data collected in 2018 (Green, 2019) and 2020 (Kenworthy, 2021). The exact sites surveyed during the field work week were dependent on the prevailing conditions i.e. weather, tides, vessel activity (Figure 4).

Figure 4. Seagrass bed monitoring stations within the Solent Maritime SAC, June 2021. Source: Google, © 2021 CNES / Astrium, Maxar Technologies.

At each sampling site the skipper placed a shot line as close as possible to the site target position Table 2).

Table 2. Positions (west to east) of the seven sampling stations in the Solent Maritime SAC surveyed between 14-18 June 2021.

Site name / no.	Latitude (WGS84)	Longitude (WGS84)
Yarmouth Harbour	50° 42.453'N	1° 30.280'W
Yarmouth 3	50° 42.579'N	1° 28.796'W
Beaulieu 1	50° 46.693'N	1° 22.016'W
Beaulieu 2	50° 46.786'N	1° 21.874'W
Cowes Harbour	50° 46.045'N	1° 17.052'W
Osborne 1	50° 45.740'N	1° 15.765'W
Osborne 2	50° 45.508'N	1° 15.346'W

Three buddy pairs dived each site to record data and collect samples at pre-defined locations. On entering the water, pair 1 contacted the surface to confirm seagrass was present. As long as seagrass was present, pairs 2 and 3 then entered the water at 5-minute intervals to give the previous pair time to descend and attach their tape measure to the shot, thereby avoiding ‘congestion’ of divers.

Each survey station was defined as a circular area of 30 m radius divided into three working areas – one per diver pair (Figure 5). These working areas were defined approximately as:

- Pair 1 - 0° and 120°
- Pair 2 - 120° and 240°
- Pair 3 – 240° and 360°

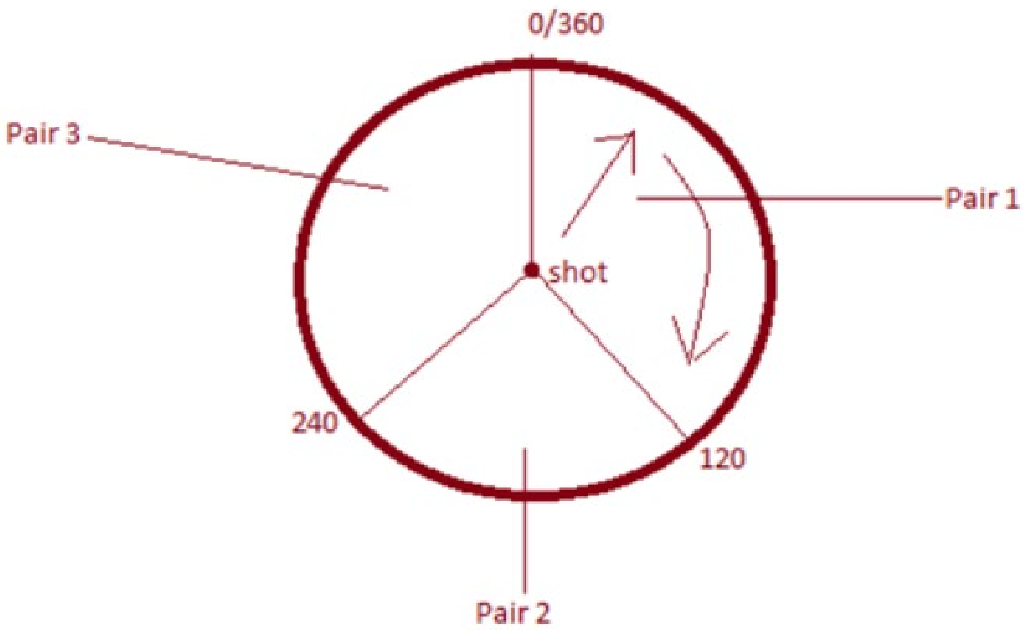

Figure 5. Approximate representation of the layout of each seagrass survey station. Pair 1 - 0° and 120°, Pair 2 - 120° and 240°, Pair 3 – 240° and 360°.

The actual working areas per diver pair were pre-determined by the random calculated vectors along which divers should survey the seagrass. Graduation of sample bearings ensured buddy pairs were not attempting to work on the same bearing at the same time.

Each buddy pair carried out the following methodology:

- One diver attached the tape measure to the shot line, the pair then headed from the shot on a compass bearing and distance as stated on their first sample bag. Upon reaching the distance stated they placed the bottom left corner of a 0.25 m^2 quadrat down at the predetermined distance on the tape measure.

- Diver 1:
    - Photographed the quadrat.
    - Recorded % cover of seagrass in a 0.25 m^2 quadrat to the nearest 5%.
    - Recorded sediment type.[1]
    - Recorded total % cover of other algae.
    - Recorded presence of any non-native species.
    - Counted the total number of shoots within the 0.25 m^2 quadrat.

[1] *No sediments were sampled for particle size analysis.*

- Diver 2:
  - Placed a 0.0625 m^2 quadrat adjacent to the 0.25 m^2 on the opposite side of the tape measure (i.e. right bottom corner aligned with left bottom corner of larger quadrat).
  - Cut all seagrass shoots within the quadrat whilst ensuring that shoots were cut low on the stem so that the plant stayed intact but not too low that the rhizome would be damaged. This allows the shoot to regrow.
  - Placed the shoots in the labelled plastic sample bag, tied and placed in a mesh bag.

After completion of each quadrat, each diver pair returned to the shot for a new bearing and distance, written on the next sample bag. The sample bags and survey form were all pre-labelled so that all diver pairs worked in a clockwise direction from their start point, ensuring that there was no overlap between pairs. If the next quadrat was within a short distance of the previous there was no need to return all the way to the shot. At each site, 25 quadrats were surveyed and sampled (i.e. 8-9 quadrats per buddy pair); the exception being Cowes Harbour where only 17 were surveyed due to very poor visibility during the survey.

If divers completed the quadrat survey and had sufficient time and air, they were able to conduct a short search for seahorses. Licence no. L/2019/00144/3 was issued by the Marine Management Organisation, under The Wildlife and Countryside Act 1981 (As Amended) Section 16: Power to grant licences, to intentionally disturb the species *Hippocampus guttulatus* and *Hippocampus hippocampus* whilst occupying place of shelter or protection, for the purposes of scientific (research) or educational purposes. To undertake this survey the divers unclipped their tape measure from the shot line and deployed a delayed surface marker buoy.

2.3 Post-dive sample analysis

All the shoots sampled from each 0.0625 m^2 quadrat were analysed post-dive at the end of each diving day to ensure no degradation of the samples. Shoots were assessed for:

- Maximum leaf length
- Degree of infection with *Labyrinthula* sp.
- Abundance of epiphytes
- Presence of invertebrate eggs
- Presence of flowering plants

Following training to ensure consistency of measurements and visual assessments, divers took each shoot collected and measured its longest leaf length to the nearest cm. On each shoot, each intact leaf was assessed to estimate the percentage cover of *Labyrinthula* sp. infection and epiphyte cover on a scale of 0-5 (Table 3). Culturing and isolation methods were not employed to prove *Labyrinthula* sp. infection. A photograph showing infection and epiphyte cover on a *Zostera* sp. plant is shown in Figure 6. Sample processing was conducted in pairs, recording data onto hard copy data sheets. Data were then entered onto a spreadsheet following completion of sample processing.

Table 3. Scoring scale used for recording level of leaf infection and epiphyte cover.

Description – leaf infection / epiphyte cover	% Affected	Score
Uninfected / bare	0	0
Minimal	0-2	1
Up to a quarter	3-25	2
Up to half	26-50	3
Over half	51-75	4
Almost all	76-100	5

Figure 6. Amphipod tubes on the surface of a Zostera leaf (left hand side) and Labyrinthula sp. infection (black patch on right hand side).

2.4 Statistical analysis

2.4.1 Data analysis

Univariate analyses were carried out in Minitab 16. Correlations were investigated using the Pearson product moment correlation coefficient to test for relationships between pairs of variables.

Scatter plots and box plots were created in Microsoft Excel. The boxplots illustrate the mean, median, interquartile ranges and variation in the data. With regard to the whiskers, these extend up from the top of the box to the largest data element that is less than or equal to 1.5 times the interquartile range (IQR) and down from the bottom of the box to the smallest data element that is larger than 1.5 times the IQR; these may or may not also be the maximum and minimum values. Values outside the whisker range are considered as outliers and are represented by dots.

2.4.2 Power analysis

The power of a statistical test to detect change is an important consideration in the design and execution of any experiment or monitoring programme. The collection of too few samples might mean that incorrect conclusions are reached if data cannot demonstrate significant differences when they are known to exist (Type II errors), whilst the collection of too many samples can be a waste of resources. Power analysis therefore is important in predicting future survey and analytical costs while ensuring that data collected are fit for purpose.

The power analysis results presented for this survey are based on the outputs from the MONITOR programme which uses simulation procedures to evaluate how each component of a monitoring program influences its power to detect change (Gibbs & Ene, 2010). The programme is devised with population monitoring in mind and allows the user to define the planned sampling design. Outputs indicate the power to detect specified levels of change over any specified time range based on the known or estimated population mean and standard deviation. Further explanation of the tests is provided alongside the outputs in Section 3.8.

2.4.3 Historical data

None of the data from previous surveys available was suitable for statistical comparison with that collected during the 2021 monitoring due to historical variation in the techniques, survey effort, survey season and different project aims. For qualitative comparison purposes, parameters such as shoot density and percentage cover from previous surveys have been cited alongside the 2021 data but no quantitative analyses have been undertaken.

The quantitative data collected in the present survey do provide a solid baseline against which future data can be compared assuming that the methods and sites used here are repeated. Interpretation of any comparison with future surveys would be aided by repeated extent surveys such as that by Green (2019) and Kenworthy (2021).

3 Results and Discussion

To re-cap, the overall objectives of the survey were to collect high-quality data to:

- allow key attributes of the seagrass bed feature to be assessed;
- provide supplementary evidence to inform a condition assessment of the seagrass beds;
- to compare with existing data where possible; and
- provide an indication on the condition of the feature to allow Natural England to undertake a formal condition assessment.

This results section reports the known extent and distribution of the seagrass beds, their percentage cover and density, and additional data on bed structure and health. Finally, power analyses consider how effectively the data can determine changes over time or changes related to management measures and, how efficient the sampling methodology is.

Summary descriptions and example images of each of the seven monitoring sites within the Solent Maritime SAC are provided in 'Appendix A – Site Descriptions'.

3.1 Extent and distribution

Monitoring of the extent and distribution of the seagrass beds within the Solent Maritime SAC was not an aim of the 2021 diving surveys. Extent and distribution were last monitored and reported by the Environment Agency in 2018 and 2020 (Green, 2019; Kenworthy 2021). Figure 7 to Figure 10 summarise the results of surveys from the main beds sampled in the present study as graded categories of low to high percentage cover.

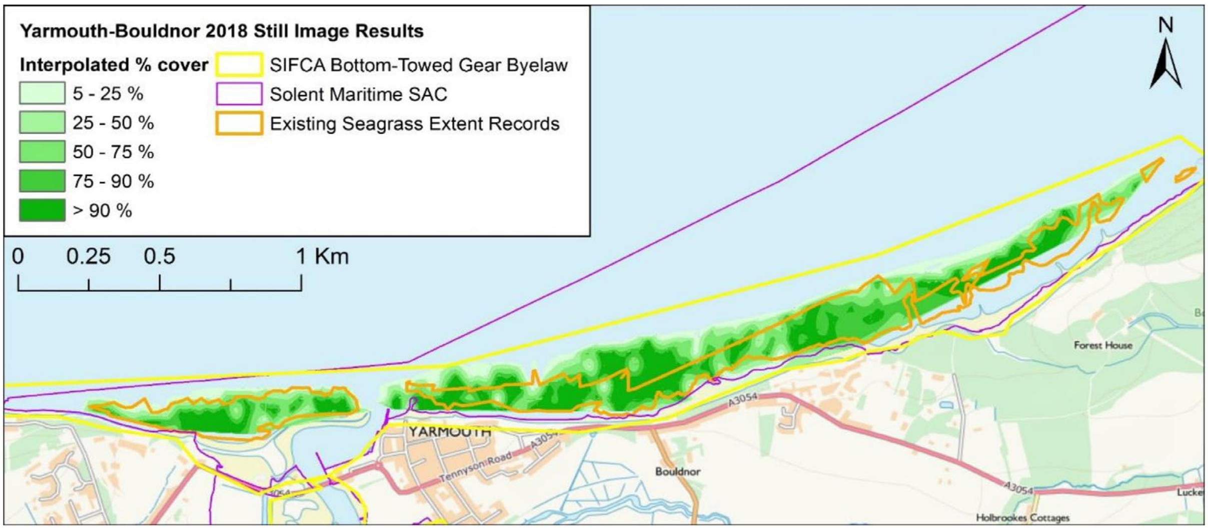

Figure 7. Interpolated map (using Natural Neighbour algorithm) of subtidal seagrass extent (61.02 ha.) and percentage cover from the 2018 drop-camera survey around Yarmouth and Bouldnor (Source: Green, 2019).

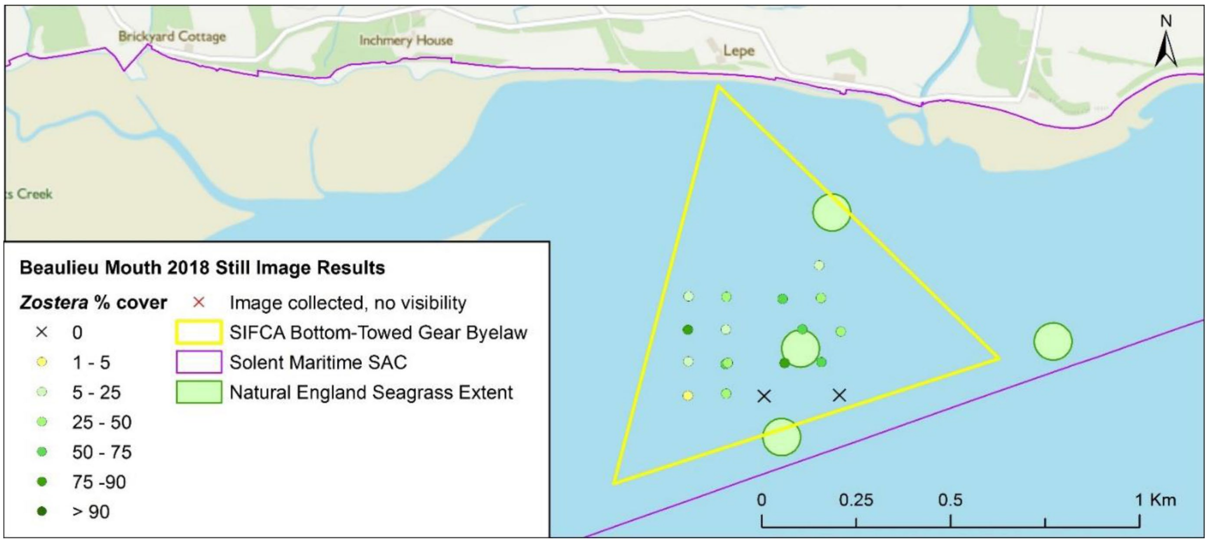

Figure 8, Percent cover of subtidal seagrass (Zostera marina) from still images at drop-camera stations during the 2018 survey at the mouth of the Beaulieu Estuary, reported as 12.04 ha. (Source: Green, 2019).

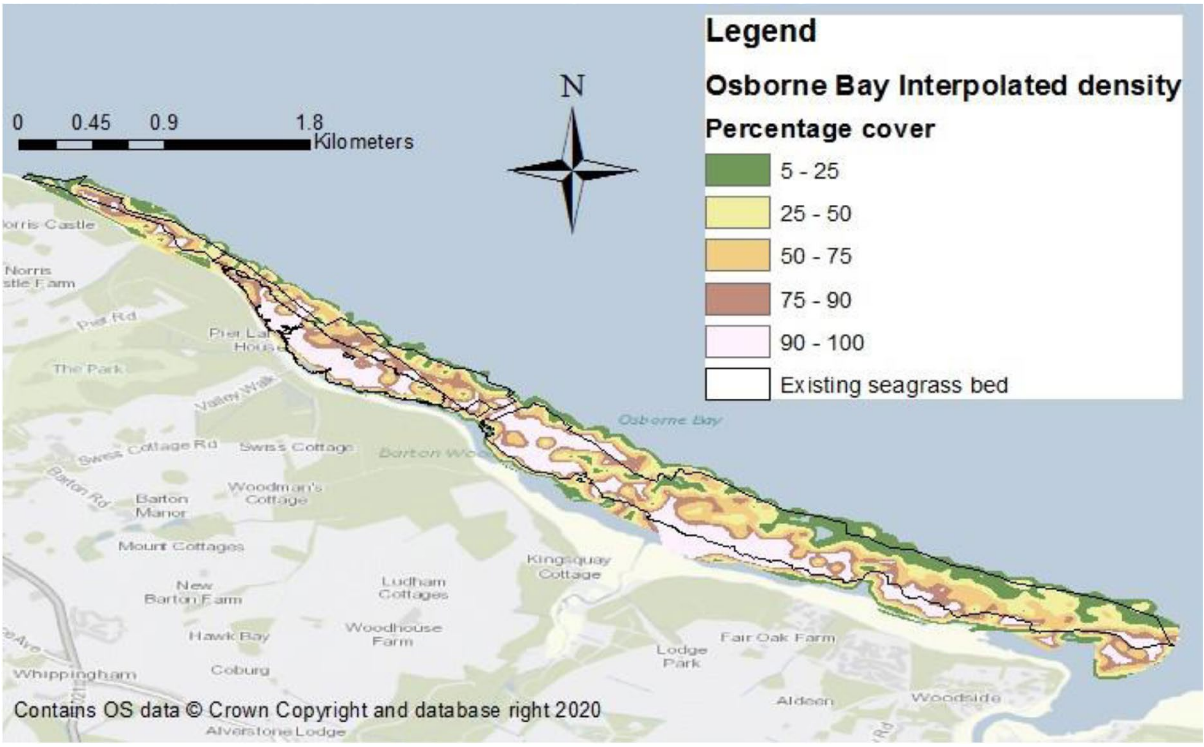

Figure 9. Interpolated map (using Natural Neighbour algorithm) of subtidal seagrass extent (164.7 ha.) and percentage cover from the 2020 drop-camera survey in Osborne Bay. Note the different and less intuitive colour key compared with previous figures (Source: Kenworthy, 2021).

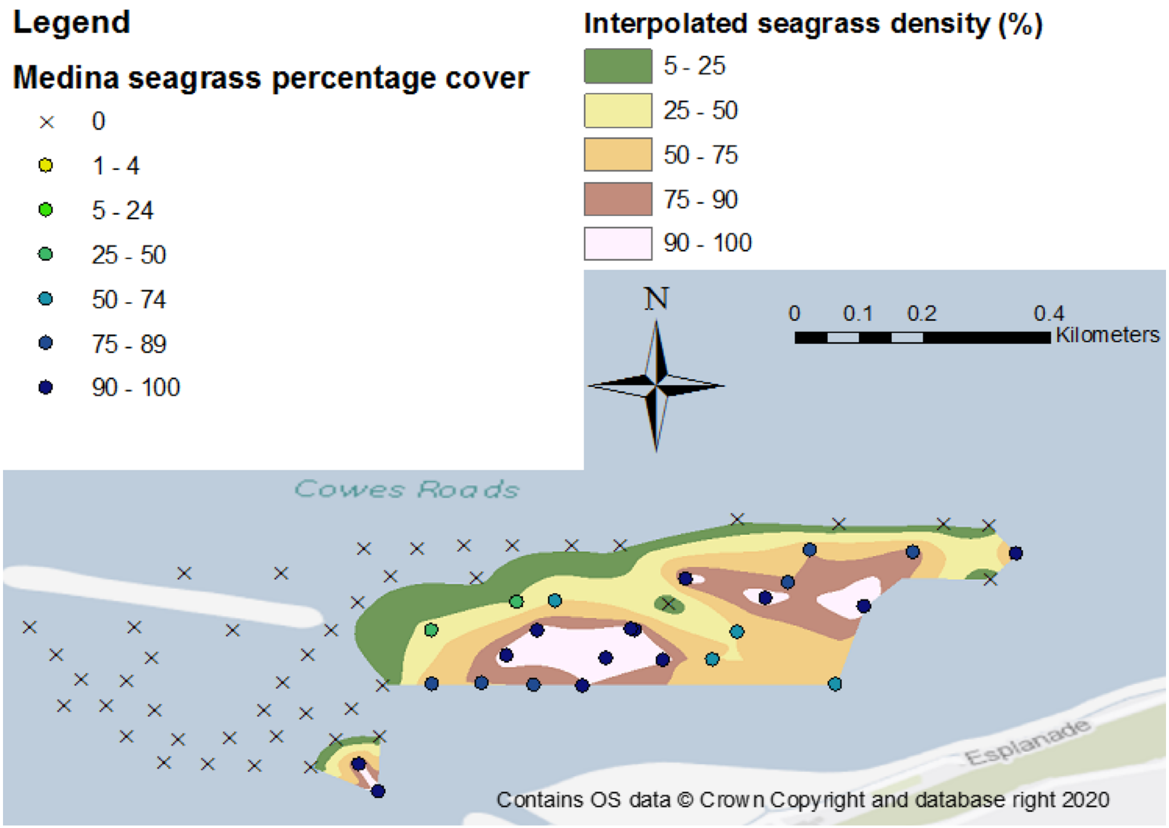

Figure 10. Interpolated map (using Natural Neighbour algorithm) of subtidal seagrass extent (12.13 ha.) and percentage cover from the 2020 drop-camera survey in the Cowes (Medina) seagrass beds. Note the different and less intuitive colour key compared with previous figures (Source: Kenworthy, 2021).

Although the resolution in the figures above was limited by the frequency and methodology of sampling (1 m^2 quadrats at 50 m intervals) they provide good visualisations of the seagrass bed distributions in each area, highlight areas of more patchy cover and enabled successful planning of the 2021 diver survey stations.

The 2018 EA survey data suggested an overall increase in bed extent at Yarmouth despite the area to the west of Yarmouth potentially having declined in extent between 2011 and 2018. However, Green (2019) noted the 2011 surveys appeared to include additional areas of seagrass bed and used echosounder survey methods as opposed to drop cameras. This made it "*difficult to determine the full change in extent*". Furthermore the Beaulieu bed was not fully surveyed in 2018 making meaningful comparisons between bed extents with 2011 data impossible.

The 2020 EA survey data again suggest an overall increase in the Osborne Bay bed extent since 2006 but the different survey seasons and methodologies between the surveys prevent any meaningful comparisons (Kenworthy, 2021). The data within Marsden & Scott (2015) do not distinguish between *Z. marina* and *Z. noltei* making comparisons of areal cover impossible. One assertion from the comparison with historical data noted the landward expansion of the bed "*particularly around Kings Quay within the Kings Quay Shore SSSI and Solent and Southampton Water SPA*" (Kenworthy, 2021). However, Kenworthy (2021) again noted the different survey season and the presence of *Z. noltei* in the nearshore area which may confuse any direct comparisons.

The Cowes Harbour seagrass bed, called the Medina bed in Kenworthy (2021), was judged to be of a similar size in 2020 when compared to data from 2006 (Kenworthy, 2021). The 2020 data suggested the bed extended further east than previously understood in 2006 but compared well with more recent surveys by the Hampshire and Isle of Wight Wildlife Trust (Marsden and Scott, 2015). Direct comparisons based on unit area could not be made between surveys due to underwater visibility issues preventing full mapping from taking place with the drop camera in 2020 (Kenworthy, 2021).

Overall, the drop camera data represent an element of the distribution and patchiness of seagrass beds within the SAC; given the resolution of the data (samples spaced at ~50 m), patchiness at smaller scales (<50 m) cannot be assessed.

3.2 Seagrass bed structure: *in situ* quadrat data

In this section the results of the 2021 surveys are presented and temporal comparisons are given for each parameter where previous data are known to exist.

In addition to exposure, water depth and substrate can be key environmental drivers that influence the presence and distribution of seagrass (Borum et al., 2004). Increasing water depth is associated with a decrease in light levels, thereby limiting the ability of seagrass to grow and establish beds. The data obtained during the 2021 quadrat monitoring showed some weak, positive correlations of percent cover and shoot density with depth, contrary to what would be expected. Seagrass percent cover was weakly positively correlated with increasing depth ($R = 0.212$, $p = 0.006$) but shoot density per m^2 was not correlated with depth ($R = 0.053$, $P = 0.508$) (Figure 11). This slight reversal of the recognised relationship of percent seagrass cover with depth is most likely owing to the restricted scale of the sampling sites within the wider seagrass bed boundaries and thereby not extending sampling to greater depths.

There was a similar weak positive correlation of percent algal cover and sampling depth ($R = 0.240$, $p = 0.002$). Again, as the depth range sampled did not cover full depth profiles across each bed, further sampling would be needed to determine any relationship more thoroughly and is likely beyond the requirements of the present monitoring programme.

All sediments were recorded as either sand, mud, muddy sand or sandy mud with one quadrat at ‘Osborne 1’ being rock and sand. These records were made on a visual (and therefore somewhat subjective) basis by each surveyor and should not be subjected to any statistical analysis. Despite this, there was no obvious difference between seagrass cover or density data with how the substrate types were categorised.

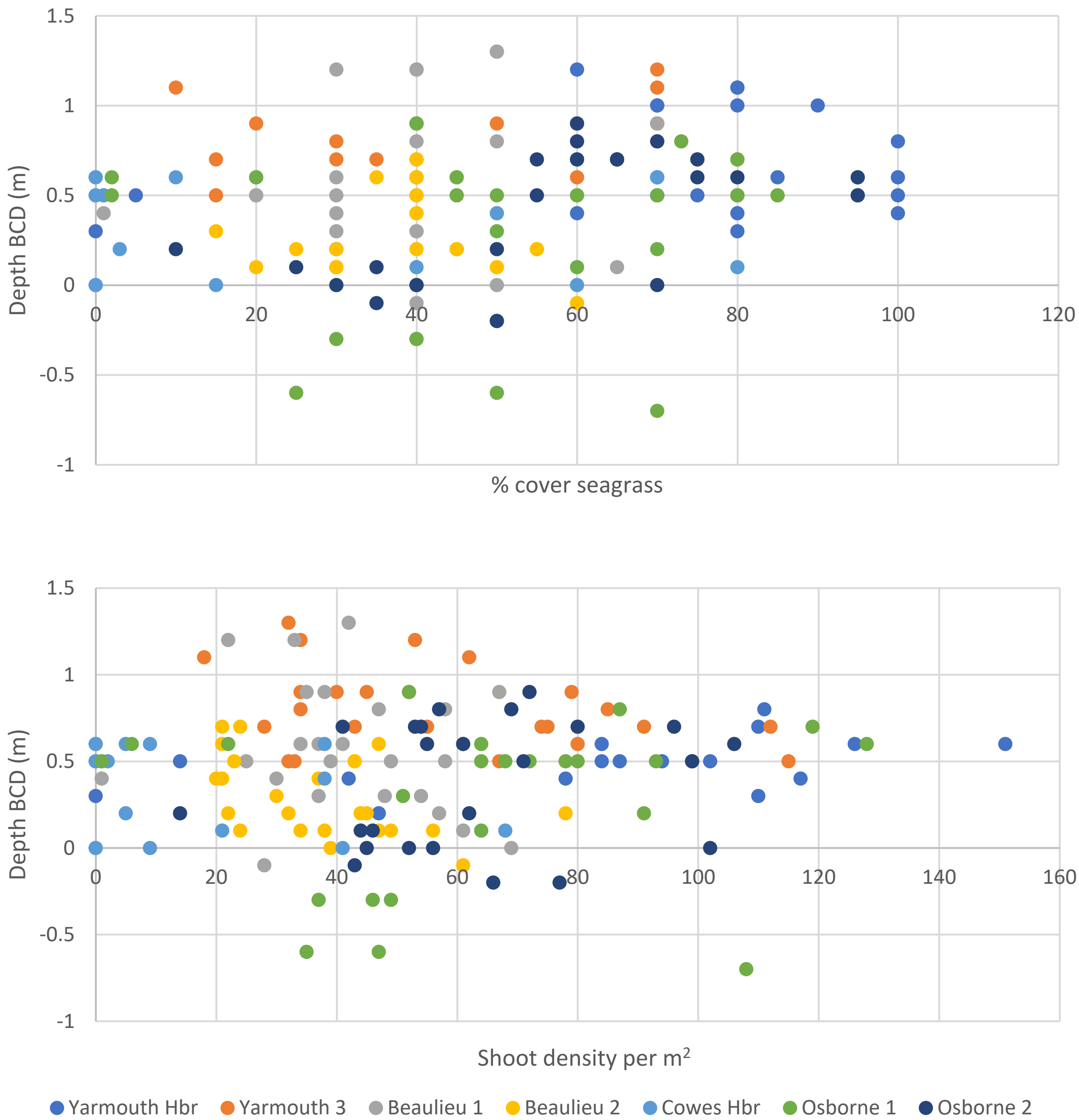

Figure 11. Percentage seagrass cover (top) and shoot density per m2 (bottom) plotted against depth below chart datum (BCD) from seven sites in the Solent Maritime SAC, June 2021.

3.2.1 Seagrass % cover

The mean percentage cover of seagrass assessed at each sampling location in the SAC ranged between 26.2% and 69.4% (Figure 12). The mean percentage cover across all sites was 48.5%. Seagrass was present in every quadrat surveyed with the exception of one at 'Beaulieu 1' and five at 'Cowes Harbour'.

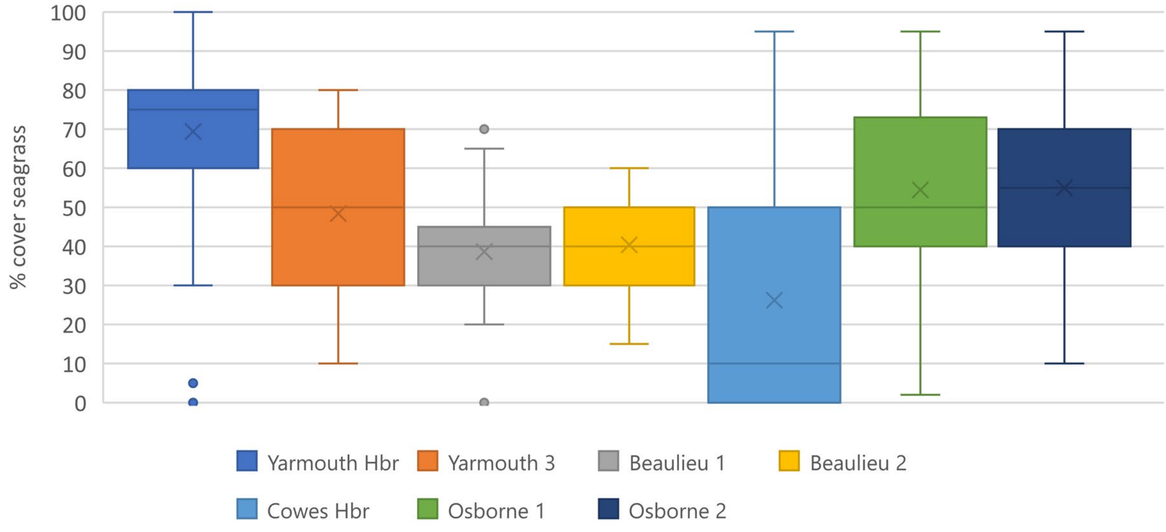

Figure 12. Boxplot of percentage cover seagrass assessments within 0.25 m2 quadrats (n=25, except n=17 at Cowes Harbour) at each of seven sites within the Solent Maritime SAC in June 2021. Boxes show mean (x), median (-), interquartile ranges (boxes), whiskers and outliers.

The EA data illustrate the variable density of seagrass within each bed (Figure 7 to Figure 10). The data in Figure 12 demonstrate which sampling sites were either more patchy (a greater range in values) or more uniform in terms of seagrass cover and appear to align well with the more extensive drop camera survey data (Figure 7 to Figure 10). Data for % cover at the Beaulieu sites were less variable than at the other sites, the latter all recording quadrats with seagrass ranging from 0-30% to 80-100% cover. Seagrass was only absent from one quadrat at the Beaulieu sites with all others ranging between 15-70% cover.

Owing to the different sampling methods, extents and survey seasons, comparisons cannot be made with percentage cover values for any of the beds cited in Marsden & Scott (2015), Green (2019) and Kenworthy (2021). The same issue was noted by Green (2019).

Kenworthy (2021) did note that limited patchiness was observed within the Osborne Bay bed where density was high (>50% cover) close to shore and in the middle of the bed, becoming less dense at the deeper boundaries. The average density was similar to that cited in the 2015 HIWWT report (Marsden & Scott, 2015) and to that recorded here ~55% at Osborne 1 and Osborne 2. Similarly, the Yarmouth Harbour site had a mean percentage cover of 69% in 2021 compared to 68% in 2018, whilst the Beaulieu sites exhibited 38-40% mean cover compared to 42% in 2018 (Green, 2019). These favourable comparisons are more than likely due to fortuitous positioning of the sampling sites in 2021, as the mean density values at Yarmouth 3 and Cowes Harbour were substantially lower than 2018 values (48% vs 78% and 26% vs 73% respectively), quite likely as a result of the different spatial sampling scales.

3.2.2 Seagrass density

The mean density of seagrass shoots per quadrat was scaled up to provide values per m^2. The mean shoot densities recorded across the sampling locations in the SAC ranged between 59 and 343 shoots per m^2 (Figure 13). The mean density for all sites combined was 209 shoots per m^2.

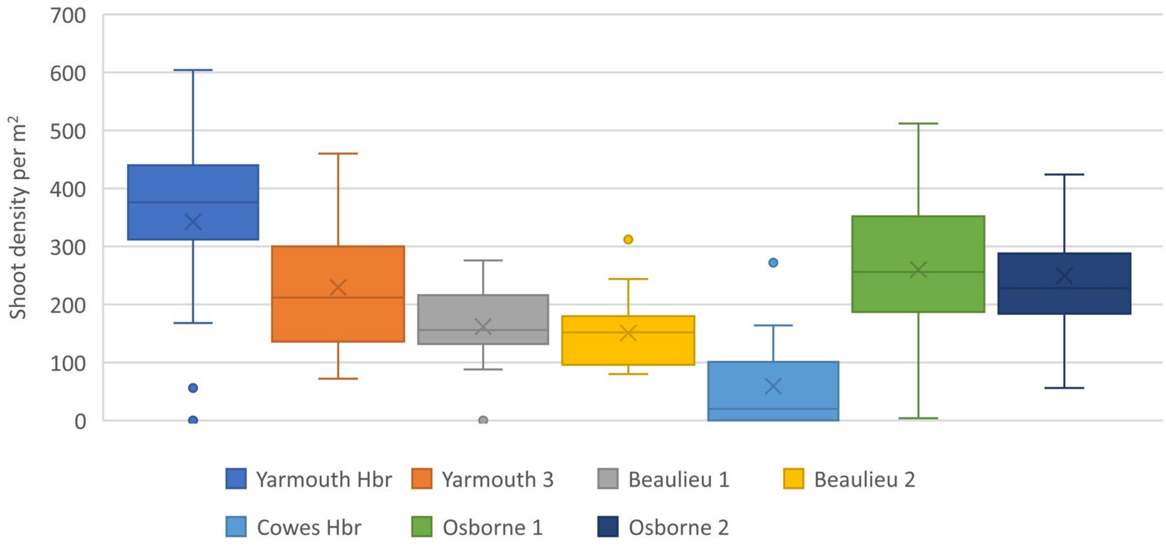

Figure 13. Boxplot of seagrass shoot density per m2 (based on 0.25 m2 quadrat counts; n=25, except n=17 at Cowes Harbour) at each of seven sites within the Solent Maritime SAC in June 2021. Boxes show mean (x), median (-), interquartile ranges (boxes), whiskers and outliers.

The data in Figure 13 exhibited a similar pattern to those for % cover (Figure 12), again reflecting the patchy distribution and variable densities of seagrass within the SAC (Figure 7 to Figure 10). Excluding outliers, shoot density data from the Beaulieu sites and from Cowes Harbour were less variable than for the other sites; the latter all recording quadrats with seagrass densities ranging between 0 to ~400-600 shoots per m^2. The density was lowest overall at the Cowes Harbour site though it should be noted that nine quadrats went unsurveyed at this location due to the extremely poor visibility. Similarly, eight quadrats were unsurveyed at the Yarmouth Harbour site which had the highest mean shoot density.

Not surprisingly, there was a strong correlation between seagrass % cover and shoot density per m^2 ($R = 0.853$, $p < 0.001$) (Figure 14).

Again, owing to the different sampling methods, extents and survey seasons, statistical comparisons cannot made with density data for any of the beds cited in Marsden & Scott (2015), Green (2019) and Kenworthy (2021). The same issue was noted by Green (2019). Marsden & Scott (2015) cited data from surveys in Osborne Bay from June to August 2006 and 2007 where SCUBA diver reported densities in excess of 100 shoots per m^2 and leaves reaching 70 cm. These data compare reasonably well with those from the present survey but without positional data from those surveys, no meaningful interpretation can be made.

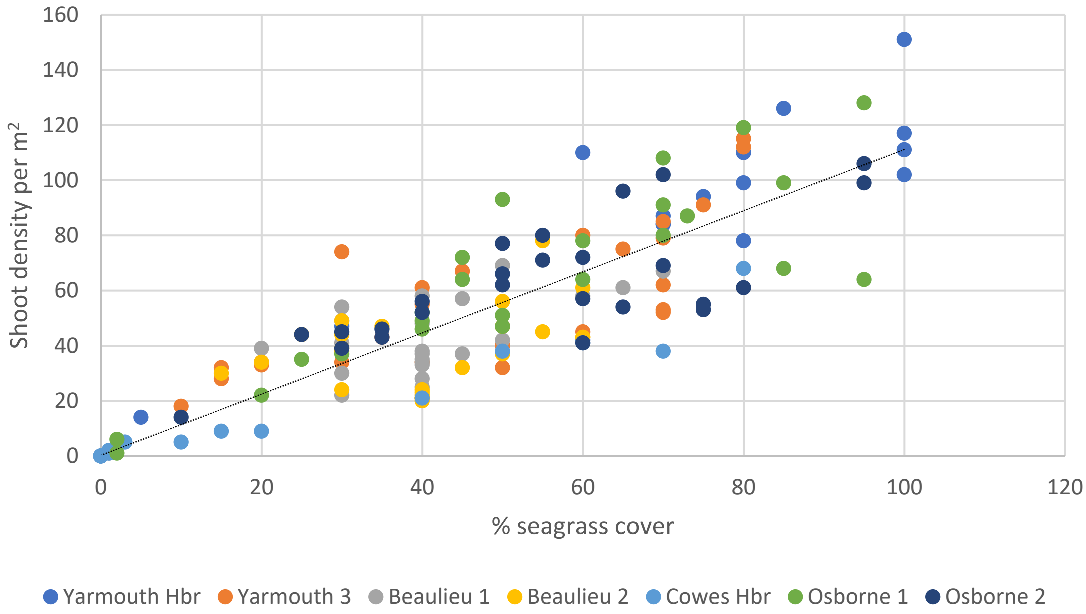

Figure 14. '% seagrass cover' plotted against 'shoot density per m2' from seven sites in the Solent Maritime SAC, June 2021. Trendline shows the significant and strong correlation (R = 0.853, p < 0.001).

3.2.3 Algal cover

The mean percentage cover of algae in the seagrass beds assessed at each sampling location in the SAC ranged between 4.2% at 'Cowes Harbour' and 48.3% at 'Yarmouth 3' (Figure 15). The mean percentage cover across all sites was 21.3%. 'Yarmouth 3' may have had the highest overall % algal cover values compared to the other sites owing to it being a slightly more sheltered location in most directions compared with the other sampling sites.

Again, owing to the different sampling methods, extents and survey seasons, statistical comparisons cannot be made with algal cover data for any of the beds cited in Marsden & Scott (2015), Green (2019) and Kenworthy (2021).

3.2.4 Summary data

Summary statistics for the parameters described in the preceding sections are provided in Table 4 including % cover of seagrass, shoot counts per m^2, and % algal cover during quadrat surveys of seven seagrass sites within the Solent Maritime SAC, June 2021. Maximum values are in bold, minimum values in grey.

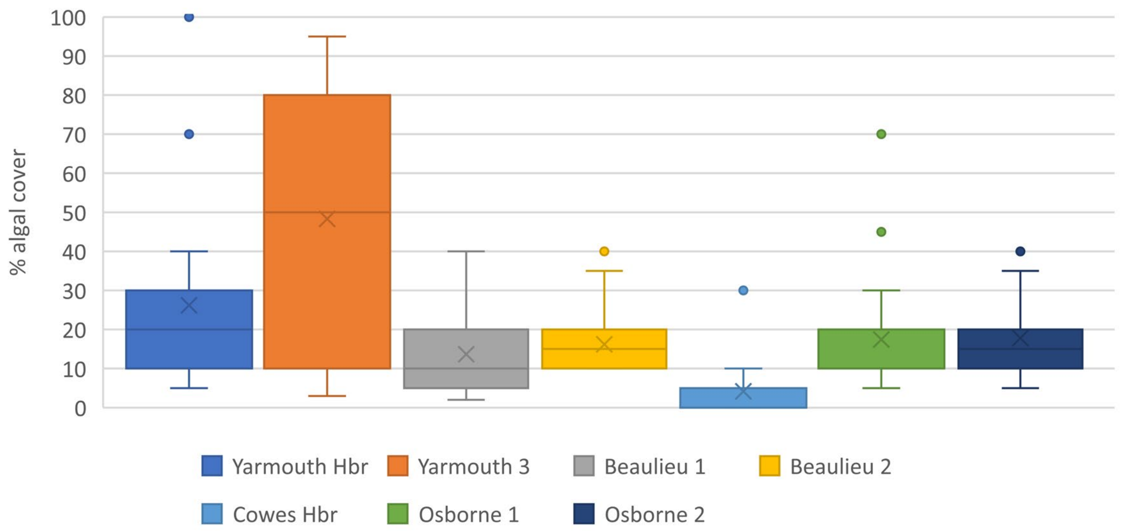

Figure 15. Boxplot of % algal cover in 0.25 m2 quadrats (n=25, except n=17 at Cowes Harbour) at each of seven sites within the Solent Maritime SAC in June 2021. Boxes show mean (x), median (-), interquartile ranges (boxes), whiskers and outliers.

Table 4. Summary statistics for the parameters measured including % cover of seagrass, shoot counts per m2, and % algal cover during quadrat surveys of seven seagrass sites within the Solent Maritime SAC, June 2021. Maximum values are in bold, minimum values in grey.

Site	Mean % cover seagrass	Mean shoot count (per m^2)	% cover algae	Depth (m BSL)	Depth (m BCD)	No. quadrats with no seagrass	% quadrats with no seagrass
Cowes Hbr	26.2	59.3	4.2	1.8	0.3	**5**	**29**
Yarmouth Hbr	**69.4**	**342.6**	26.2	2.4	0.7	0	0
Yarmouth 3	48.4	229.4	**48.3**	2.5	**0.8**	0	0
Beaulieu 1	38.6	161.6	13.6	3.5	0.6	1	4
Beaulieu 2	40.4	150.9	16.2	1.8	0.3	0	0
Osborne 1	54.5	260.2	17.4	3.0	0.3	0	0
Osborne 2	55.0	249.6	17.8	4.5	0.4	0	0
Overall	48.5	209.0	21.3	-	-	6	3.6

3.3 Seagrass bed structure: quadrat sample data

3.3.1 Leaf length and health

To provide some indication of the health of the seagrass plants within the SAC, the longest leaf length on each shoot was measured and, scores of 0-5 were assigned to each leaf on each shoot to indicate both the degree of infection with *Labyrinthula zosterae* and the level of epiphyte cover. These parameters are summarised in Figure 16 to Figure 18 and provide an indication of the variability throughout the SAC.

The single longest leaf length was 100 cm from Yarmouth Harbour. However, the site with the longest mean lengths overall was Cowes Harbour with mean lengths of 46.4 cm, despite this site having the lowest overall density of seagrass. Excluding outliers, both Yarmouth Harbour and Cowes Harbour also had the greatest range of leaf lengths with the longest leaves from both sites exceeding 80 cm. The shortest mean leaf lengths were from Yarmouth 3 with a mean of 26.3 cm respectively.

The overall mean leaf length for the seagrass within the Solent Maritime SAC was 34.3 cm (±15.8 stdev). Previous surveys by the EA (Green, 2019; Kenworthy, 2021) did not measure seagrass leaf lengths through sampling but presented mean bioheight data throughout each of the seagrass beds. The bioheight data from the Yarmouth, Cowes and Osborne sites recorded in 2018 and 2020 appear to be within comparable ranges with those from the present surveys but are presented only in 20 cm length classes and cannot be compared statistically. Bioheight data were not obtained for the Beaulieu sites in 2018. Mean leaf lengths from seagrass in Priory Bay on the Isle of Wight were reported as 29.6 cm in June 2013 (Jones and Unsworth, 2016), not too dissimilar to the overall SAC mean of 34.3 cm in the present study.

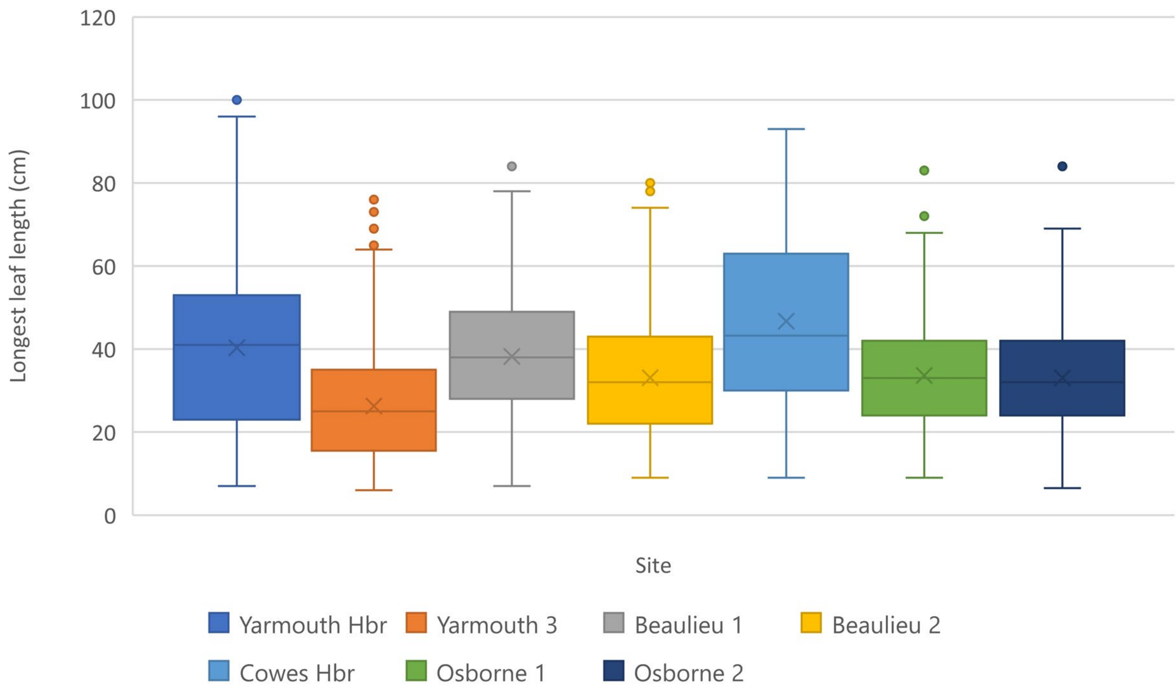

Figure 16. Boxplot of longest leaf lengths per shoot (n=25) at each of seven sites within the Solent Maritime SAC in June 2021. Boxes show mean (x), median (-), interquartile ranges (boxes), whiskers and outliers.

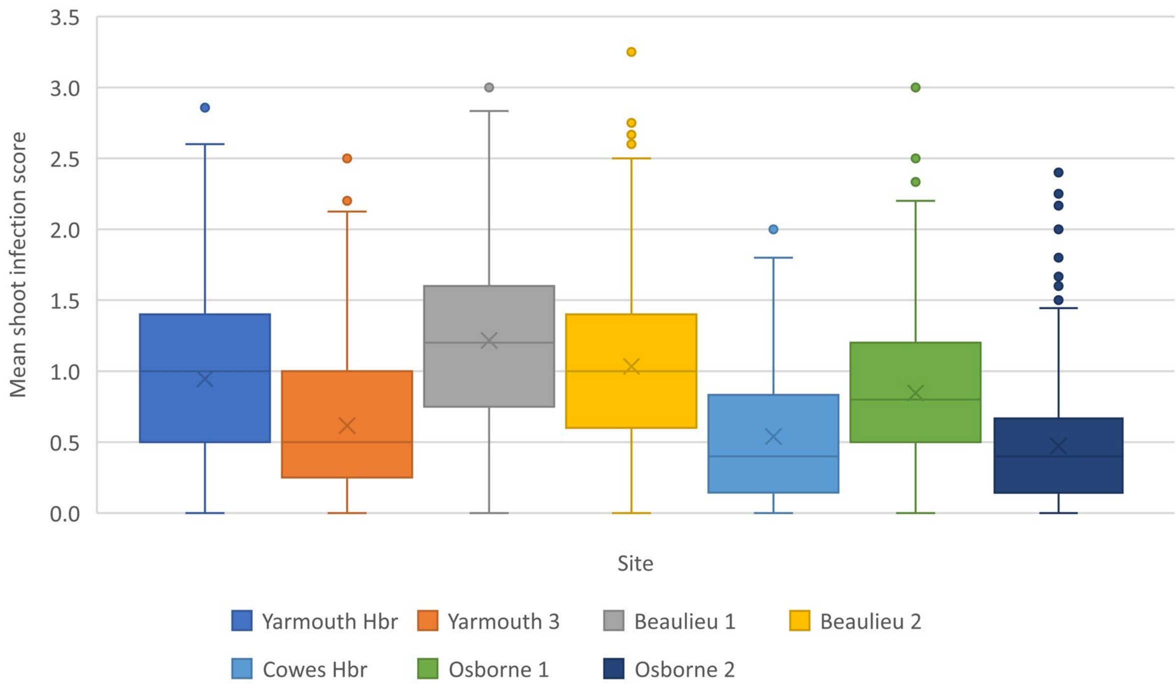

Figure 17. Boxplot of overall shoot infection scores (n=25) at each of seven sites within the Solent Maritime SAC in June 2021. Boxes show mean (x), median (-), interquartile ranges (boxes), whiskers and outliers.

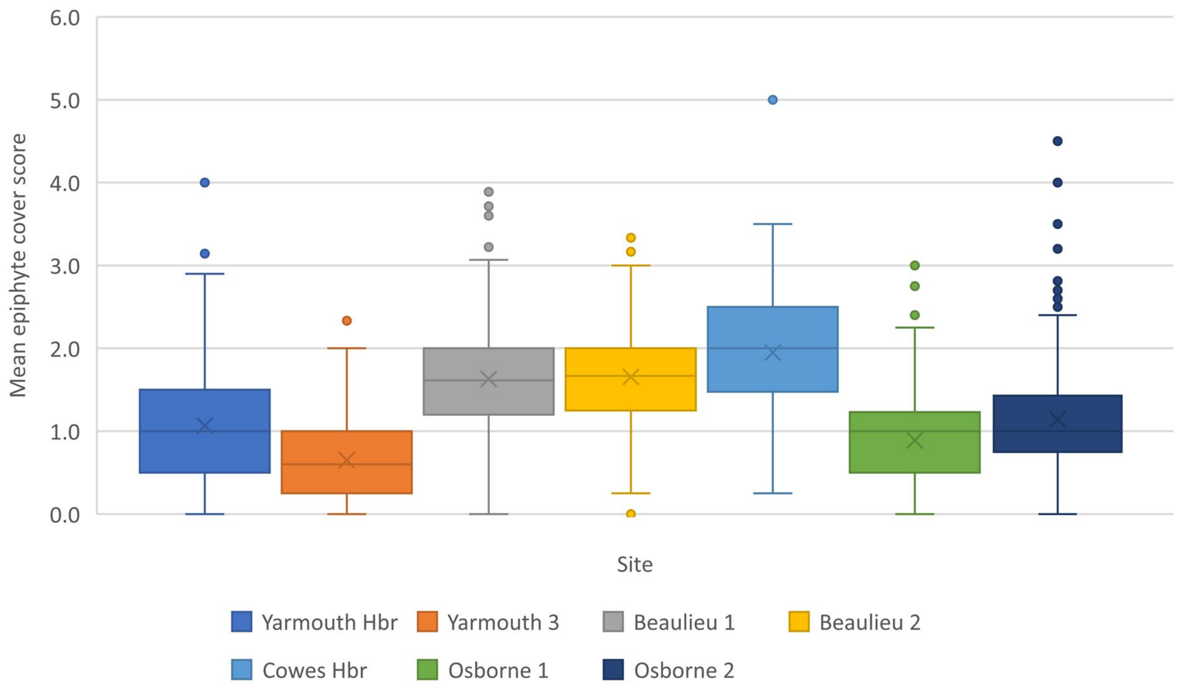

Figure 18. Boxplot of overall epiphyte cover scores (n=25) at each of seven sites within the Solent Maritime SAC in June 2021. Boxes show mean (x), median (-), interquartile ranges (boxes), whiskers and outliers.

The mean shoot infection scores were low for all the sites, ranging between 0.5 and 1.2 (Figure 17). The lowest mean infection scores of 0.5 were from Osborne 2 and Cowes Harbour. The highest mean shoot infection scores (1.0 to 1.2) were recorded at both the Beaulieu sites at the mouth of the Beaulieu Estuary. The overall mean infection score for the seagrass in the SAC was 0.8 (±0.6 stdev).

Overall mean epiphyte cover scores per shoot were lowest at the Yarmouth and Osborne Bay sites, ranging between 0.7 and 1.1. The mean scores were highest at the two Beaulieu sites and at Cowes Harbour where they ranged between 1.6 and 2.0. The overall mean epiphyte cover score for the seagrass in the SAC was 1.1 (±0.7 stdev). Epiphytic growth included filamentous algae, snakelock anemones, fine hydroids, turf and encrusting bryozoans and amphipod tubes.

Table 5 provides further detail on the leaf and shoot parameters recorded from the samples taken during each site survey.

Table 5. Descriptive statistics for the parameters measured from shoot samples collected during quadrat surveys of seven seagrass sites within the Solent Maritime SAC, June 2021.

Site	Longest leaf length (cm)				Infection score			Epiphyte score			Mean shoot count (per m^2)
	Mean	Stdev	Min	Max	Mean	Min	Max	Mean	Min	Max	
Cowes Hbr	46.7	19.6	9.0	93.0	0.5	0.0	2.0	2.0	0.3	5.0	59.3

Site	Longest leaf length (cm)				Infection score			Epiphyte score			Mean shoot count (per m²)
	Mean	Stdev	Min	Max	Mean	Min	Max	Mean	Min	Max	
Yarmouth Hbr	40.3	19.2	7.0	100.0	1.0	0.0	2.9	1.1	0.0	4.0	342.6
Yarmouth 3	26.3	13.1	6.0	76.0	0.6	0.0	2.5	0.7	0.0	2.4	229.4
Beaulieu 1	38.2	14.6	7.0	84.0	1.2	0.0	3.4	1.6	0.0	3.9	161.6
Beaulieu 2	33.1	14.1	9.0	80.0	1.0	0.0	3.3	1.7	0.0	3.3	150.9
Osborne 1	33.6	13.5	9.0	83.0	0.8	0.0	3.0	0.9	0.0	3.0	260.2
Osborne 2	33.1	12.6	6.5	84.0	0.5	0.0	2.4	1.1	0.0	4.5	249.6
Overall	34.3	15.8	6.5	100.0	0.8	0.0	3.4	1.1	0.0	5.0	209.0

3.3.2 Flowering plants

Seagrass, specifically *Zostera marina* has been recorded to flower and seed subtidally in the Solent between May and July (Tubbs & Tubbs, 1983). The results from the present survey bear this observation out. Table 6 shows the total number of plants sampled and assessed from the 166 quadrats sampled, including the number and percentage of flowering plants at each sampling site. Overall, 5.2% of the plants were flowering at the time of survey. No comparable data are available for flowering plants. The percentage recorded during this survey was comparable with the 5% flowering plants reported for Plymouth Sound from a July survey in 2018 (Bunker & Green, 2019).

Table 6. Number and percentage of flowering seagrass (Zostera marina) plants sampled from 0.25 m2 quadrats within the Solent Maritime SAC, June 2021.

	Site							Total
	Yarmouth Harbour	Yarmouth 3	Beaulieu 1	Beaulieu 2	Cowes Harbour	Osborne 1	Osborne 4	
Total no. plants	513	539	310	261	95	419	503	**2,640**
Total no. flowering plants	23	18	31	7	13	14	30	**136**
% flowering plants	4.5	3.3	10.0	2.7	13.7	3.3	6.0	**5.2** (mean)

Anecdotal observations during the quadrat surveys suggested the occurrence of mature flowering strands of seagrass were clumped where they occurred within each sampling location. Where flowering plants occurred, often multiple flowering plants would be sampled within a quadrat.

3.3.3 Presence of eggs on leaves

Eggs of various mollusc species and polychaete worms were recorded on seagrass leaves. Table 7 shows the total number of plants sampled and assessed from the 166 quadrats surveyed including the number and percentage of those with eggs on the leaves at each sampling site.

Table 7. Number and percentage of plants with leaves supporting eggs of other species (mainly molluscs) sampled from 0.25 m2 quadrats within the Solent Maritime SAC, June 2021.

	Site Yarmouth Harbour	Yarmouth 3	Beaulieu 1	Beaulieu 2	Cowes Harbour	Osborne 1	Osborne 4	Total
Total no. plants	513	539	310	261	95	419	503	**2640**
Total no. with eggs present	6	42	11	29	1	11	17	**117**
% with eggs present	1.2	7.8	3.5	11.1	1.1	2.6	3.4	**4.4** (overall)

3.4 Seahorse observations

One short-snouted seahorse (*Hippocampus hippocampus*) was recorded during the surveys and documented using a camera without flash (Figure 19). The exact location is held by Natural England. Both species are reported from the Solent Maritime SAC (NBN, 2021).

Figure 19. The short-snouted seahorse recorded during the surveys of seagrass beds in the Solent, June 2021.

3.5 Other incidental species observations

Other incidental species photographed during the survey are listed here. The list is not exhaustive but covers only those taxa identifiable in the images available. The data cannot be quantified.

- Snakelocks anemone, *Anemonia viridis*
- Tubeworm, *Sabella* sp.
- Slipper limpet, *Crepidula fornicata*
- Bryozoans, cf. *Electra pilosa*
- Spider crab, *Maja brachydactyla*
- Spider crab, *Macropodia* sp.
- Sea squirt, *Polycarpa* sp.
- Sea squirt, *Botrylloides* sp.
- Black goby, *Gobius niger*
- Various foliose red algae
- Filamentous red and green algae

- Red alga, cf. *Chondria dasphylla*
- Wireweed, *Sargassum muticum*
- Sea lettuce, *Ulva* sp.

3.6 Non-native species

Non-native species were not recorded quantitatively during the survey and sampling work, but the presence of several species was noted. These included:

- Slipper limpets, *Crepidula fornicata*
- Sea squirt, *Botrylloides* sp. (Note: this was not listed as the native *B. leachii* by the surveyors and was recorded in the non-native section of the data forms. A more precise identification was not made.)
- Wireweed, *Sargassum muticum*

Crepidula were recorded at Beaulieu 1, Yarmouth 3 and Osborne 1 and 2. *Botrylloides* sp. was recorded at Yarmouth 3 and Osborne 1 whilst *Sargassum muticum* was recorded from Yarmouth Harbour and Yarmouth 3 and Osborne 1 (Figure 20).

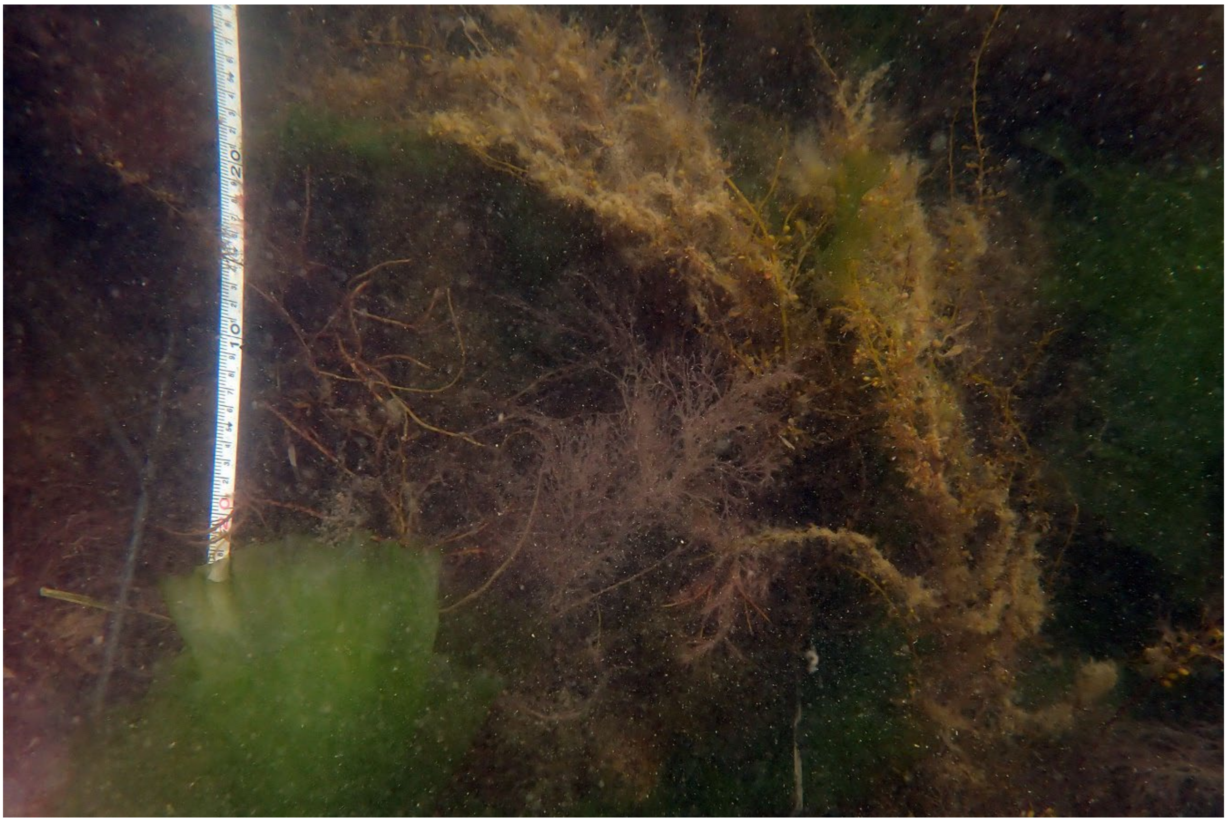

Figure 20. Wireweed, *Sargassum muticum* observed in the seagrass bed at Yarmouth 3 in the Solent Maritime SAC, June 2021.

3.7 Anthropogenic influences

Seagrass beds can be sensitive to various anthropogenic activities. Direct measurement of such influences was outside the scope of the monitoring surveys in June 2021 although some can be considered here.

"*In subtidal situations, nutrient enrichment may lead to excessive growth of opportunistic epiphytic algal species, or blooming species such as,* Ulva, Chaetomorpha *and* Ectocarpus *on seagrass beds, potentially compromising the health and viability of seagrass by overlying and smothering them*" (WFD-UKTAG, 2014). Seagrass in Priory Bay on the Isle of Wight has been reported to have nitrogen (N) above the global average but phosphorus (P) levels below the global average, with the N:P ratio being highly elevated which suggests a nutrient imbalance at the site (Jones & Unsworth, 2016). Identifying the source of these elevated nutrient levels and determining if they persisted throughout the SAC was beyond the scope of this study. Light levels in Priory Bay were considered to be potentially limited based on the C:N ratios reported by Jones & Unsworth (2016). Again, whether this applies to the other beds with the SAC requires further study.

No confirmed evidence of anchor damage was recorded during the surveys in June 2021, however, there was suspected evidence of anchor scars at Yarmouth 3, indicated by sediment disturbance (see Appendix A – Site Descriptions).

3.8 Statistical Power

As stated in Section 2.4.2, the power analyses of the univariate shoot density data were completed using the MONITOR programme (Gibbs & Ene, 2010), outputs from which indicate the power to detect specified levels of change over a specified time range based on the known or estimated population mean and standard deviation. In the power analysis outputs presented here, the data used were those from the 2021 quadrat surveys. The power analyses were run on the default assumption of wanting a 90% chance of detecting a real change with the significance level of that change set at the standard 5% level i.e. power = 0.9. Where a power level of 0.9 was not achievable, power levels of 0.8 were investigated. These parameters can be altered in future if there was reason to accept the findings of less powerful monitoring designs or to set significance thresholds at lower levels. Although there are no established conventions, it is common practice to seek power estimates exceeding 0.80 (Cohen, 1988) i.e. a monitoring program with power estimates in excess of 0.80 would detect trends, should they occur, >80% of the time. A starting default value of 0.9 desired power is used here to give higher confidence that any population changes could be captured. *"In a monitoring context* [a significance (p) level of] *0.1 or 0.2 is perfectly reasonable depending on the seriousness of missing important trends versus the costs of exploring false detections. Justifying significance level is a critical part of designing monitoring programs*" (Gibbs & Ene, 2010). Two monitoring designs were entered into the MONITOR interface depending on the hypotheses that might wish to be tested:

- Firstly, data were analysed on the basis of wanting to monitor for time trends in the mean shoot density per sampling site (regression) over three or four survey events during a ten-year period. This was based on the assumption that annual monitoring at the site is unlikely, but any future data would still need to be able to determine whether density was increasing or decreasing. In this case a "route regression" approach was used, whereby trends in sample measurements are determined for each sampling station in each bed, and then averaged across the whole bed.
- Secondly, the power analyses were conducted on the basis of comparing the mean shoot density per sampling site values on a 'before / after' basis (i.e. to determine if potential management measures might be effective) to test a hypothesis that an increase in seagrass density might occur.

3.8.1 Time trends

The ability to detect directional change over time is important to be able to determine if the seagrass bed structure is changing in a positive or negative manner. Natural factors such as wave action, temperature and turbidity can influence bed structure in any given year, so the ability to determine directional change must account for this variability and also contain sufficient time points to be confident that a trend is present. Of the three parameters recorded during the *in-situ* quadrat surveys the shoot density data are the least subjective, being based on actual counts rather than visual estimates. Therefore, these data were used for the power analysis as they are not subject to any recorder variability.

The WFD-UKTAG (2014) document notes the variability inherent in seagrass beds in terms of cover or density may be as high as 30%. Where data allow, it is suggested to use a five-year rolling mean value for shoot density to reduce noise and identify longer term trends; in such cases variation of ~15% is considered "*as tolerable evidence of natural variation and decreases in extent of >15% should be viewed suspiciously*" since a 30% reduction when using rolling means could mask underlying trends (WFD-UKTAG, 2014). On this basis, power analysis was conducted to determine the power to detect positive or negative trends in the shoot density within the different Solent Maritime SAC seagrass beds of 15% to 30%.

Table 8 shows the power of the present monitoring programme design to detect time trends in the seagrass shoot density data. The changes in shoot density indicated are the overall changes over the full time period. The results suggest the power to detect changes of ±30% or higher is consistently high (almost always >0.9) no matter the sampling interval. The power to detect changes of ~15% over a 9–11-year period gave very similar power values. Power analysis could not be undertaken for the Cowes seagrass bed as data exist only from one sampling station at this site.

These results are based on repeated sampling at the same two stations within each bed. Moving to different locations in beds of variable / patchy shoot density would likely have the effect of increasing the variability in the data and lowering both the power of the monitoring to detect change and the confidence in any conclusions drawn.

Table 8. Statistical power to detect trends in shoot density per m^2 of varying magnitude over three or four different survey occasions at the 5% significance level in the Yarmouth seagrass bed.

Sampling interval	% change in mean shoot density per m^2	Power			
		Yarmouth	Beaulieu	Cowes	Osborne
Every 5 years, over an 11-year period x3 surveys Yrs 0, 5 and 10	±15%	0.966	0.959		0.994
	±30%	0.982	0.990	n/a	0.997
	±40%	0.997	0.997		0.998
Every 3 years, over a 10-year period x4 surveys Yrs 0, 3, 6 and 9	±15%	0.893	0.989		0.969
	±30%	0.871	0.993	n/a	0.999
	±40%	0.990	0.998		1.000
Every 2 years, over a 9-year period x5 surveys Yrs 0, 2, 4, 6 and 8	±15%	0.950	0.964		0.960
	±30%	0.921	0.994	n/a	0.973
	±40%	0.994	0.999		0.996

Should the seagrass shoot density change by 15% year-on-year, the power of the monitoring design was very high (>0.999) no matter which of the survey interval options were selected. Such a change would likely be so dramatic that it would be highly noticeable on a visual basis within one or two years, even without statistics.

Whilst changes in shoot density can be informative about the state of seagrass within a bed, it does not provide information on expansion or contraction of the overall bed, particularly given that only two monitoring sites are sampled within each bed, based on the known presence of seagrass; extrapolation of these data to represent and draw conclusions for an entire bed would not be appropriate. Monitoring of the bed extent and boundary by drop camera or multibeam methods is likely to provide the best indication of this parameter, although the same considerations must be given to determining trends in bed extent from natural variation, viewing any changes <15% in either direction as unlikely to be indicative of a trend (WFD-UKTAG, 2014). Bed boundary / area cover data coupled with the shoot density data would provide a statistically powerful method for detecting changes.

3.8.2 Management effects

The second way to assess statistical power is to consider the ability of the present monitoring design to detect ‘before/after’ effects of potential management measures to protect the seagrass. In this instance there may be one or more years’ monitoring data pre-management following by subsequent years post-monitoring. Considering the same monitoring intervals as those in Table 8 with a single 'pre-management' year and two to four 'post-management' monitoring years, the present design only had power values of 0.096 to 0.110 to detect a change of 30% in shoot density at any of the seagrass beds being monitored.

The 'Optimise' function in MONITOR was used to investigate what combinations of survey interval, numbers of sites and variations of acceptable power and significance might enable some detection of significant change in shoot density following changes to management measures. Based on the available data for each seagrass bed (maximum of two survey stations), the Optimise function was unable to propose any monitoring designs, even with a power of >0.8 and a significance level set at p = 0.1.

Even using all the data from across all the seagrass beds monitored in 2021, the Optimise power analysis function was unable to offer any monitoring designs with sufficient power (likely to be deemed acceptable in terms of effort and cost) to detect management changes over a 10-year period. This result is similar to that obtained for the Studland Bay bed where the analysis suggested that six annual surveys (3 'before' / 3 'after' management measures) have a power of only 0.830 to detect a 30% change in density using 14 monitoring stations at the 10% significance level (Doggett & Northen, 2021). These low powers cited to detect 'before / after' changes of such a magnitude are in line with similar findings for the seagrass beds in Torbay (Field, 2019), likely as a result of the high variability between and within sampling stations in each seagrass bed.

3.8.3 Sampling efficiency

A final aspect to examine in terms of statistical power was the sampling efficiency of the surveys. From every sampling point, all the shoots within a 0.0625 m^2 quadrat were collected; n = 2,640 from the entire survey. From each shoot the longest leaf length was measured (n = 2,640) before every leaf (n = 12,829) was then assessed for infection and epiphyte growth. As a general rule of thumb, the ideal minimum (or large enough) sample size for most statistical analyses is n = 30. Naturally the processing of these samples and subsequent data entry required considerable time, effort and cost from the survey team with additional staff contracted in to undertake the data entry; it is likely that the number of shoots to process post-dive can be reduced without influencing the final mean values obtained per site. Since the number of leaves assessed for infection and epiphytes is not independent of the number of shoots, the optimisation of 'n' should apply to the number of shoots assessed per quadrat rather than the number of leaves.

Given that four separate beds were surveyed throughout the SAC, each potentially with their own unique environmental and anthropogenic influences, the optimal number to sample is examined per site. The 2,640 shoots sampled across the 166 quadrats gave an average count of 16 shoots per quadrat. However, the shoots were not equally distributed across quadrats or sample sites with the number of shoots per quadrat ranging from 0-70 throughout the SAC and the number of shoots sampled per site ranging from 95 at Cowes Harbour to 1,052 at Yarmouth. The impact of reducing the number of shoots sampled was investigated in two different ways:

- Minitab was used to randomly generate a sample of up to n = 250 shoot samples from each seagrass bed where two sample stations existed. Assuming an equitable distribution of the data, this would average five shoots per quadrat - still a very high 'n'. In reality the random sample was proportionate to the original distribution of the data meaning the total shoot samples per quadrat ranged between n = 1 and n = 21.
- To test the impact of a massive reduction in sample size (and the only sensible approach for the Cowes Harbour seagrass bed where very few shoots were sampled (n=95) compared with the other seagrass beds) a random sample of 30 shoots was generated for comparison with the full original sample data collected at each site.

The reduced data sets for each seagrass bed generated by these two selection processes were then compared to the original data per bed by means of either 2-tailed *T*-tests or Mann-Whitney tests (depending on sample size) to check for significant differences in mean shoot lengths, *Labyrinthula* sp. infection and epiphyte cover. The results for each site are presented below.

3.8.3.1 Cowes Harbour

The first approach to reducing the sample size from the Cowes seagrass bed to n_{max} = 20 was not applicable since only one quadrat yielded 24 shoots with all other <20 and the final sample size for comparison would have been n = 91 as opposed to the original n = 95.

Generation of a sample size of n = 30 provided a comparable data set. The non-parametric Mann-Whitney test was used to compare the median values as the data were not normally distributed and the sample size was too low as to permit the use of T-tests. Reduction of the overall sample size to n = 30 resulted in no significant differences compared with the original sample, between the median values of any of the three parameters measured Table 9.

Table 9. Mann-Whitney test comparisons of original survey samples to a reduced data set where n = 30 shoots for the whole Cowes Harbour seagrass site.

Parameter	n	Median	W-value	*p*-value
Longest leaf length	95	43.0	5979.0	0.975
	30	44.3		
Infection score	95	0.40	5742.0	0.158
	30	0.55		
Epiphyte score	95	2.00	6192.0	0.231
	30	2.00		

3.8.3.2 Yarmouth

Reduction of the sample sizes to n = 250 resulted in no significant differences in the mean longest leaf length, infection score or the mean epiphyte cover score per shoot (Table 10).

Table 10. T-test comparisons of original survey samples (n = 1,052) to a reduced data set where n = 250 for the Yarmouth seagrass survey sites.

Parameter	n	Mean	Stdev	SE	df	*T*-value	*p*-value
Longest leaf length	1,052	33.1	17.8	0.55	381	-0.92	0.356
	250	34.3	17.4	1.1			
Infection score	1,052	0.777	0.570	0.018	381	-0.24	0.811
	250	0.786	0.560	0.035			
Epiphyte score	1,052	0.853	0.617	0.019	370	-0.37	0.714
	250	0.870	0.631	0.040			

Reduction of the overall sample size to n = 30 again resulted in no significant differences compared with the original sample, between the median values of any of the three parameters measured Table 11.

Table 11. Mann-Whitney test comparisons of original survey samples to a reduced data set where n = 30 shoots for the Yarmouth seagrass survey sites.

Parameter	n	Median	W-value	*p*-value
Longest leaf length	1,052	30.25	568718.0	0.578
	30	33.00		
Infection score	1,052	0.75	568815.0	0.616
	30	0.75		
Epiphyte score	1,052	0.80	567990.0	0.322
	30	0.90		

3.8.3.3 Beaulieu

Reduction of the sample sizes to n = 250 resulted in no significant differences in the mean longest leaf length, infection score or the mean epiphyte cover score per shoot (Table 12).

Table 12. T-test comparisons of original survey samples (n = 571) to a reduced data set where n = 250 for the Beaulieu seagrass survey sites.

Parameter	n	Mean	Stdev	SE	df	*T*-value	*p*-value
Longest leaf length	571	35.9	14.6	0.61	483	-0.60	0.550
	250	36.5	14.2	0.91			
Infection score	571	1.133	0.646	0.027	498	-0.86	0.390
	250	1.173	0.612	0.039			
Epiphyte score	571	1.642	0.655	0.027	513	-0.48	0.630
	250	1.664	0.601	0.038			

Reduction of the overall sample size to n = 30 again resulted in no significant differences compared with the original sample, between the median values of any of the three parameters measured Table 13.

Table 13. Mann-Whitney test comparisons of original survey samples to a reduced data set where n = 30 shoots for the Beaulieu seagrass survey sites.

Parameter	n	Median	W-value	*p*-value
Longest leaf length	571	35.00	172209.0	0.715
	30	34.00		
Infection score	571	1.00	171816.5	0.953
	30	1.00		
Epiphyte score	571	1.66	171613.0	0.781
	30	1.75		

3.8.3.4 Osborne Bay

Reduction of the sample sizes to n = 250 resulted in no significant differences in the mean longest leaf length, infection score or the mean epiphyte cover score per shoot (Table 14).

Table 14. T-test comparisons of original survey samples (n = 571) to a reduced data set where n = 250 for the Osborne Bay seagrass survey sites.

Parameter	n	Mean	Stdev	SE	df	*T*-value	*p*-value
Longest leaf length	922	33.3	12.7	0.42	385	0.09	0.927
	250	33.2	13.1	0.83			
Infection score	922	0.643	0.526	0.017	402	-1.17	0.243
	250	0.600	0.514	0.032			
Epiphyte score	922	1.028	0.593	0.020	371	-0.81	0.418
	250	1.065	0.645	0.041			

Reduction of the overall sample size to n = 30 again resulted in no significant differences compared with the original sample, between the median values of any of the three parameters measured Table 15.

Table 15. Mann-Whitney test comparisons of original survey samples to a reduced data set where n = 30 shoots for the Osborne Bay seagrass survey sites.

Parameter	n	Median	W-value	*p*-value
Longest leaf length	922	32.50	439379.0	0.975
	30	33.00		
Infection score	922	0.57	440085.0	0.611
	30	0.40		
Epiphyte score	922	1.00	439369.5	0.981
	30	1.00		

Not only did the approach to reducing sample size to n = 250 or n = 30 result in no overall change to the population estimates of these parameters but the same patterns of spatial differences or similarities between the sites remained as apparent as with the original data where n = 2,640 (Figure 21).

When developing the index to assess and monitor wasting disease in *Zostera marina*, Burdick *et al*. (1993) suggested that "*for the population estimate to fall within 1 standard error of the mean of 20 shoots more than 95 % of the time, 14 shoots must be indexed*." Although they based this statement on the use of percentage data rather than the 0-5 scale, it is perhaps not surprising that sample sizes of either n = 250 or n = 30 were adequate in the present study to represent the parameters of leaf length, infection score and epiphyte cover score against the rigorously sampled 2021 data for the Solent seagrass beds.

For the approach of processing fewer shoot samples to be representative of the sites in subsequent surveys, all shoots would still need to be collected from each 0.0625 m^2 quadrat to avoid any sampling bias i.e. to avoid divers selecting only the larger, easier shoots to cut. Then, a random approach to shoot selection post-dive would need to be applied before length measurements and infection / epiphyte assessments are undertaken. The random selection of five shoots per quadrat sample would generate a total sample size somewhere between 900 and 1,000 shoots from a full week's survey. Although this remains a substantial sample size it would leave an easily achievable maximum of 40-45 shoots to process per sampling site per diver pair post dive which this exercise demonstrates would still provide a valid representation of the plants present in each bed. Further benefits include divers being less fatigued each day and substantial cost savings can be made via reductions in data entry and sample processing.

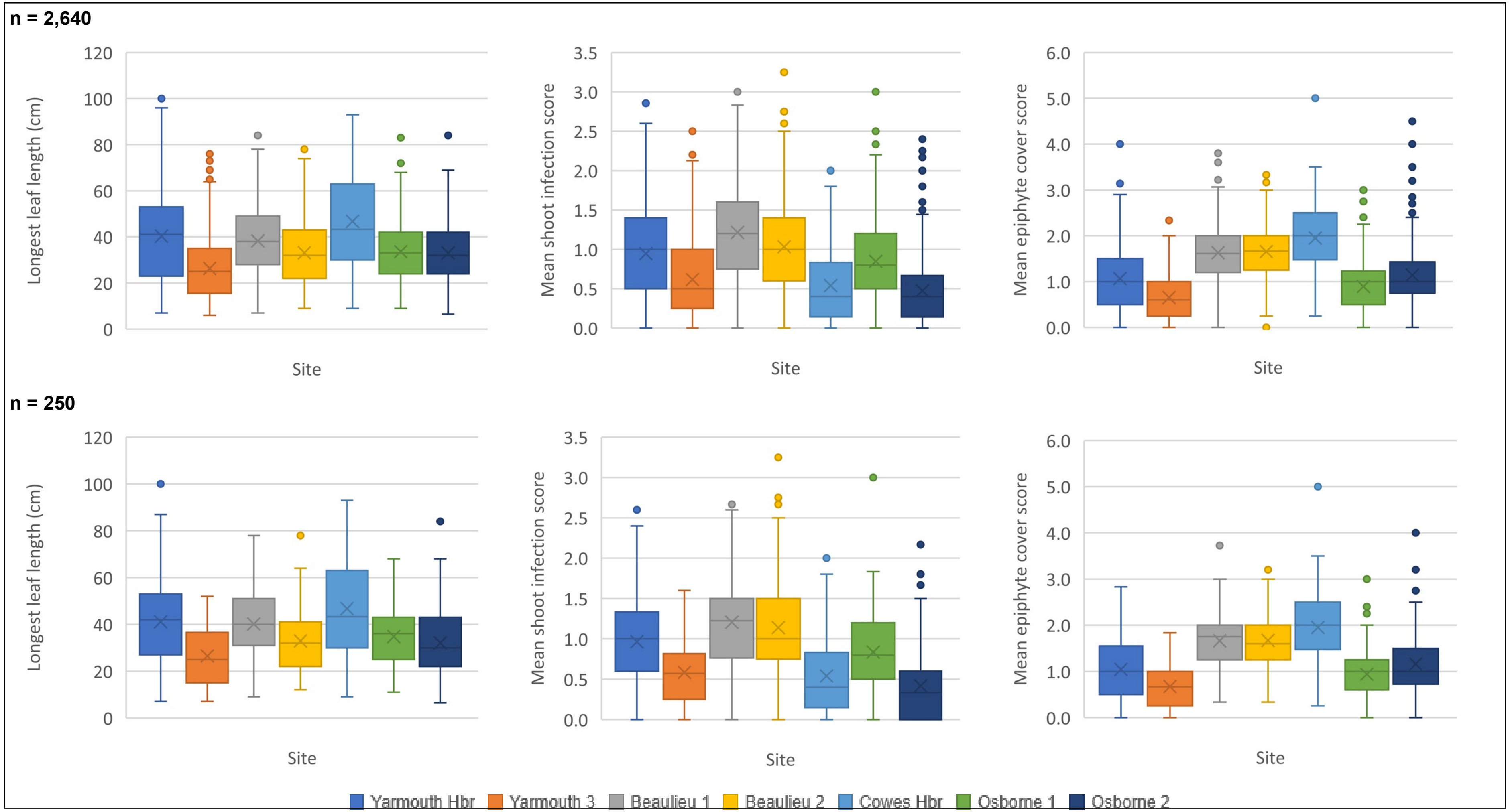

Figure 21. Boxplots of longest leaf lengths per shoot, mean shoot infection scores and mean epiphyte cover scores across all seven sampling sites in The Solent Maritime SAC in June 2021. Top plots show data for all shoots processed (n = 2,640). Lower plots show data for a randomised subsample (n = 250, except Cowes Harbour (blue) which remained at n = 95) from the original data collected, showing near identical values across the sites to the data above. Boxes show mean (x), median (-), interquartile ranges (boxes), whiskers and outliers.

4 Condition assessment

The last formal condition assessment for the Solent Maritime SAC was undertaken by Natural England in June 2018. The condition at that time for of the subtidal seagrass beds sub-feature within the feature: *Sandbanks which are slightly covered by sea water all the time* of the Solent Maritime SAC was considered to be **'Unfavourable – unknown'.**

As part of this report the authors were asked to make any comments regarding their assessment on the condition of the 'subtidal seagrass beds' sub-feature of the SAC, based on the following attribute targets:

Designated feature: **Sandbanks which are slightly covered by sea water all the time**	**Attribute**	**Conservation Objective**
Sub-feature: Subtidal seagrass beds *Zostera marina/angustifolia* beds on lower shore or infralittoral clean or muddy sand	Extent: presence and spatial distribution. Structure and function: quality and composition[1] of characteristic biological communities[2] including diversity and abundance of species forming part of or inhabiting the habitat. Represented by species composition of characteristic biotope SS.SMp.SSgr.Zmar.	Maintain in or bring into favourable condition. Where favourable condition means: **Extent** is stable or increasing. **Structure and functions**, quality and biological community composition are sufficient to ensure that its condition remains healthy and does not deteriorate Maintain species composition - presence and abundance of composite species should not deviate significantly from baseline.
	Structure: rhizome structure and reproduction	Restore the extent and structure of the rhizome mats across the site, and conditions to allow for regeneration of seagrass beds.

Designated feature: **Sandbanks which are slightly covered by sea water all the time**	Attribute	Conservation Objective
	Structure: biomass	Restore the leaf / shoot density, length, percentage cover, and rhizome mat across the sub-feature at natural levels (as far as possible), to ensure a healthy, resilient habitat.
	Structure: non-native species and pathogens (habitat)	Reduce the introduction and spread of non-native species and pathogens, and their impacts.

[1] Species composition of communities includes a consideration of both the overall range of species present within the community, as well as their relative abundance. Species considered need not be restricted to sessile benthic species but could include mobile species associated with the benthos. Species composition could be altered by human activities without changing the overall community type. Within each component community, species composition and population structure should be taken into consideration to avoid diminishing biodiversity and affecting ecosystem functioning within the habitat (JNCC 2004).

[2] For the purpose of assessing the condition of the seagrass feature, the 'communities' are described as biotopes using the Marine Habitat Classification (Connor et al., 2004).

As previously stated in the report, no statistically comparable data sets exist for the seagrass beds of the Solent Maritime SAC, consequently comparisons with previous work have been qualitative in nature. However, it is considered the seagrass bed extent data collected by the Environment Agency in 2018 and 2020 (Green, 2019; Kenworthy, 2021) and the data from the 2021 survey provide two sets of baseline data against which quantitative comparisons can be made in future to determine any changes in habitat and community parameters over time.

4.1.1 Anthropogenic impacts

As stated in Section 3.7 there was no confirmed evidence of anthropogenic impacts recorded within the Solent Maritime SAC seagrass beds in June 2021. However, there was suspected evidence of anchor scars at Yarmouth 3, indicated by sediment disturbance and shown in images in Appendix A for 'Yarmouth 3' site. Nonetheless, the limited spatial extent of the present surveys in often very large seagrass beds should be considered i.e. the lack of evidence form the present surveys should not be extrapolated to suggest there are no impacts throughout the wider seagrass beds.

It is noted that the 2018 NE condition assessment states "*There is no turbidity data and we are using Environment Agency WFD classifications as a proxy for dissolved oxygen and nutrient levels. There is also limited sediment contaminant* *level data."* In Section 5.4 the authors discuss that to aid interpretation of any biological survey data it is important to establish continuous measures of water quality and turbidity that will be influencing the condition of the beds. This would also extend to establishing and measuring sediment contamination levels and monitoring physical impacts e.g. anchoring activity.

4.1.2 Extent: presence and spatial distribution of seagrass bed habitats

Notable community: *Zostera marina*, seagrass beds - SS.SMp.SSgr.Zmar

Feature target: Restore the total extent and spatial distribution of seagrass beds.

Feature outcome: Extent should be stable or increasing

Monitoring of the extent and distribution of the seagrass beds within the Solent Maritime SAC was not an aim of the 2021 diving surveys. Extent and distribution were last monitored and reported by the Environment Agency in 2018 and 2020 (Green, 2019; Kenworthy 2021). Section 3.1 describes the present knowledge and evidence base for the spatial extent of the seagrass within the Solent Maritime SAC.

The authors do not feel it is possible at this stage to make any judgement based on quantitative evidence as to whether or not the extent and distribution of the seagrass beds within the Solent Maritime SAC have been maintained or are declining or increasing.

4.1.3 Structure and function: biomass, rhizome structure and reproduction

Notable community: *Zostera marina*, seagrass beds - SS.SMp.SSgr.Zmar

Feature target: Restore the leaf / shoot density, length, percentage cover, and rhizome mat across the sub-feature at natural levels (as far as possible), to ensure a healthy, resilient habitat. Restore the extent and structure of the rhizome mats across the site, and conditions to allow for regeneration of seagrass beds.

Feature outcome: Structure, functions and quality are sufficient to ensure its condition remains healthy and does not deteriorate.

Density and percent cover values from previous surveys cannot be compared statistically due to the different methods used. Considering this, the values cited between surveys are broadly in range with the current study, suggesting that the overall density / percent cover of the seagrass, where it occurs, has not changed significantly and has likely been maintained. Further surveys would be required to determine trends in data either way and give higher confidence to this assertion which cannot currently be supported with statistical evidence.

Data on algal cover and leaf length compared favourably with that from previous surveys, albeit using different survey methods. No historical site data were available to make comparisons for infection levels and the number of flowering plants. Rhizome structure was not assessed as part of this survey. Nonetheless, the overall feel for the seagrass beds' health, structure and function appeared good. The level of *Labyrinthula zosterae* infection on shoots was low as were the levels of epiphytic growth.

4.1.4 Structure and function: species composition of component communities

Notable community: *Zostera marina*, seagrass bed biological community

Feature target: Maintain the community composition

Feature outcome: Composition of the characteristic biological communities (including diversity and abundance of species forming part or inhabiting the habitat) are sufficient to ensure that its condition remains healthy and does not deteriorate.

The biological community composition was not recorded in during the 2021 survey and the 2018 NE condition assessment notes there is a lack of evidence to assess this attribute. A review of Seasearch data might provide some reliable information on the communities depending on the dates and locations of records.

4.1.5 Structure and function: non-native species throughout the SAC

Attribute: Structure: non-native species and pathogens (habitat)

Target: Reduce the introduction and spread of non-native species and pathogens, and their impacts.

Supporting notes: Non-native species may become invasive and displace native organisms by preying on them or out-competing them for resources such as food, space or both. In some cases this has led to the loss of indigenous species from certain areas (JNCC, 2004). A pathogen causes disease or illness to its host. Pathogens include bacteria, viruses, protozoa and fungi.

Site-specifics:

The non-native species (NNS) recorded during the 2021 surveys of the Solent Maritime SAC were the slipper limpet, *Crepidula fornicata*, wireweed, *Sargassum muticum* and a sea squirt, *Botrylloides* sp. (see notes in Section 3.6). Quantitative records were not made so only their presence was recorded but it was noted that the presence of non-native species across all the sites was generally low, the exception being *S. muticum* at Yarmouth Harbour which was noted as being locally abundant in the survey area. *C. fornicata* were recorded from three sites (Beaulieu 1, Yarmouth 3 and Osborne 1 and 2); *Botrylloides* sp. was recorded from two sites (Yarmouth 3 and Osborne 1), and *S. muticum* was recorded from three sites (Yarmouth Harbour and Yarmouth 3 and Osborne 1).

The 2018 NE condition assessment notes *there are several records of non-native species across the SAC. Currently these do not appear to be having an adverse* *effect on communities present although their continued introduction and subsequent spread should be monitored. The threat of introduction or spread of invasive non- indigenous species (INIS) remains.* Based on the available evidence from the 2021 survey, the authors would concur with this.

5 Conclusions

5.1 Extent and distribution

Measuring the extent and distribution of the seagrass beds was not within the remit of the 2021 survey. Review of the available data suggests little discernible change has occurred in any of the beds, but firm conclusions are compromised by the variation and timing of historical survey methods.

5.2 Seagrass bed structure

Owing to the different sampling methods, extents and survey seasons, comparisons cannot be made with percentage cover values or shoot densities for any of the beds cited in Marsden & Scott (2015), Green (2019) and Kenworthy (2021). The same issue was noted by Green (2019).

The 2021 data show patchy cover and variable densities of seagrass within the known beds in the SAC. The data by site and overall for cover and density and, for leaf length and health are summarised in Table 4 and Table 5 in Sections 3.2.4 and 3.3.1 respectively. Whilst it is difficult to infer the reasons for the differences observed between beds at different sites, we can summarise the main findings for each bed from the 2021 data.

5.2.1 Cowes Harbour

Cowes Harbour recorded the **lowest % cover of seagrass** at 26 %, and only 59 shoots per m^2 but also an equally **low % cover of algae** of 4.2 %, the lowest of all sites. However, it had the **longest mean leaf lengths** overall with mean lengths of 46.4 cm, despite this site having the lowest overall density of seagrass. Both Cowes Harbour and Yarmouth Harbour had the greatest range of leaf lengths, from 7-9 cm to in excess of 90 cm. Mean leaf infection scores were joint lowest with Osborne 2 at 0.4, whilst the overall mean epiphyte score was the highest at 2.0.

5.2.2 Yarmouth

Yarmouth was marginally deeper than the other sites at 0.7/0.8 m BCD. It may also be afforded slightly more shelter from most directions. Yarmouth Harbour recorded the **greatest % cover of seagrass** at 69 % but also significantly **higher % cover of algae** within the beds at 26-48%. With the greatest % cover of seagrass Yarmouth Harbour also recorded the **highest mean shoot density** of 342 shoots per m^2 and also the **single longest leaf** at 100 cm. In contrast, Yarmouth 3 had a mean shoot count of just 229 shoots per m^2 and the longest leaf length of only 76 cm.

Excluding outliers, both Yarmouth Harbour and Cowes Harbour had the greatest range of leaf lengths, from 7-9 cm to in excess of 90 cm. Overall mean infection scores at the Yarmouth sites were 0.5 and 1.0 and fell within the means of the other sites, whilst mean epiphyte cover scores were relatively low compared to the other sites at 0.6 and 1.0.

5.2.3 Beaulieu

Overall the Beaulieu sites showed least variability in both % cover of *Zostera* and shoot density. **Shoot density** was recorded in a mid-range of 151 – 162 shoots per m^2 at both Beaulieu sites, where the overall range within the SAC in 2021 was 59 – 342 shoots per m^2. Mean **% *Zostera* cover** ranged from 39 – 40% whilst mean **% algal cover** was 10-15% (within the ranges recorded at other sites).

Excluding outliers, the Beaulieu sites had leaf lengths ranging from 7 to 78 cm. The *Zostera* at Beaulieu sites had the highest mean infection scores of 1.0 to 1.2 and the second highest epiphyte scores of 1.6 to 1.7.

5.2.4 Osborne Bay

Osborne sites 1 and 2, southeast of Cowes Harbour, yielded comparable results with **% seagrass cover** of 54 – 55% and **mean shoot counts** of 250 – 260 shoots per m^2. **Algal % cover** was ~17% at both sites and overall the sites had the lowest mean **longest leaf length** of 33 – 34 cm.

Excluding outliers, the Osborne sites had leaf lengths ranging from 7 to 69 cm. The mean infection scores were among lowest of all the sites at 0.4 – 0.8 whilst the mean epiphyte score was 1.0 at both sites.

5.2.5 Community composition

Seagrass community taxa were not recorded quantitatively during the survey but the presence of several species was noted either from *in situ* records or from analysis of photographs (see Sections 3.4 to 3.6).

- Invertebrate eggs of various mollusc and polychaete species were recorded on seagrass leaves.
- One short-snouted seahorse *Hippocampus hippocampus* was recorded.
- Non-native species observed during the survey work included slipper limpets *Crepidula fornicata*, a colonial sea squirt *Botrylloides* sp. and wireweed *Sargassum muticum.* Quantitative assessments were not made but *S. muticum* was noted as being abundant at the Yarmouth Harbour site.

In conclusion, the 2021 survey data provide a statistically robust dataset for assessing some of the attributes of the seagrass beds in the Solent Maritime SAC. Repeatable data collection methods for percentage cover of seagrass beds and shoot density are established and some differentiation between the beds is evident. The point data collected here correspond well with the extent and distribution data for the seagrass beds, as described in Green (2019) and Kenworthy (2021).

The 2021 data show a patchy distribution and variable density of seagrass within the known beds in the SAC. This should be interpreted in context of the localised sampling method, not a systematic grid covering the entire beds which would not be possible with the survey effort required for *in situ* sampling. The health of the beds can only be gauged from the epifaunal leaf cover and *Labyrinthula zosterae* infection both of which were found to be low for all sites, indicating the *Zostera* plants to be in good health. Green (2019) noted that in 2018 high epiphyte cover was observed on the seagrass shoots, particularly in dense beds, and around Yarmouth Harbour; this was not substantiated by the 2021 data, albeit covering a far lesser extent of the bed than Green (2019).

Whilst there was no obvious visual evidence of anthropogenic impacts it was thought that disturbance observed at 'Yarmouth 3' could be attributable to anchor damage. Again, the localised nature of the survey sites did not give a systematic view of each entire bed, being designed specifically to provide statistically robust data on the identified attributes of percentage cover, shoot density, length, health etc. Any observation of impacts was incidental.

5.3 Effectiveness of data collection methods and technical equipment

One of the aims of the survey was to validate the sample design/intensity through post-survey power analysis. In 2021, 166 quadrats were sampled from the seven sites, 2,640 shoots were measured and 12,829 leaves were assessed for epiphyte cover and *Labyrinthula zosterae* infection. The post-survey processing and measuring took considerable time for surveyors each evening during the week whilst data entry tasks carried over post-survey.

Power analysis, in section 3.8, suggests sampling effort in the field should be maintained, collecting all shoots from each 0.0625 m^2 quadrat to avoid any sampling bias but reducing post-dive shoot processing considerably to just five shoots per quadrat. This approach will still provide a valid representation of each seagrass bed whilst benefitting divers in the field and reducing overall project costs.

As discussed, the 2021 survey design provides a baseline from which statistical analysis of future surveys may show changes in shoot density. However, these data alone do not provide information on expansion or contraction of the overall bed, particularly given that only one or two monitoring sites are sampled per bed, based on the known presence of seagrass; extrapolation of these data to represent and draw conclusions for an entire bed would not be appropriate. Monitoring of the bed extent and boundary by remote methods such as drop camera or multibeam methods is likely to provide the best indication of this parameter. The combination of the two monitoring approaches would provide a statistically powerful method for detecting and evidencing changes.

The in-water work during the survey was straightforward and the equipment required for the tasks was practical to use. Pre-dive briefings for each dive pair and careful preparation of sample bags and distance / bearing information meant each diver pair could complete their tasks easily and without error.

5.4 Future Survey Recommendations

- The historical seagrass data for the Solent Maritime SAC encompasses a broad range of survey methods, spatial scales and seasonality meaning no quantitative comparisons can reliably be made. A repetitive, quantitative, prescriptive monitoring programme needs to be instigated to really be able to understand any changes that are occurring within the seagrass beds of the SAC. The authors acknowledge that this project aims to address this issue.

- The quantitative data collected in the present survey provide a solid baseline against which future surveys can be compared assuming that the methods and sites used here are repeated. Interpretation of any comparison with future surveys would be aided by repeated extent surveys such as that by Green (2019).

- In order to interpret any changes observed in future survey data it is important to establish continuous measures of environmental parameters such as temperature, water quality and turbidity that will be influencing the condition of the seagrass beds.

- Similarly, measures of anthropogenic influence would also assist in the interpretation of any observed changes indicated by survey data. For example, enhanced monitoring of anchoring activity either shore-based or with drones would quantify activity levels over a summer season, which the authors are aware is being conducted as part of this project. If water clarity permitted it, drones could be used to monitor anchor scars, or they may need specific surveys by divers. The 2021 methodology only reports on incidentally observed sediment disturbance which cannot be attributed to or quantified against any particular impact.

- The species within the seagrass community were not recorded as part of the 2021 methodology due to poor visibility and / or limited time. Collecting quantitative community species data would provide further evidence for the community structure and function of the seagrass beds. Seasearch data might be applicable for this purpose if it has been collected near to the survey sites in recent years.

- Alongside monitoring the attributes of the seagrass beds, Natural England should continue to monitor any changes from management measures, to assess by 2023 whether there is evidence of:
    - Less anchoring;
    - Fewer anthropogenic impacts;
    - Successful seagrass bed restoration; and / or
    - Expansion or contraction of seagrass beds.

6 References

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Appendices

Appendix A – Site Descriptions

Description of the habitats/biotopes monitored

The Solent Maritime SAC is a complex site which encompasses a major estuarine system and fully marine habitats with an unusual tidal regime which includes double tides and long periods of slack water at both high and low tide. The SAC includes one of the only major, sheltered channels in Europe, lying between a substantial island (the Isle of Wight) and the mainland. Sediment habitats within the site include subtidal sandbanks and extensive areas of intertidal mudflats and sandflats, which often support eelgrass (*Zostera* species).

All the sites surveyed represented the *Zostera* biotope: SS.SMp.SSgr.Zmar *Zostera marina*/*angustifolia* beds on lower shore or infralittoral clean or muddy sand (JNCC, 2015).

The following sections provide summaries of each site comprised of various observation made by the surveyors during the field surveys.

Survey Sites, 2021

Survey stations were identified prior to the survey based on a range of depths and anticipated seagrass densities, the latter based on Environment Agency (EA) echosounder and drop camera survey data collected in 2018 (Green, 2019) and 2020 (Kenworthy, 2021). The exact sites surveyed during the field work week were dependent on the prevailing conditions i.e. weather, tides, vessel activity. From the central point, on which the shot was dropped, lines radiated out on randomised bearings and distances (up to a maximum of 30m from the centre) at which point the quadrat was placed. A total of 25 quadrats were sampled at each ‘station’ (radial sample area).

Site name / no.	Latitude (WGS84)	Longitude (WGS84)
Yarmouth Harbour	50° 42.453'N	1° 30.280'W
Yarmouth 3	50° 42.579'N	1° 28.796'W
Beaulieu 1	50° 46.693'N	1° 22.016'W
Beaulieu 2	50° 46.786'N	1° 21.874'W
Cowes Harbour	50° 46.045'N	1° 17.052'W
Osborne 1	50° 45.740'N	1° 15.765'W
Osborne 2	50° 45.508'N	1° 15.346'W

Yarmouth Harbour, 16th June 2021

- The site is situated ~150 m west of the entrance to Yarmouth Harbour in an area of dense *Zostera marina* providing 30-100% cover over a thin sand layer atop a piddock-bored blue clay. A surface chalk fraction was also recorded. 0.2 – 1.2 m BCD.
- One surveyor reported anchor scars but there is no direct evidence to demonstrate this.
- The non-native alga *Sargassum muticum* was abundant. Dead slipper limpet shells, *Crepidula fornicata* were evident in images from the survey.
- Small spider crabs, *Maja brachydactyla* were common. The fan worm, *Sabella pavonina* was recorded as ‘present’ amongst the seagrass.

Figure 22. Fragments of ‘blue clay’ amongst the seagrass at Yarmouth Harbour. Video Screen grab.

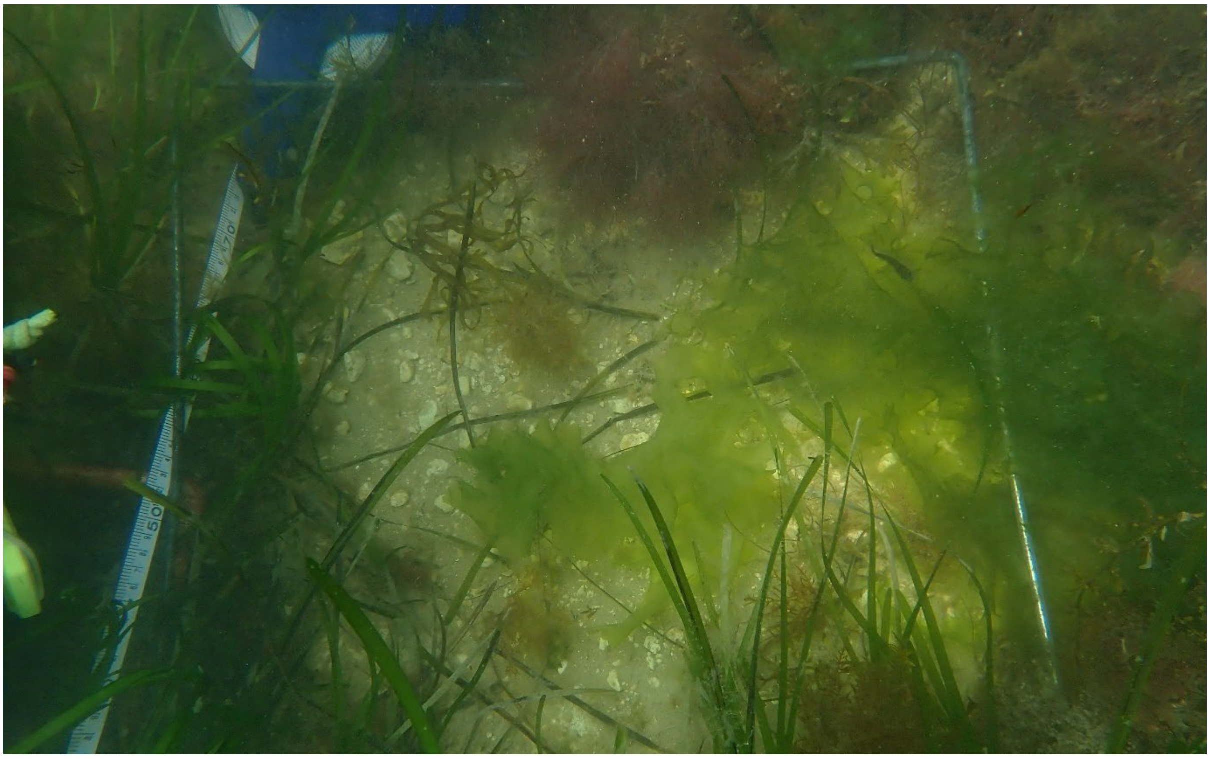

Figure 23. Fragments of chalk mixed with sand within a quadrat at Yarmouth Harbour.

Figure 24. The non-native alga Sargassum muticum among the seagrass at the Yarmouth Harbour site, June 2021.

Yarmouth 3, 17th June 2021

- The site is situated ~1.4 km E of Yarmouth Pier head toward Bouldnor Cliffs in an area of fairly dense *Zostera marina* providing 10-80% cover over a thin sand / sandy muddy layer also atop a piddock-bored grey-blue clay slope, becoming piddock-bored brown/black hard clay. 0.5 – 1.3 m BCD.
- The non-native alga *Sargassum muticum* was noted occasionally as were slipper limpets, *Crepidula fornicata*.
- A small specimen of the non-native alga *Grateloupia turuturu* was recorded ‘tangled’ with other algae and was considered likely to be drift weed rather than colonising the seagrass. This species is more often associated with pontoons in the UK, although has been shown to have started to colonise shores in the Solent.
- Seabed disturbance was noticeable due to the exposure of the bedrock/clay. The cause of this was unknown.

Figure 25. Disturbance of seabed sediments (yellow oval) at site Yarmouth 3, June 2021, cause unknown.

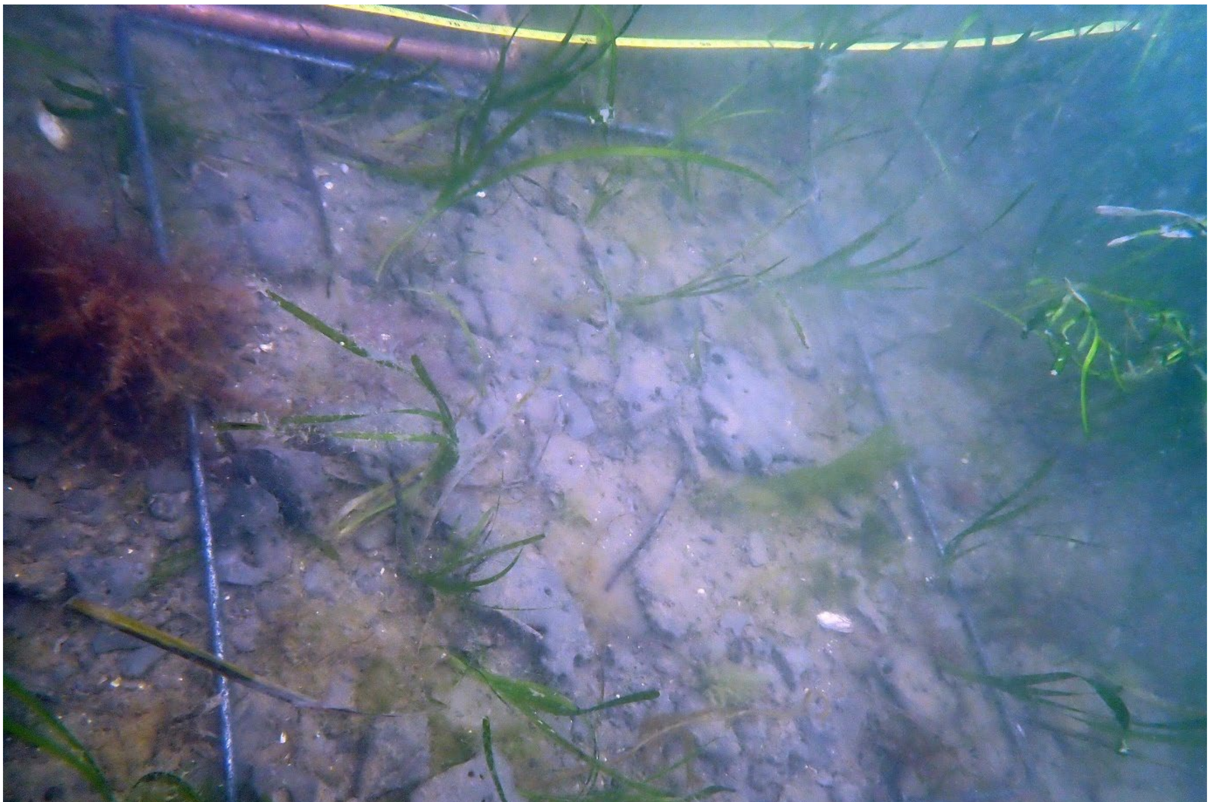

Figure 26. Exposed lumps of piddock-bored grey-blue clay in quadrat at site Yarmouth 3, June 2021.

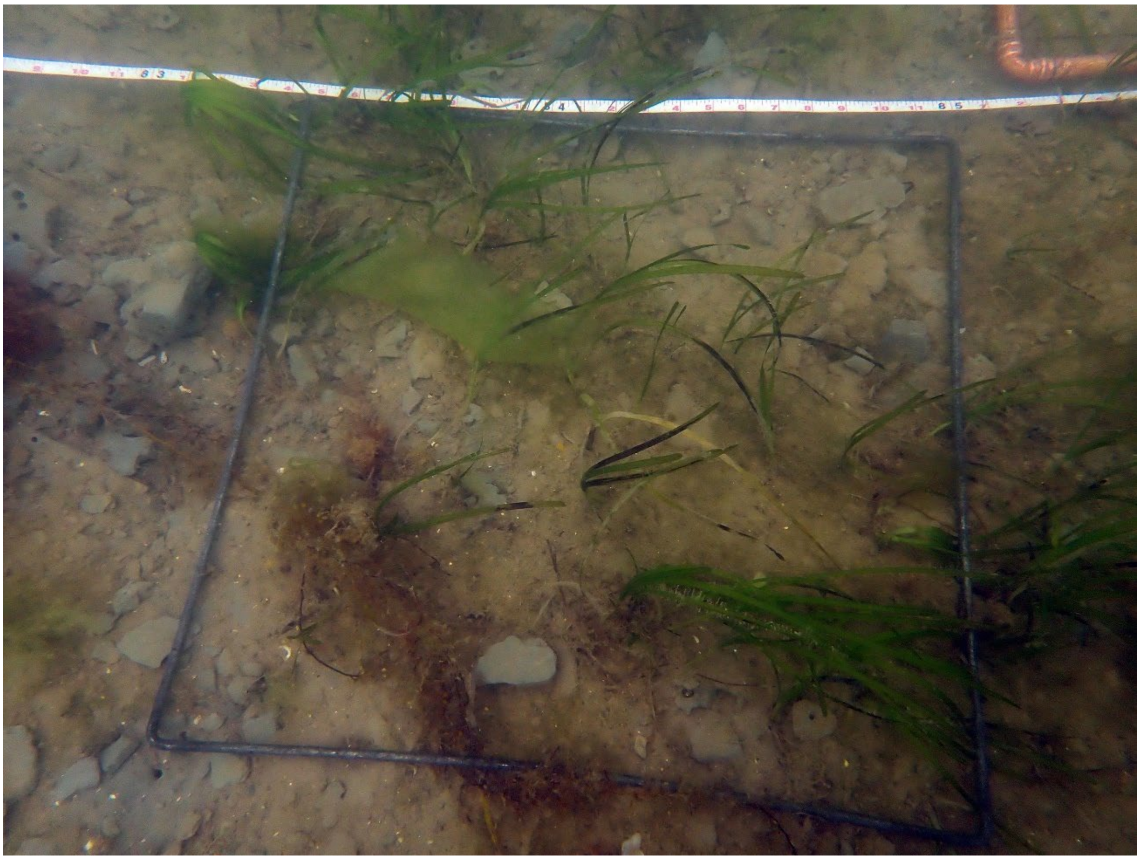

Figure 27. Exposed lumps of piddock-bored grey-blue clay in quadrat at site Yarmouth 3, June 2021.

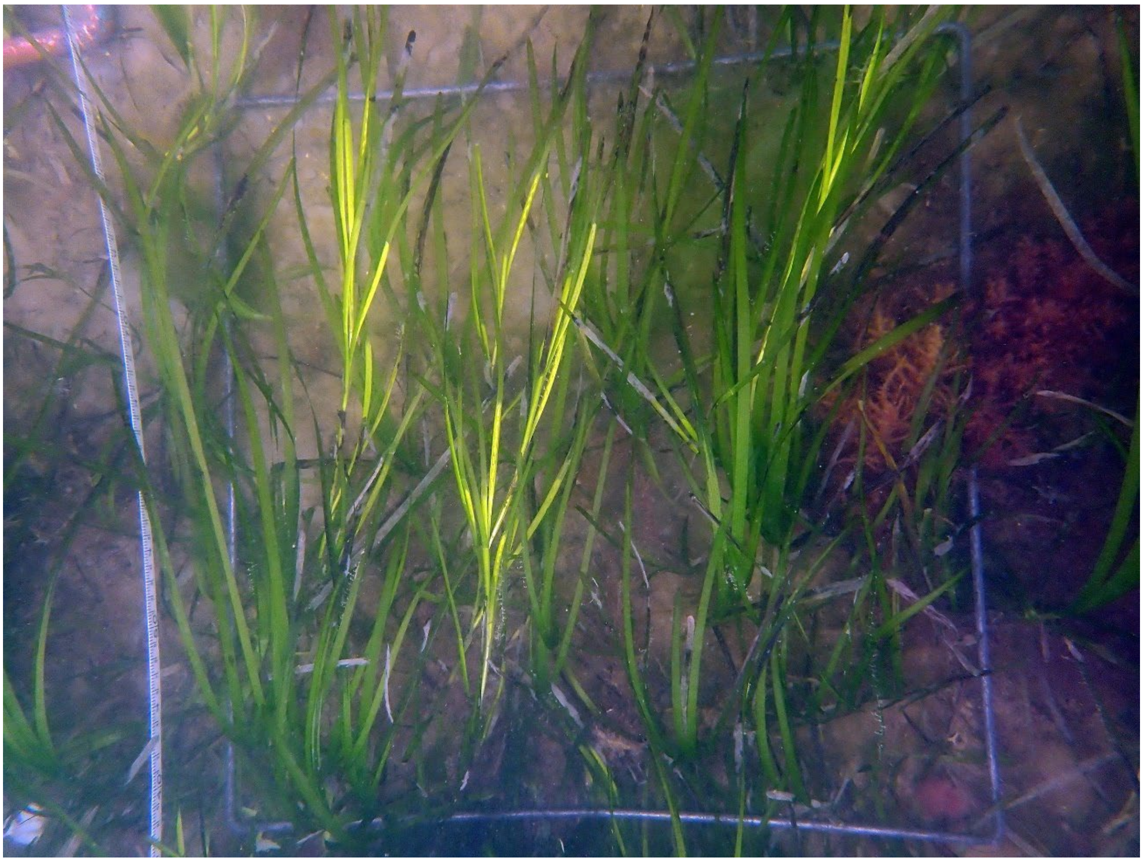

Figure 28. Flowering shoots in a quadrat at site Yarmouth 3, June 2021.

Beaulieu 1, 16th June 2021

- Beaulieu has a tidal river, navigable by small craft with a marina at Bucklers Hard. The seagrass beds are located at the mouth of the river ~1 km from Gull Island.
- The site is situated just SW of the mouth of the Beaulieu River and supports a relatively low mean density of *Zostera marina* compared to the Yarmouth and Osborne sites with patchy 20-70% cover but dense in places. The seagrass bed was over a substrate of sand and muddy sand with a shell / cobble fraction (not quantified). -0.1 – 1.3 m BCD.
- A large steel cable was observed lying on the seabed across the site with evidence of scour caused by currents flowing over it. This had led to the exposure of cobbles beneath the surface sediments upon which coralline algae and snakelock anemones *Anemonia viridis* were growing.
- The non-native slipper limpets, *Crepidula fornicata* were recorded at this site.
- Other flora and fauna observed included snakelock anemones, small tunicates *Polycarpa* sp. and various short filamentous, foliose and cartilaginous red algae.

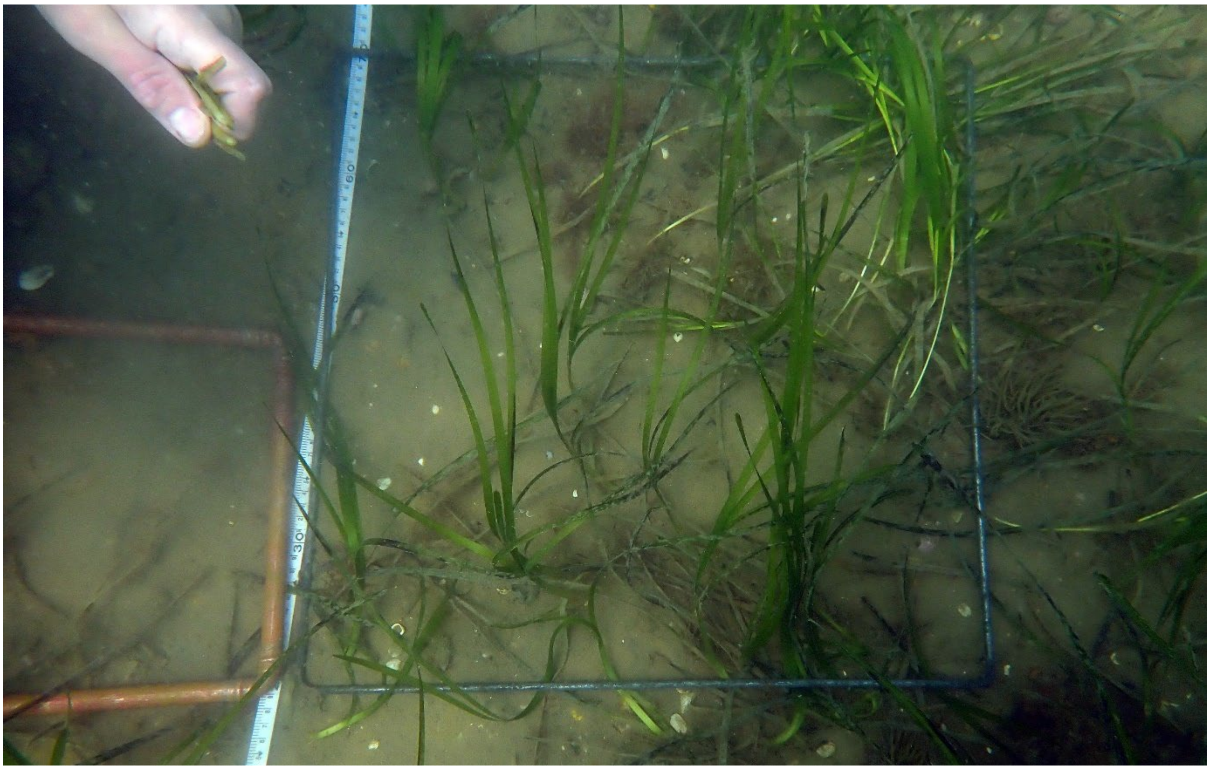

Figure 29. Survey quadrats at site Beaulieu 1, June 2021. Flowering plants are visible in the top left of the main quadrat.

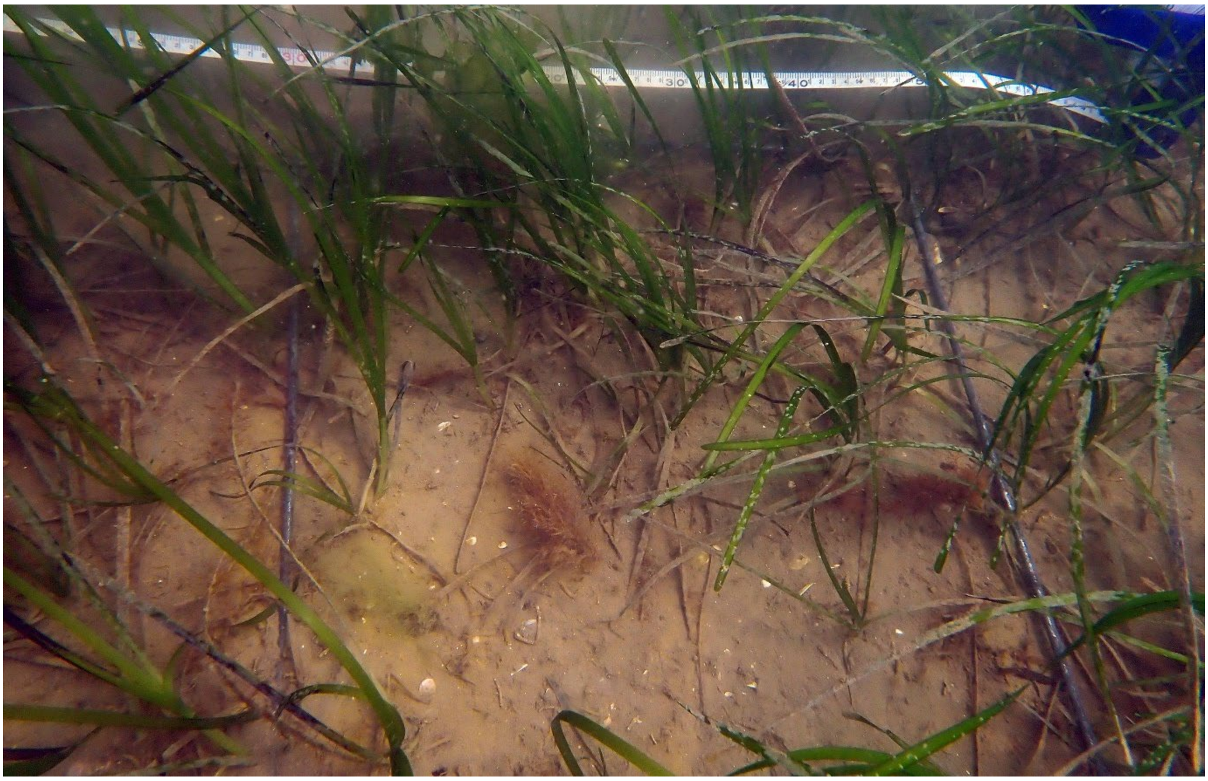

Figure 30. Survey quadrat at site Beaulieu 1, June 2021 with sparse seagrass and algae and exposed muddy sand.

Figure 32. Survey quadrat at site Beaulieu 1, June 2021 with dense seagrass and occasional flowering plants.

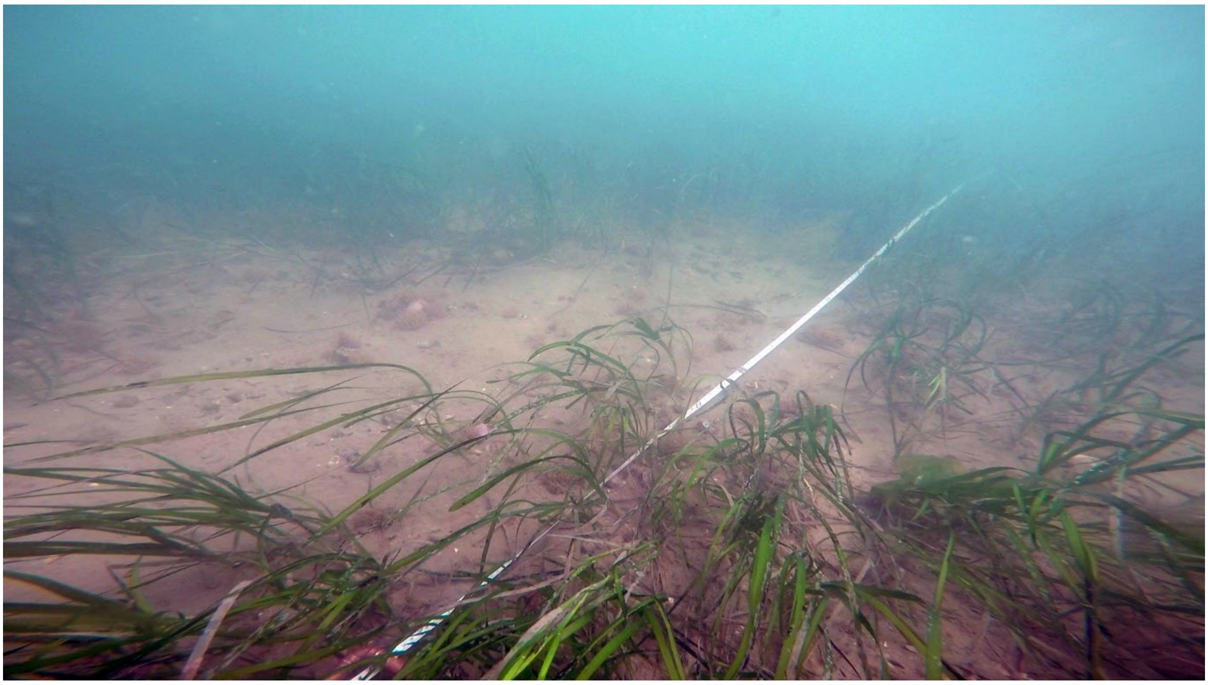

Figure 32. Patchy distribution of seagrass at site Beaulieu 1, June 2021. Video screen grab.

Figure 33. Steel cable observed at site Beaulieu 1, June 2021. Video screen grab.

Beaulieu 2, 18th June 2021

- The site is situated just south of the mouth of the Beaulieu River and supports a relatively low mean density of *Zostera marina* compared to the Yarmouth and Osborne sites with patchy 15-60% cover but dense in places. The seagrass bed was over a substrate of sand and muddy sand. -0.1 – 0.7 m BCD.
- No non-native species were recorded at the site.
- Other flora and fauna observed included spider crabs, *Macropodia* sp. and various short filamentous, foliose and cartilaginous red algae and the green alga, *Ulva* sp.

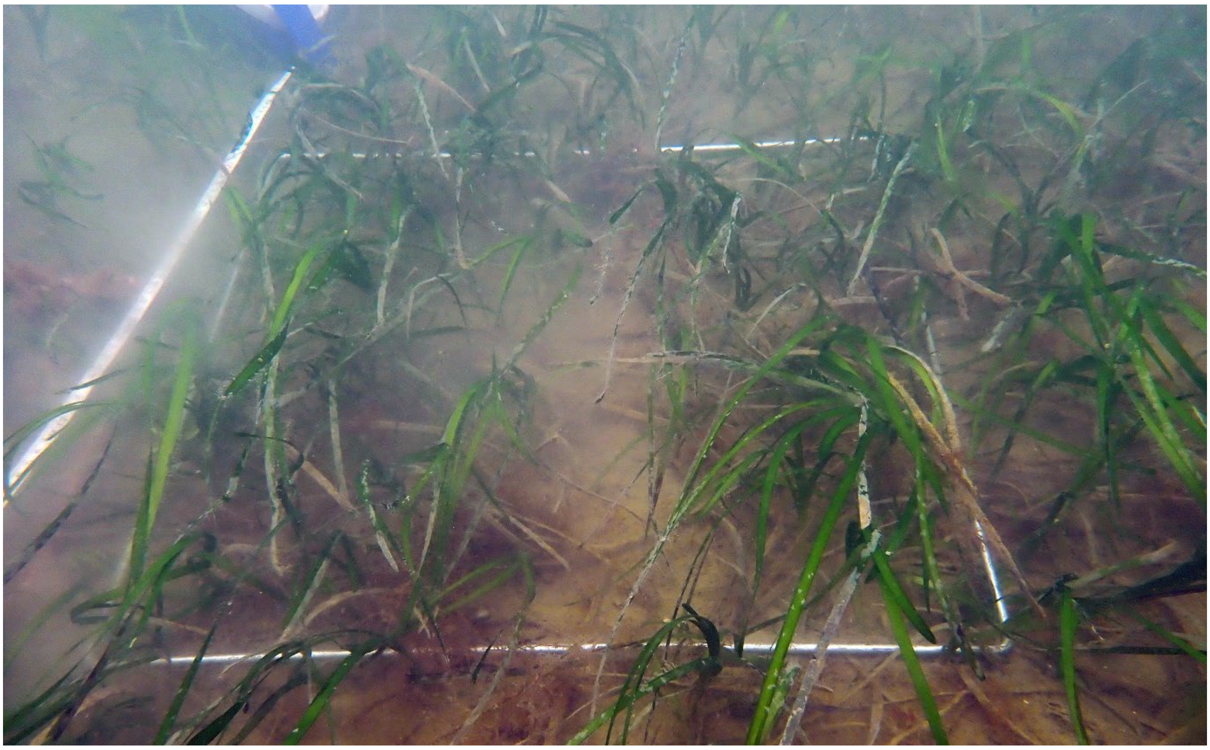

Figure 34. Survey quadrat at site Beaulieu 2, June 2021 with short, less dense seagrass and occasional red algae.

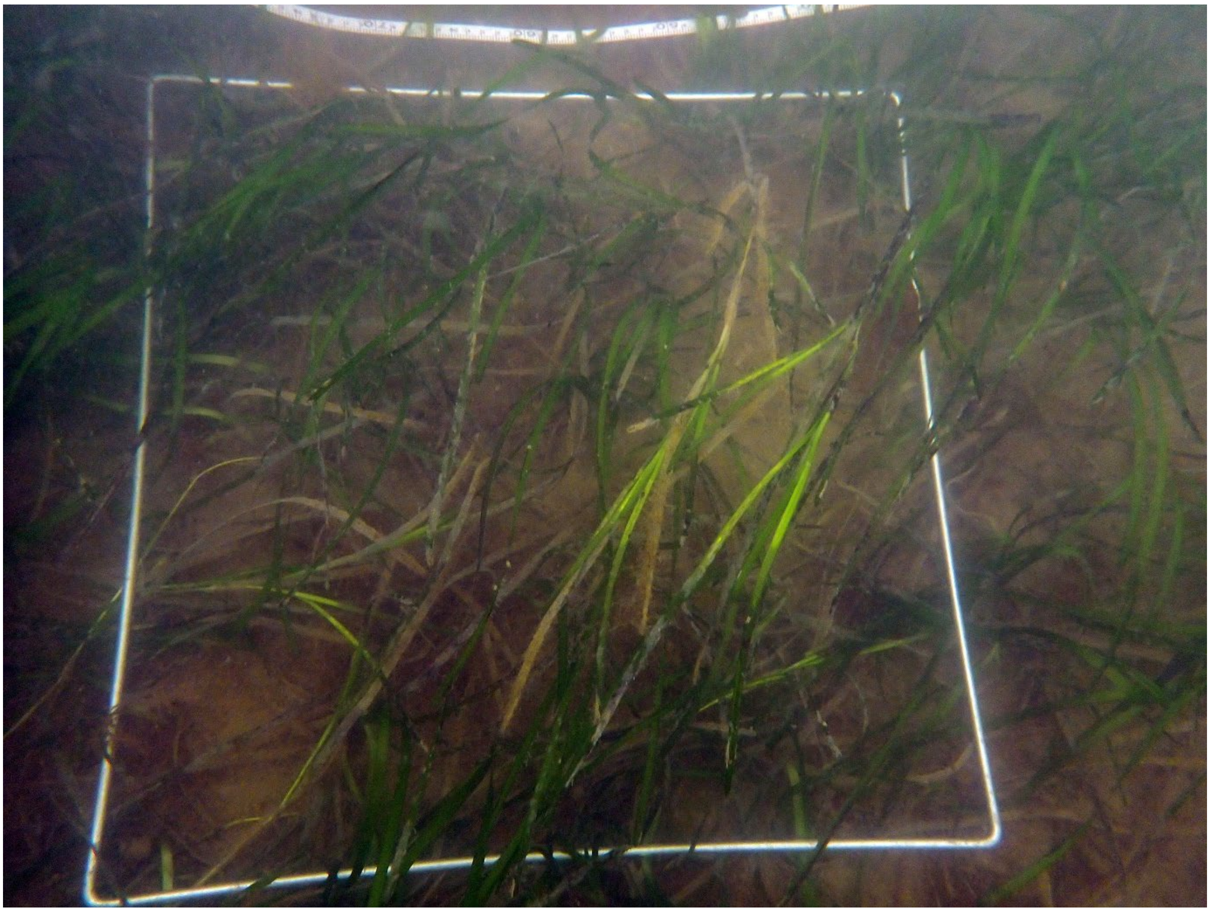

Figure 35. Survey quadrat at site Beaulieu 2, June 2021 with denser seagrass than above and occasional flowering plants.

Cowes Harbour, 17th June 2021

- On the north coast of the Isle of Wight, Cowes is a busy industrial, commercial and recreational sailing port with the seagrass beds located adjacent to the breakwater.
- The survey site was situated ~600 m NE of the harbour entrance and supported the lowest mean density seagrass of all the sites monitored. The bed was patchy with seagrass providing cover ranging from 0-100%.
- *Zostera* was long and luxuriant.
- The substrate was soft, muddy sand. 0.0 – 0.6 m BCD.
- Visibility declined significantly after four quadrats, likely owing to the soft sediments combined with an onshore breeze. All divers aborted before completing their quadrats.
- No non-native species were recorded from the site.

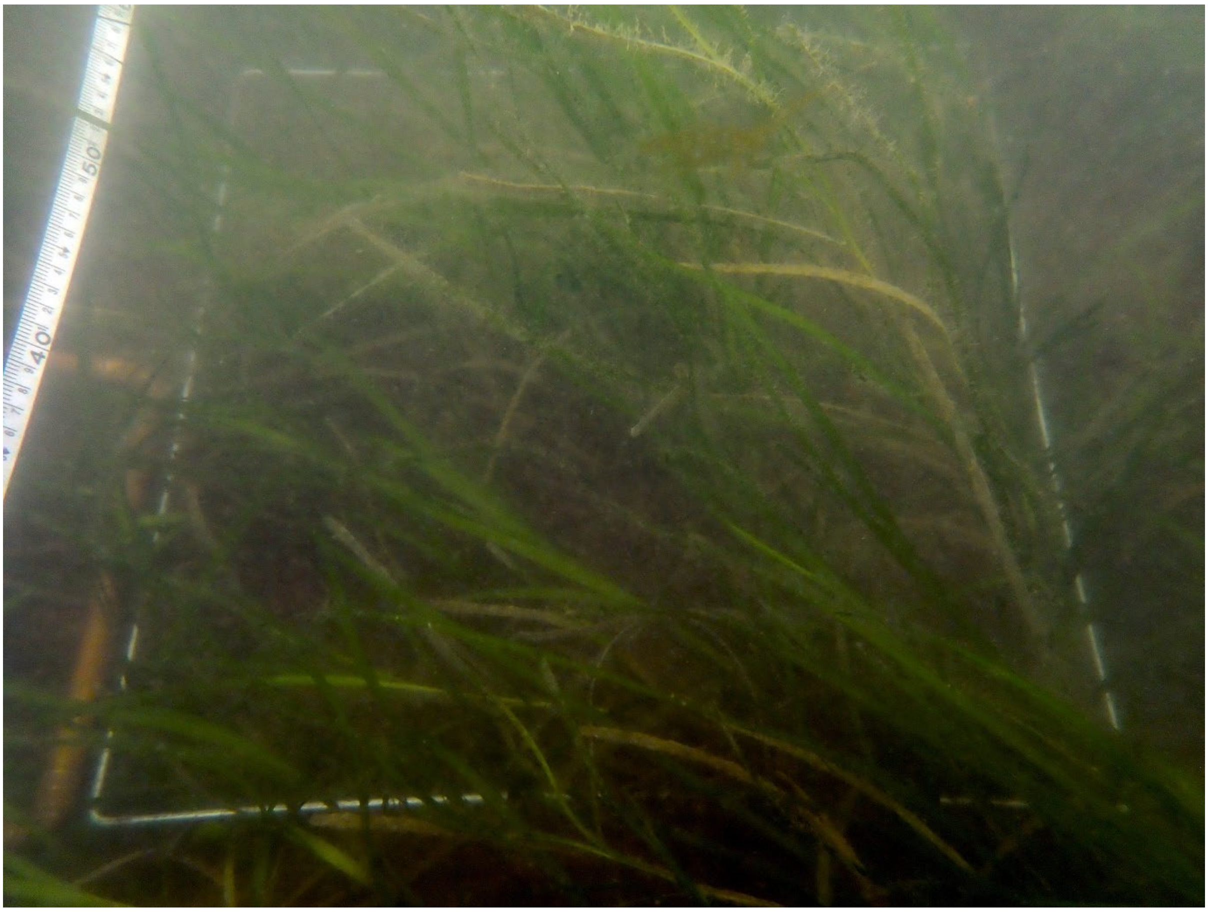

Figure 36. Long dense seagrass at the Cowes Harbour site, June 2021, in limited visibility.

Osborne 1, 15th June 2021

- On the northeast coast of the Isle of Wight, Osborne Bay has an extensive seagrass bed stretching 5.5 km from Cowes to Fishbourne.
- ‘Osborne 1’ site is situated ~80 m offshore and NW of the main area of boat moorings in Osborne Bay.
- The site has the second highest mean density of *Zostera marina* of those surveyed in June 2021, with occasionally patchy cover ranging from 5-95% cover. Shoots were often tall, dense and luxuriant.
- Substrate was a mix of mud, sand and sandy mud with a fraction (unquantified) of grey-blue clay. -0.7 – 0.9 m BCD.
- The non-native alga *Sargassum muticum* was noted occasionally as were slipper limpets, *Crepidula fornicata* and the colonial sea squirt, *Botrylloides* sp.
- No records of other taxa were made.
- Seabed disturbance was noticeable due to the exposure of clean fragments of the underlying clay. The cause of this was unconfirmed.

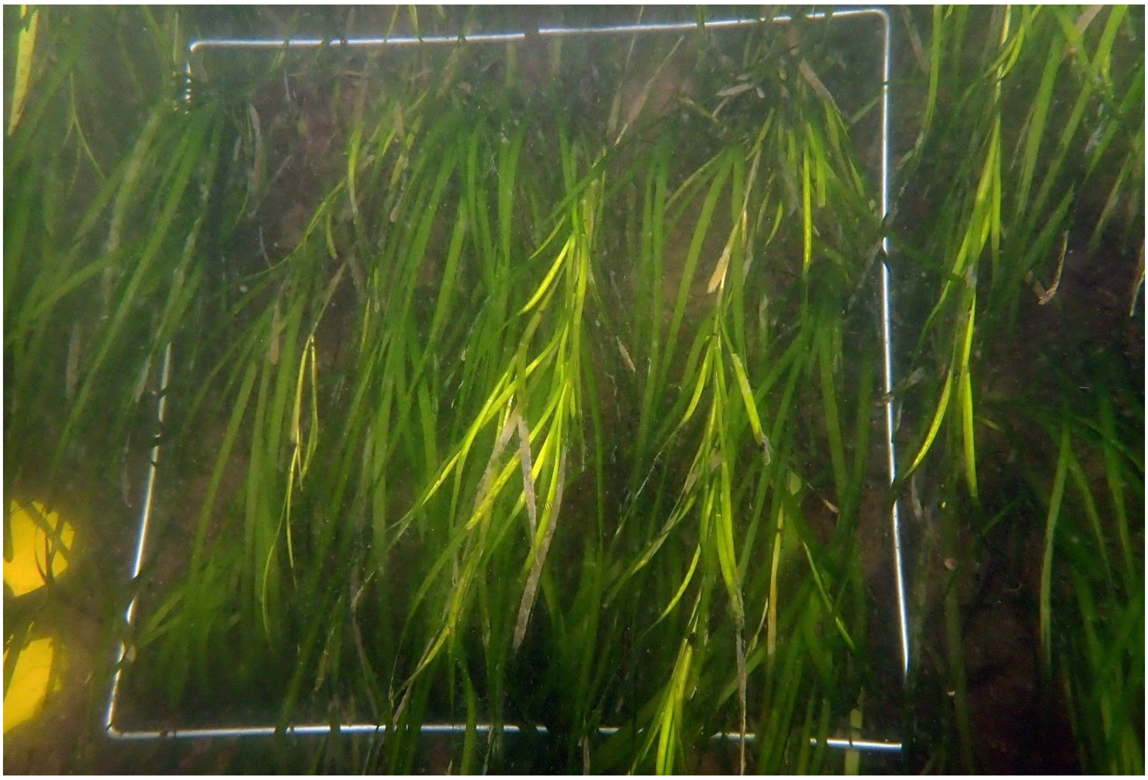

Figure 37. Long, dense luxuriant Zostera with flowering plants at site Osborne 1, June 2021.

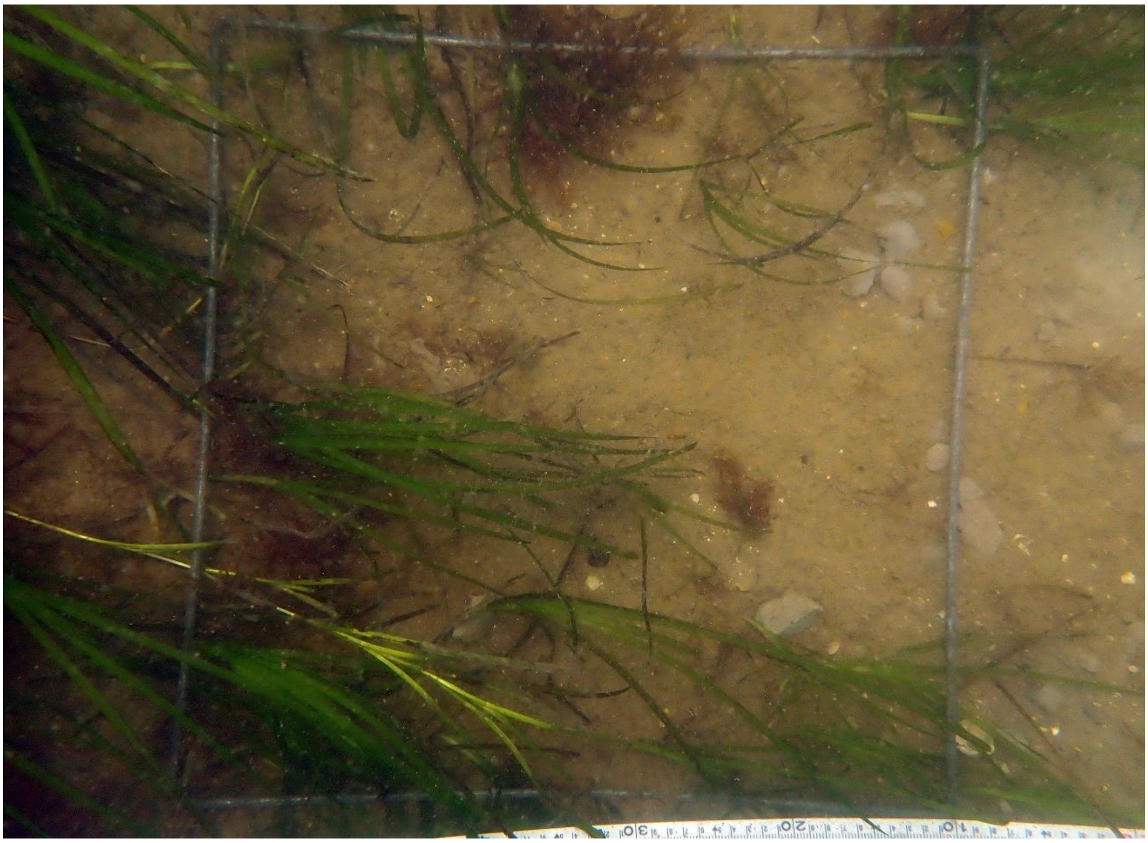

Figure 38. Patchy Zostera with visible red algae and fragments of grey-blue clay at site Osborne 1, June 2021. Clean exposed clay fragments might indicate seabed disturbance.

Osborne 2, 15th June 2021

- 'Osborne 2' site is situated ~100 m offshore within the main area of moorings in Osborne Bay.
- The site has the third highest mean density of *Zostera marina* of those surveyed in June 2021, with occasionally patchy cover ranging from 10-95% cover. Shoots were often tall, dense and luxuriant. Similar to Osborne 1.
- Substrate was a mix of mud and sand over cobbles with patches of fragmented blue clay. Notable rocky outcrop supporting sponge and algal turf. -0.2 – 0.9 m BCD.
- The non-native slipper limpets, *Crepidula fornicata* were recorded from the site.
- No records of other taxa were made.
- Seabed disturbance was again noticeable due to the exposure of the bedrock/clay. The cause of this was unknown although the surveyors noted the high number of boats in the area.

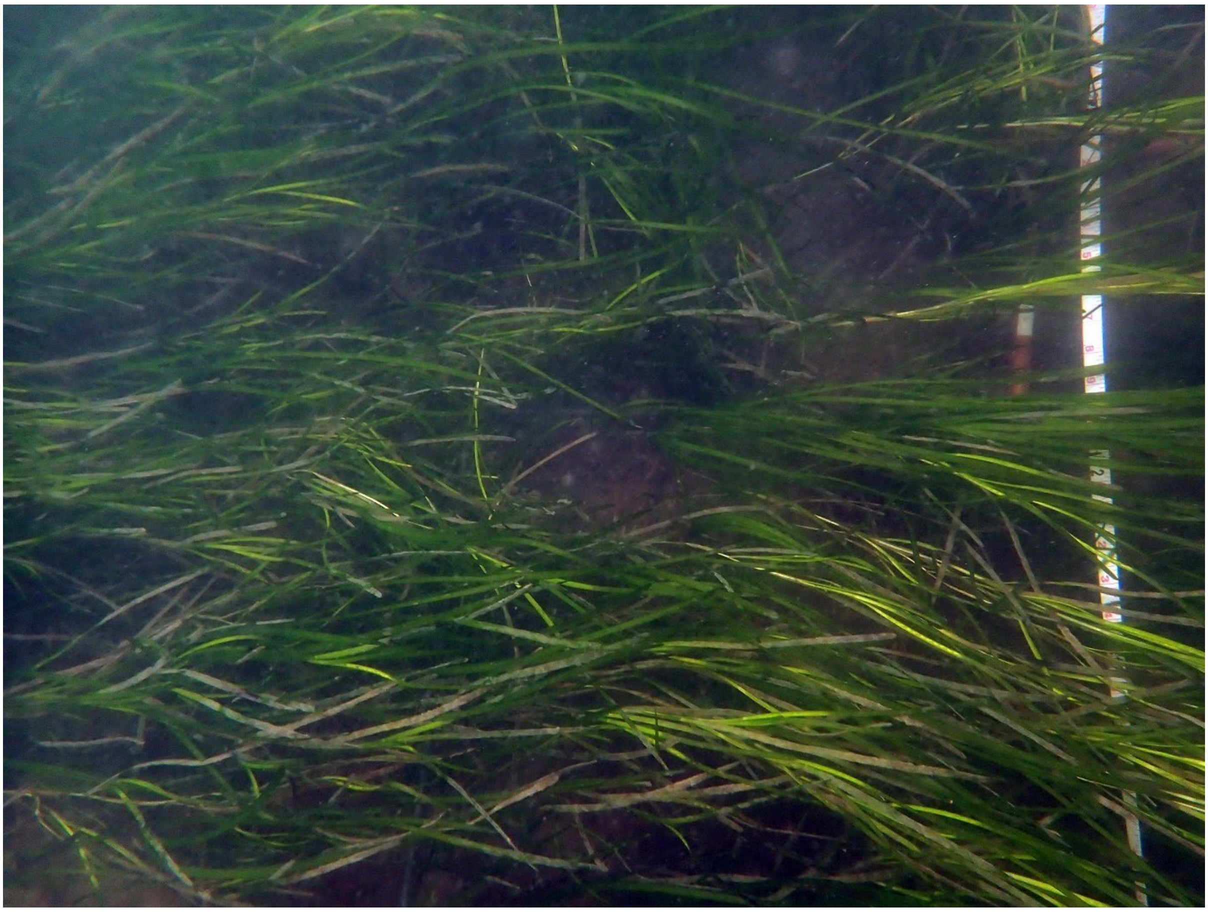

Figure 39. Dense seagrass with flowering plants in a quadrat at Site Osborne 2, June 2021.

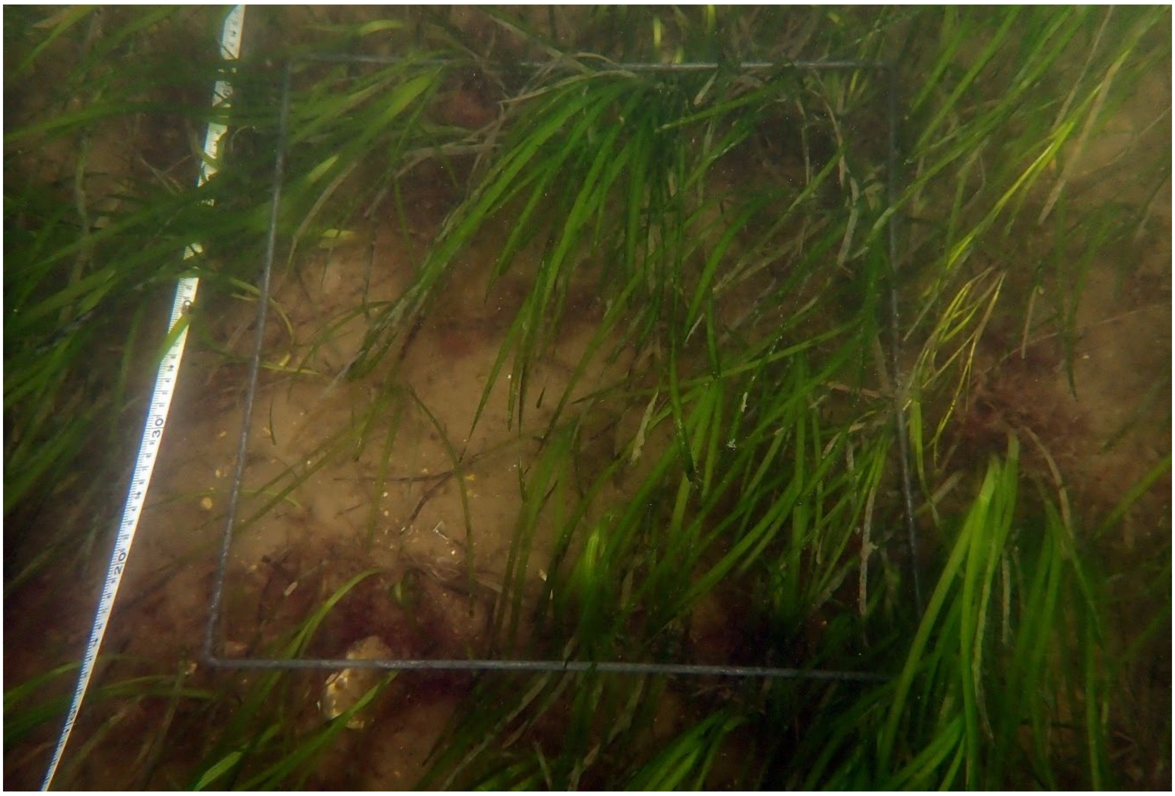

Figure 40. A small bare sediment patch in seagrass with red algae visible in the understorey at Site Osborne 2, June 2021.

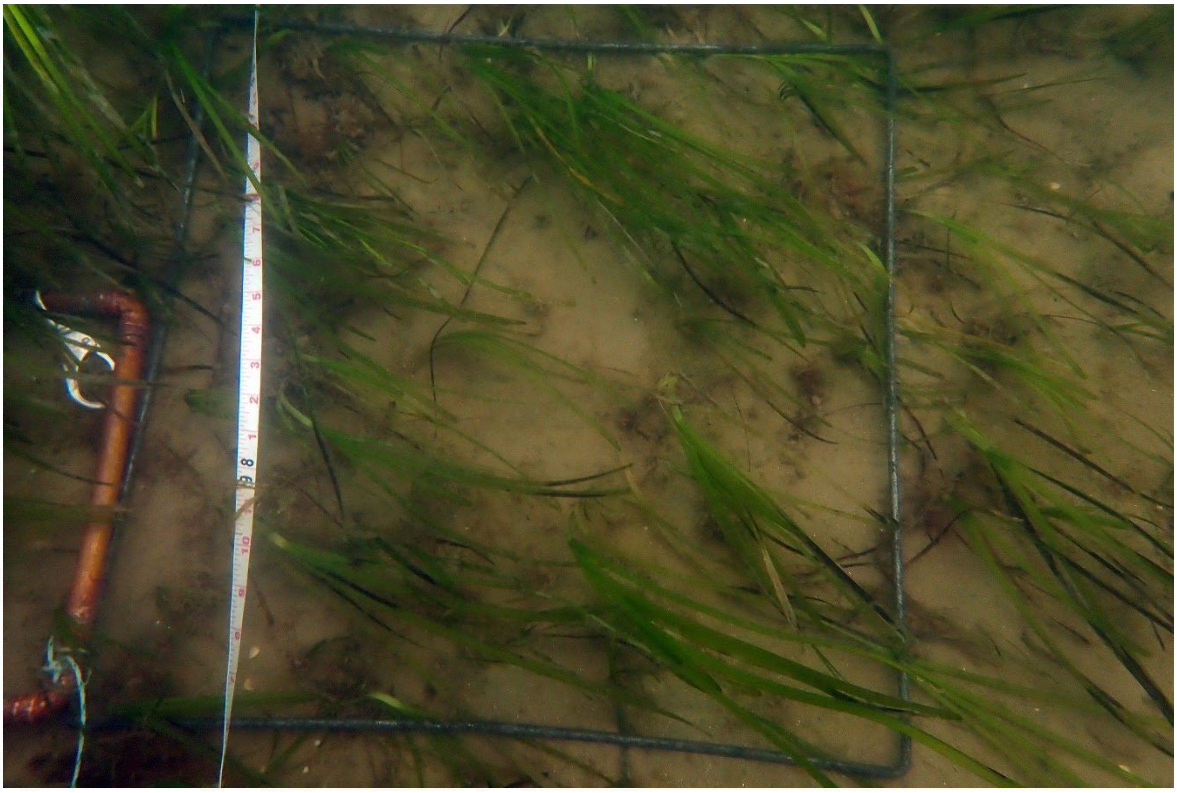

Figure 41. Sparse seagrass in survey quadrats at Site Osborne 2, June 2021.

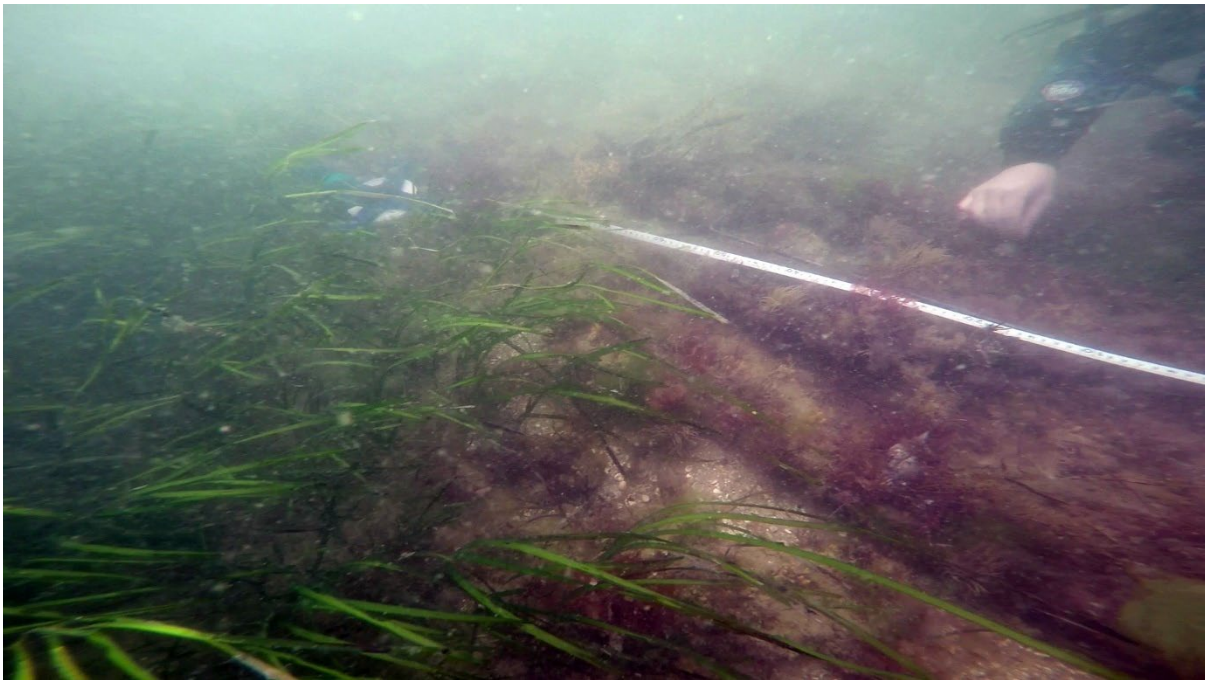

Figure 42. Edge of seagrass bed abutting rocky outcrop with red algae and sponge turf community at Site Osborne 2, June 2021. Video screen grab.

Osborne Bay, non-target sites

On 14th June 2021, two other sites in Osborne Bay were surveyed during a high-water period. These were found to be too close inshore with the second site within or bordering the intertidal zone. Consequently, the seagrass beds surveyed had either no seagrass or a high proportion of *Zostera noltei* and did not match the target habitat for these surveys. The limited data available for these sites were therefore discounted and was not presented alongside those above. The table below summarises the site notes available.

Date	Position	Sediment type	Surveyor notes
14/06/2021 AM dive	50 45.870N 01 15.962W	'Mosaic reef", mixed sediment Not a seagrass bed	Dive aborted. Cobbly ground with a thick, muddy fine sand. Seagrass present and flowering, approx. 2-5% coverage but not enough to be considered a seagrass bed. No images available.
14/06/2021 PM dive	50 44.909N 01 14.370W	Fine sand and shell/mud/fine sand	Intertidal / subtidal transition zone. Seagrass bed but 2 species present with a high proportion of *Z. noltei*. Luxuriant coverage of *Z. noltei* with patches of *Z. marina* similar to morning dive.

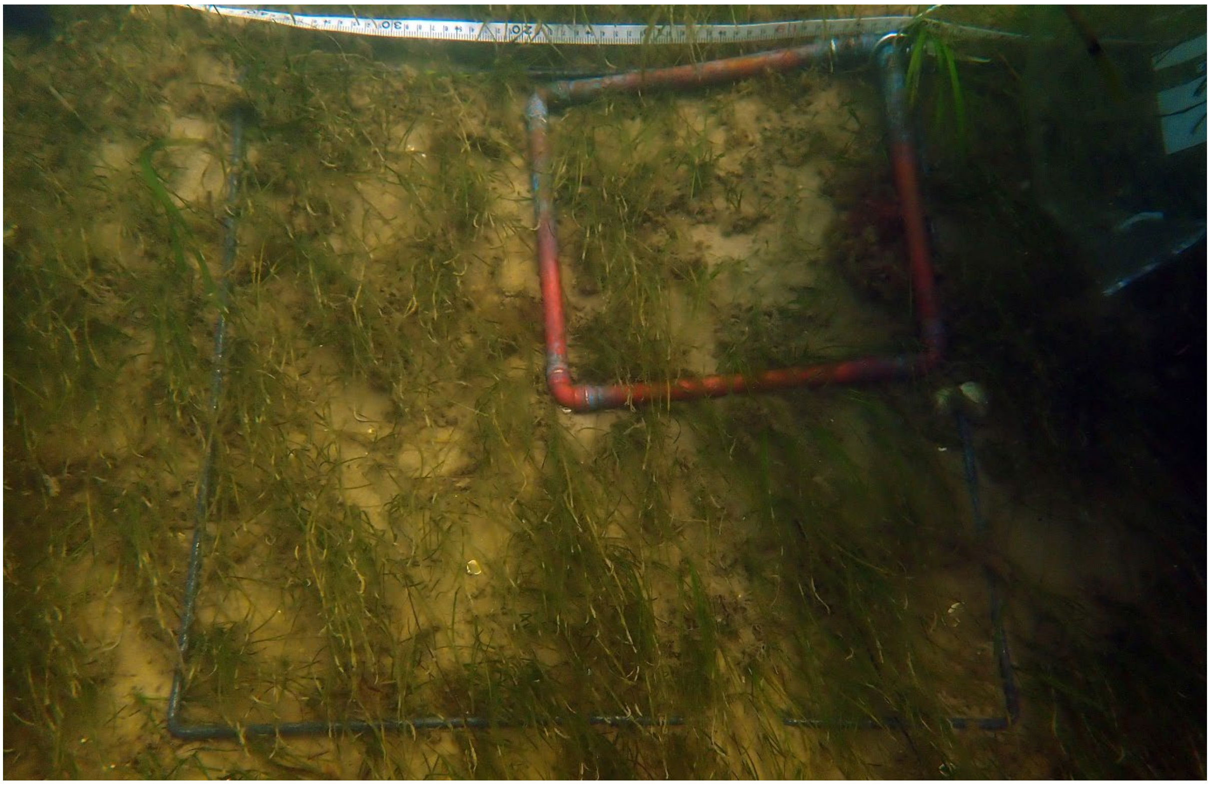

Figure 43. Dense *Zostera noltei* at the second site visited on 14th June 2021.

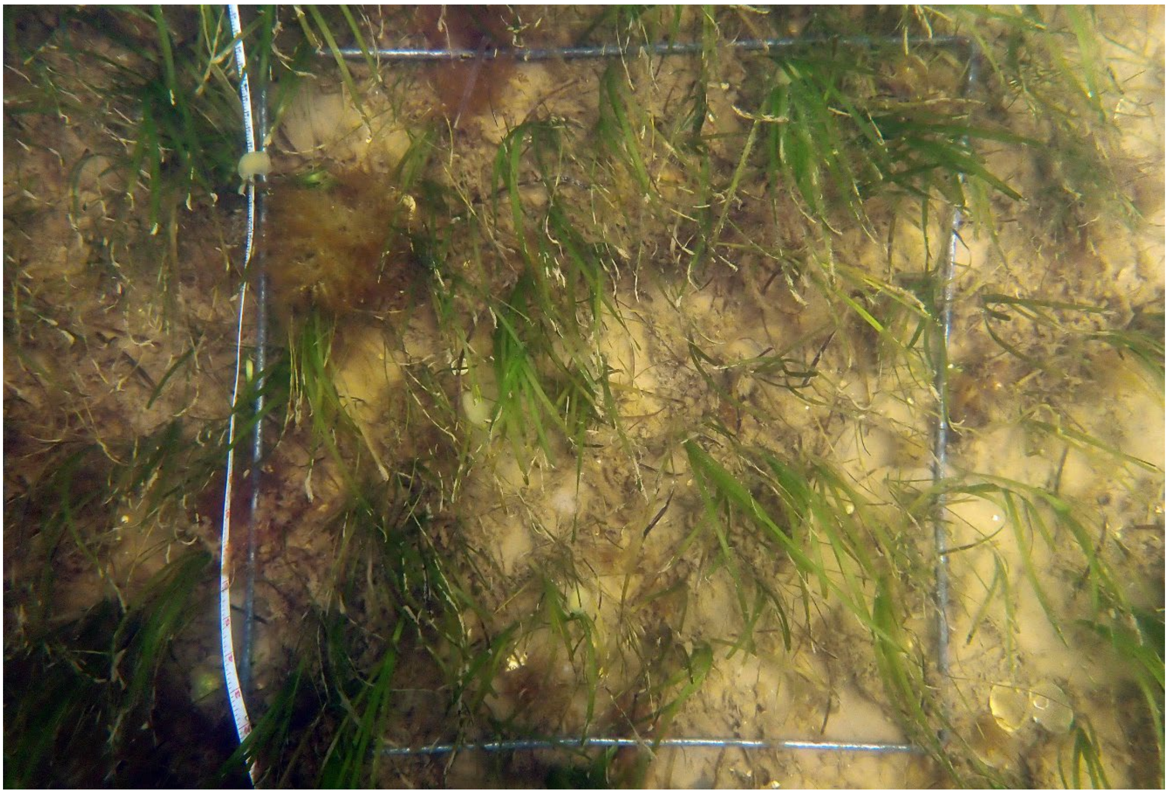

Figure 44. Mixed *Zostera noltei* and *Zostera marina* at the second site visited on 14th June 2021.

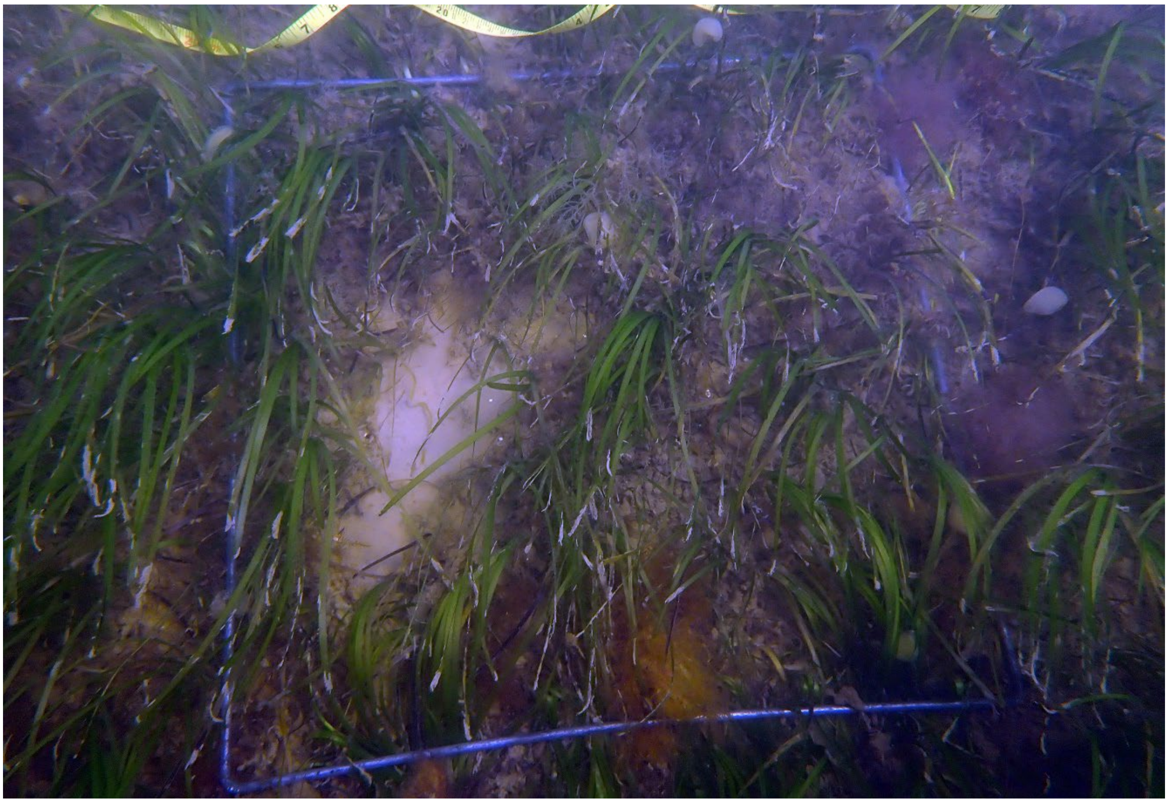

Figure 45. Mixed *Zostera noltei* and *Zostera marina* at the second site visited on 14th June 2021.

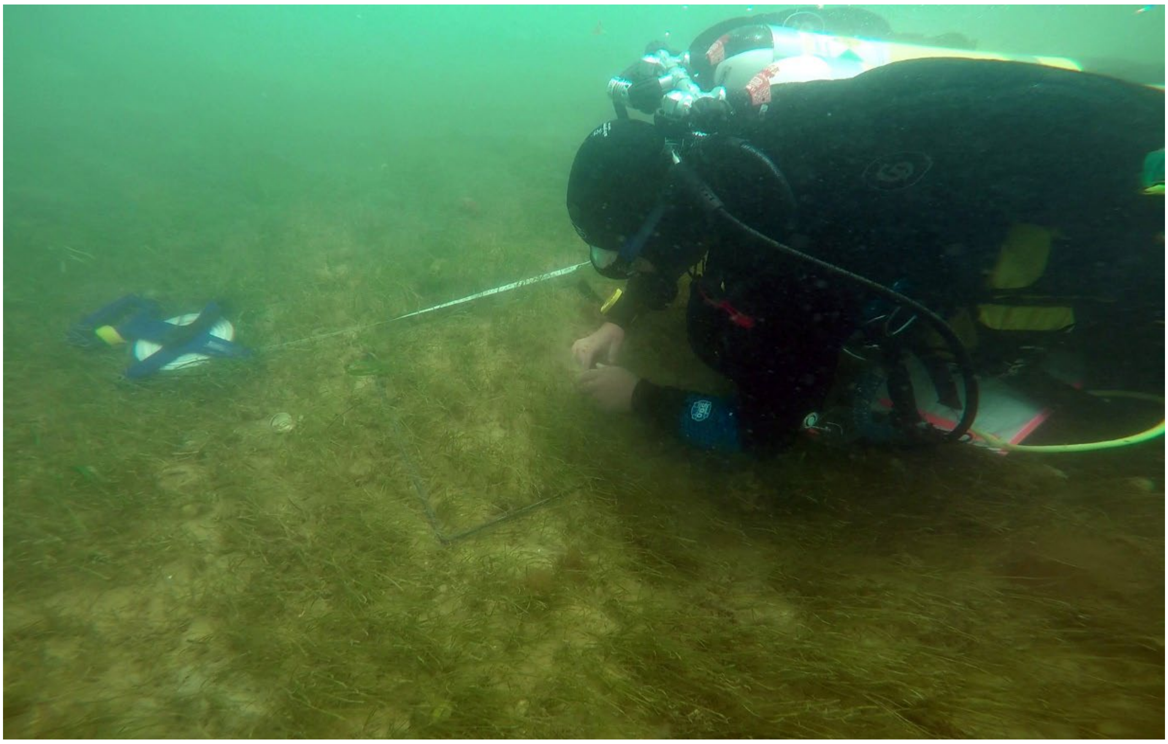

Figure 46. Surveying *Zostera noltei* at the second site visited on 14th June 2021. Video screen grab.

Appendix B – Project personnel

(All Natural England staff unless otherwise stated)

Project led by Natural England personnel

Survey contract manager	Ian Saunders / Lucy May / Lindsey Hollingsworth
Survey methodology	Ian Saunders / Lucy May
Field survey leaders	Ian Saunders / Lucy May
Survey team 2021	Ian Saunders Trudy Russell Jenny Murray Gina Wright Danielle Agnew Lucy May Rebecca Korda Lin Baldock (Marine EcoSol) Nick Owen (Marine EcoSol)
Data entry and sample processing team	Nick Owen & Lin Baldock (Marine EcoSol)
Skipper of Wight Spirit	Dave Wendes (Wight Spirit)
Data analysis and reporting	Matt Doggett and Kate Northern (Marine EcoSol)

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