Natural England Commissioned Report NECR355

Salcombe to Kingsbridge Estuary SSSI Subtidal Seagrass Surveys 2017-18

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Foreword

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Background

Natural England requested the Environment Agency undertake a drop-camera survey of the subtidal seagrass (Zostera marina) beds in the Salcombe to Kingsbridge Estuary Site of Special Scientific Interest (SSSI) in September 2017. A follow-up survey, where an echosounder was used to map the extent and drop-camera were used to sample areas not covered in 2017, was undertaken in September 2018. Aerial photography, echosounders and dive surveys have previously been used to measure the extent of the Salcombe Harbour seagrass beds.

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Keywords – subtidal seagrass (Zostera marina), Salcombe to Kingsbridge Estuary, SSSI

Further information
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Executive summary

Natural England requested the Environment Agency undertake a drop-camera survey of the subtidal seagrass (*Zostera marina*) beds in the Salcombe to Kingsbridge Estuary Site of Special Scientific Interest (SSSI) in September 2017. A follow-up survey, where an echosounder was used to map the extent and drop-camera were used to sample areas not covered in 2017, was undertaken in September 2018. Aerial photography, echosounders and dive surveys have previously been used to measure the extent of the Salcombe Harbour seagrass beds.

The drop-camera survey was undertaken using camera mounted onto a 1 m^2 photo-quadrat, and lowered of the side of the vessel. Camera stations were initially planned at 20 m intervals on a triangular grid over areas of the estuary where seagrass had been historically recorded. The survey was conducted on the Environment Agency vessel Three Rivers, within 2 hours either side of high and low tide. The images were assessed for percentage cover of *Zostera marina*, macroalgae, kelp, non-native wireweed (*Sargassum muticum*) and bare sediment. The percentage cover values were then interpolated to provide an estimation of total bed extent.

The echosounder survey used a BioSonics DT-X echosounder with a 200 kHz transducer. Lines were run at 50 m intervals parallel to the shoreline.

The Salcombe to Kingsbridge Estuary SSSI has three primary subtidal seagrass beds. The main Salcombe bed (north and south combined), on the west side of the channel, is a large elongated bed with an interpolated extent of 7.52 ha and a mean percentage cover of 74.8 % within the beds.

The fragmented beds running along the shoreline of the east side of the channel at Mill Bay / East Portlemouth had an interpolated extent of 1.41 ha and a mean percentage cover of 61.5 % within the beds.

The fragmented beds at South Sands bay had an interpolated extent of 1.20 ha and a mean percentage cover of 18 % within the beds.

Small patches of seagrass were also recorded at North Sands bay. Wireweed was recorded at multiple locations in all the beds.

Overall, the extent and density of seagrass in the Salcombe to Kingsbridge Estuary SSSI has shown an increase compared to previous records. However, confidence in comparison of extent between years is low (especially in the main Salcombe bed), as there have been several different survey methods used to measure extent since 1997.

Contents

1. Introduction

The **Salcombe to Kingsbridge Estuary SSSI** is located on the south Devon coast (Figure 1). It is a sheltered marine inlet, characterised as a ria. It has a total area of 634.5 ha and is 8.3km long with a maximum channel depth of 12.5 m below chart datum (Environment Agency 2014). The southern part of the estuary (where subtidal seagrass beds are present) is bordered by sandy beaches and rocky shores (Northen et al 2006), with a rocky steep-sided coastline at the mouth that is exposed to the prevailing southwesterly winds and waves.

The outer part of Salcombe Harbour (south of The Bar) is covered by two marine protected areas (MPAs); Start Point to Plymouth Sound and Eddystone Site of Community Importance (SCI) extending to both to the east and west and Skerries Bank and Surrounds MCZ to the east. There is minimal overlap between these MPAs and the SSSI. Two Water Framework Directive (WFD) water bodies also overlap the SSSI – the coastal 'Salcombe Harbour' and the transitional 'Kingsbridge', the split between the two is at Snapes Point.

The SSSI encompasses the subtidal and intertidal zones from The Bar (a shallow sandbank just over 1km inside the mouth of the estuary) to the top of the estuary at Kingsbridge. There are numerous creeks that extend off from the main channel, all of which have a very limited freshwater input. The SSSI is split into eight units, five of which cover the subtidal zone.

The Salcombe to Kingsbridge Estuary SSSI is notified for the following features:

- Littoral rock and inshore sublittoral rock
- Littoral sediment flats and inshore sublittoral sediment
- Geology
- Seagrass beds (SM1 Zostera communities)
- Saltmarsh

There are three key beds of subtidal seagrass (*Zostera marina*) within the estuary, all within unit 1 of the SSSI:

- South Sands
- Main Salcombe – which can be split into North (between the mouth of Batson Creek & Woodville Rocks) and South (between Woodville Rocks & North Sands).
- Mill Bay to East Portlemouth.

Intertidal seagrass beds (*Z. noltii)* are present higher up in the Kingsbridge estuary, in unit 8 of the SSSI. These are monitored annually by the Environment Agency (**Figure 1**).

1.1. Survey objectives

1. Survey the extent and record percentage cover of the *Zostera marina* beds in Salcombe to Kingsbridge Estuary SSSI using drop down cameras.
2. Record any anthropogenic impacts to the seagrass beds during the survey and any invasive non-native species.
3. Accurately record the locations of the moorings within and around the edge of the seagrass beds and create a GI layer of these.
4. Produce a map of the current extent of the *Zostera marina* beds and using appropriate interpolation methods a contour map of percentage cover of seagrass
5. Compare with 2017 Channel Coastal Observatory (CCO) photos to see how well the DDV reflects the patchiness of the seagrass beds and to provide additional information to make an observation of patchiness
6. Test the use of a hand held echo sounder to record the extent and patchiness of the *Zostera marina* beds, producing a map of the extent and patchiness of the *Zostera marina* beds using the echo sounder data.
7. Make a comparison of the results from the echosounder trial with the DDV and aerial images to inform suitability of this method for future use as a joint NE and EA survey method.
8. Compare the current extent of the *Zostera* marina beds with previous surveys and report on the condition of the extent attribute for this feature.

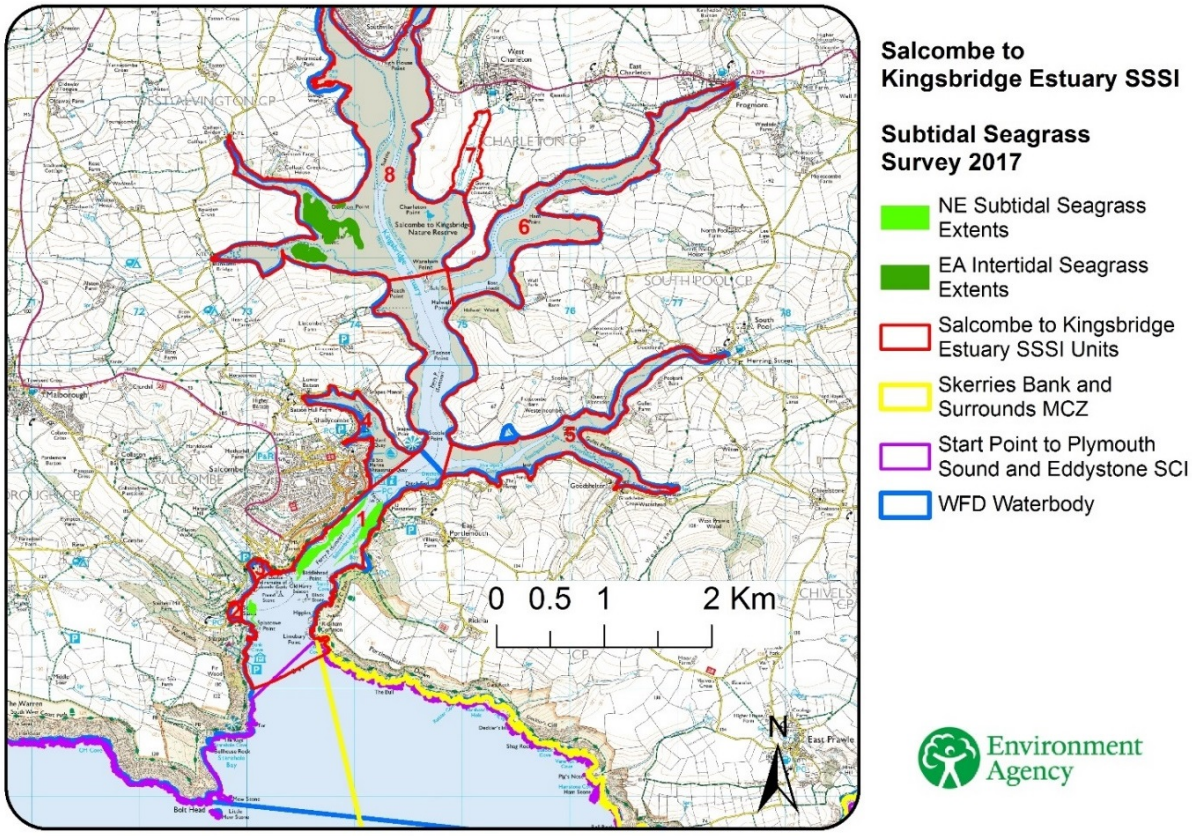


Figure 1. The component units of the Salcombe to Kingsbridge Estuary SSSI, with adjacent marine protected areas. The extents of intertidal and subtidal seagrass beds are also shown.

2. Survey methods

2.1. Survey design

Since 1997 there have been several seagrass surveys in Salcombe Harbour (Mortimer, 1997; Rhodes et al. 2006; D&SIFCA, 2014; Faithfull, 2015), using a range of different methods (diving, camera, echosounder), resulting in range of point data and extent boundaries on Natural England's evidence database.

To take account of the differing extents, a 20 m triangular grid of stations was overlaid in areas where seagrass had been previously recorded, with an additional line of stations added outside of the recorded boundaries to take account of any changes in extent. A triangular grid enables patchiness within beds to be better mapped than a square grid.

Stations were also added at North Sands and around Biddlehead Point, where there had been recent anecdotal or point locations of seagrass. In total, 660 stations were incorporated into the survey plan (**Figure 2**).

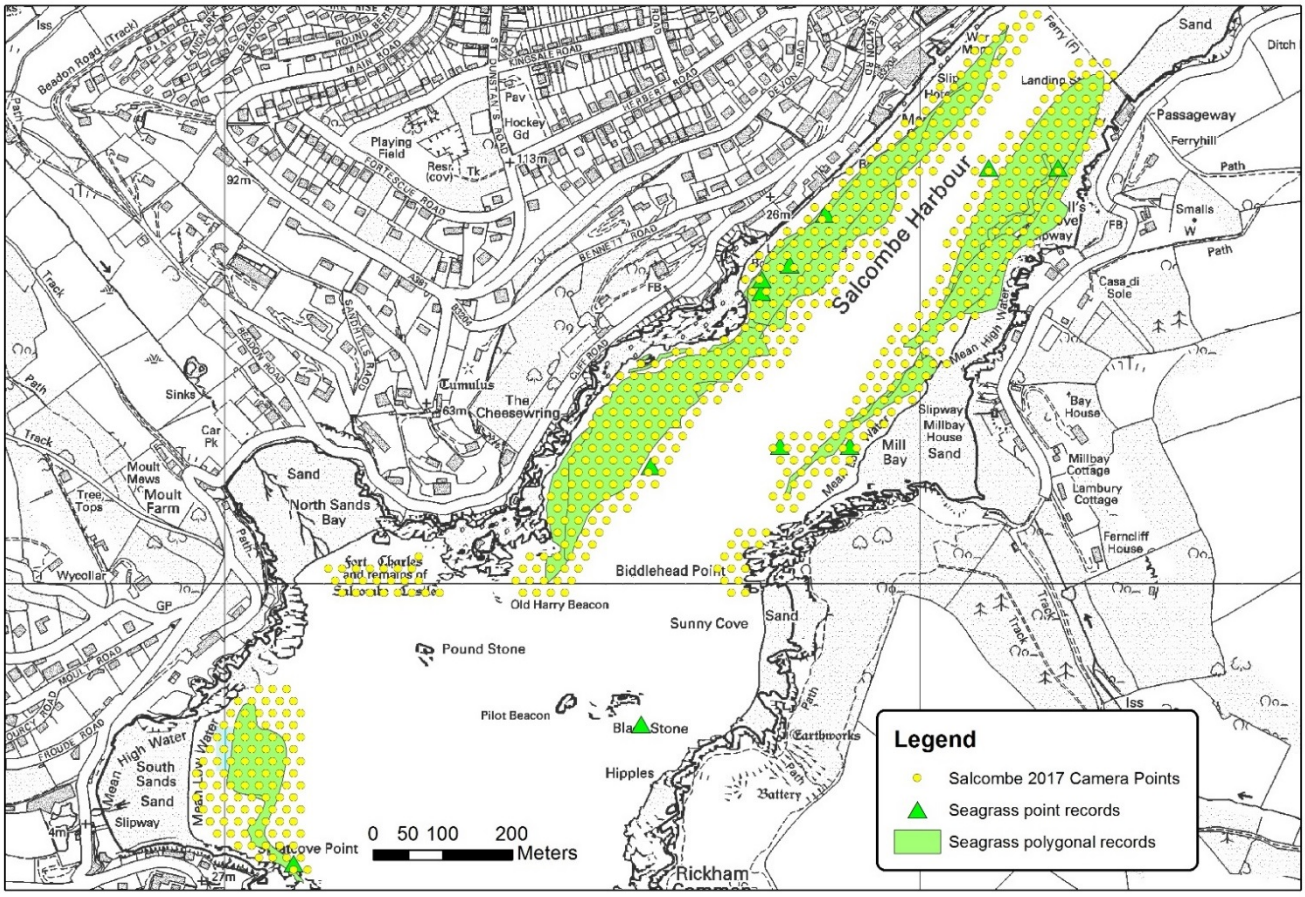


Figure 2. Location of 660 stations that were planned to be surveyed in the Salcombe to Kingsbridge Estuary SSSI subtidal seagrass survey.

2.2. Drop-camera method

The drop-camera equipment was deployed from a davit on the port side of the vessel. A 12-megapixel Go-Pro HERO4 camera in underwater housing was attached to a 1 m x 1 m (1 m2) photo-quadrat frame (**Figure 3**) constructed out of plastic piping weighed with lead weights and weighted rope. A live feed from the camera was fed back to a tablet computer on the vessel, allowing the surveyor to observe when the frame was on the seabed.

At each station for the 2017 survey, the frame was lowered into the water, and the location fixed with the handheld Garmin GPS stationed at the davit when the camera was on the seabed. Once on the seabed, the still image was captured and the digital still images were transmitted via the sea cable to be captured and saved directly to a computer in the survey cabin. The frame was then raised a few centimetres above the seabed and lowered back two more times in quick succession, with an image captured each time the frame landed on the seabed, resulting in three viable images from each station. For the 2018 survey, a similar process was followed, but only a single image was captured at each station.

Sampling aimed to take place to 2 hours +/- high or low water, to ensure the seagrass canopy was at a constant height to ensure consistent estimation of percentage cover. Some sampling took place outside this window, but this was targeted to stations that were considered to have a low chance of seagrass being present. If the current was strong and pulled the camera underneath or away from the vessel, the sampling was paused at that station until the current speed reduced.

The GPS was also used to georeference mooring buoys located over the seagrass beds once the survey was completed.

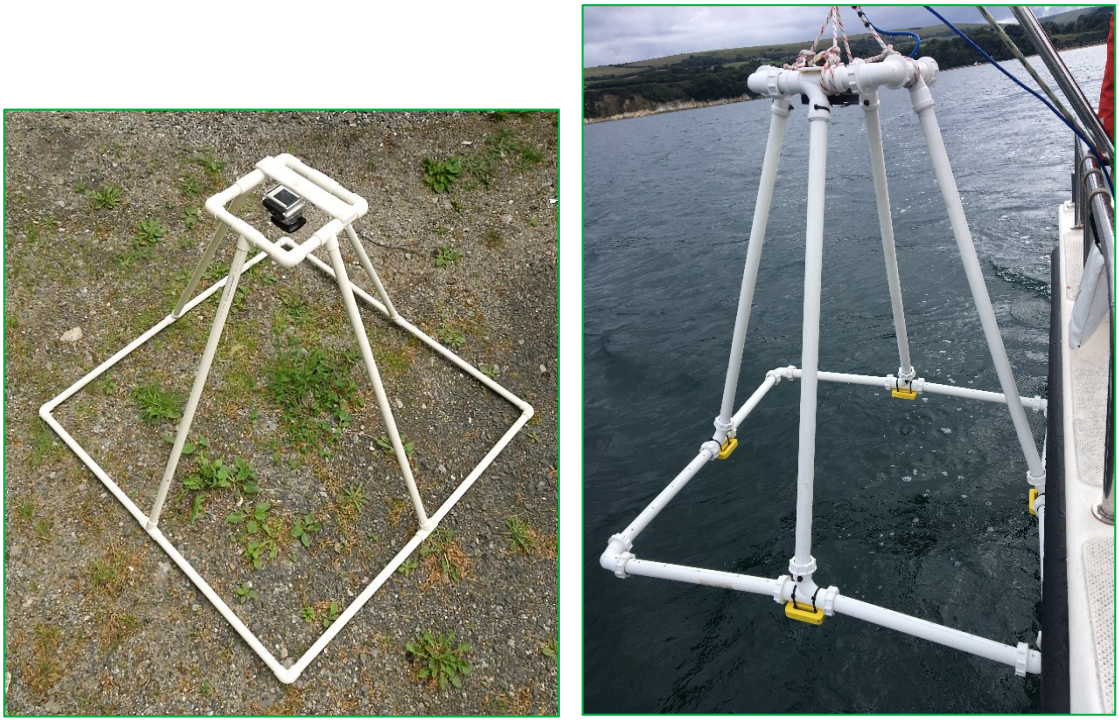


Figure 3. The 1 m^2 photo-quadrat with GoPro camera mounted directly above the quadrat.

2.3. Echosounder survey

The echosounder survey was undertaken on the 17th September 2018. A BioSonics DT-X Extreme split-beam echosounder with a 200 kHz transducer was used to survey the seagrass beds (**Figure 4**), following methods developed by Egerton and Sotheran (2011) and Green (2018). The pole-mounted transducer was positioned 60 cm below the water surface, and was mounted on a davit off the port side of the vessel.

Lines were run at 50 m intervals in a north east/south west direction for the Main and East Portlemouth beds (parallel to the shore) across the full extent of the beds. For the South Sands bed, the echosounder lines had to be run between the moorings. Surveying took place at 1 hours +/- high or low water, to ensure the seagrass canopy was not reduced by tidal currents.

The vessel survey speed was 5 knots, and the ping rate was 10 pings s-1.

Figure 4. The BioSonics DT-X Extreme surface unit (left) and pole-mounted 200 kHz transducer (right).

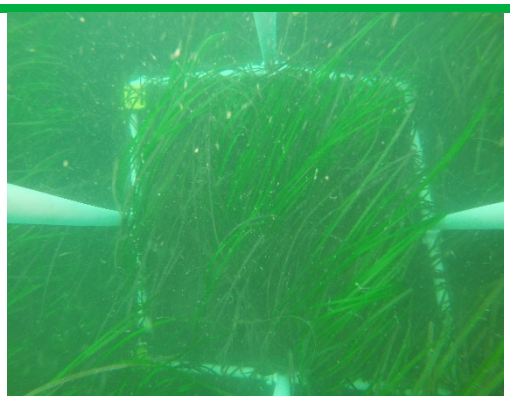
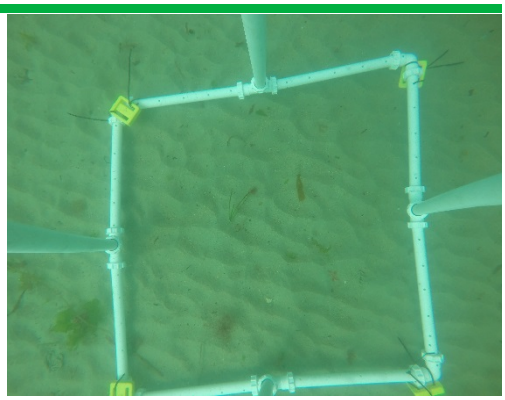
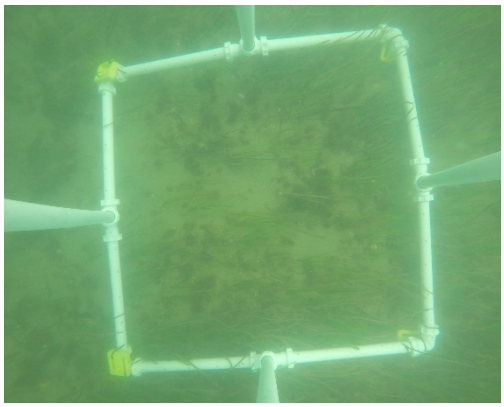
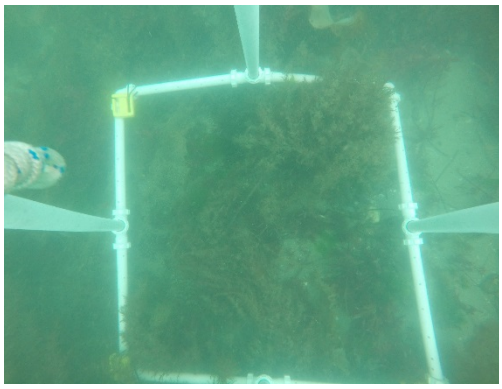
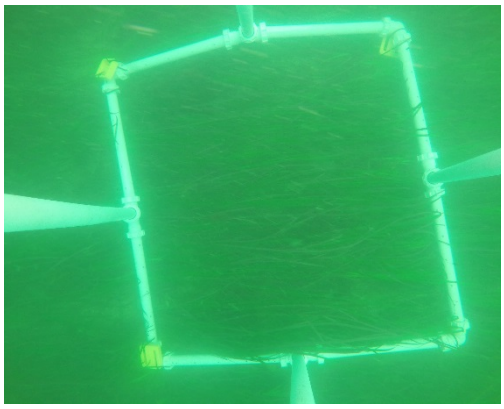
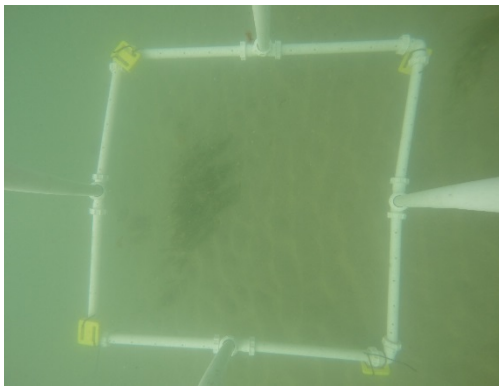
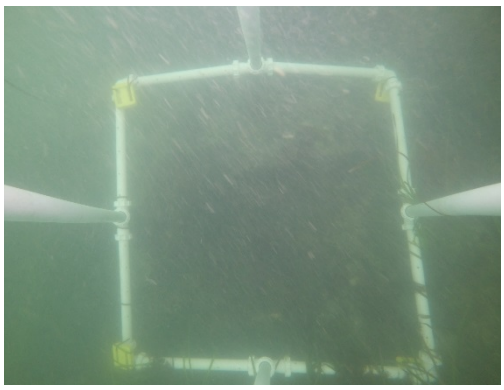
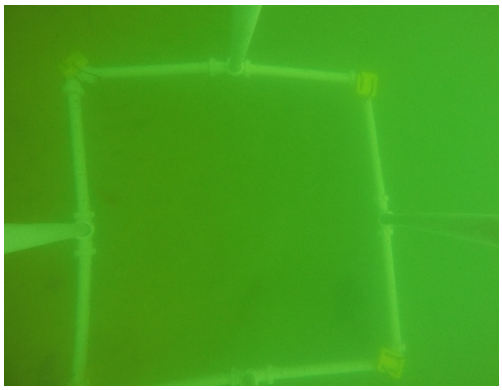
2.4. Image Analysis

Still images were assessed for visibility and initial observation of seagrass presence and absence before further analysis in the office. Visibility was highly variable. The images were classed into one of four visibility categories ranging from 1-4 (**Table 1**).

Still images collected from the drop camera were assessed by eye (following a standard Environment Agency protocol, Annex 1) for % cover of *Zostera marina*, green and red/brown macroalgae, kelp, the non-native wireweed *Sargassum muticum* and bare sediment. A 25-square grid was overlaid over the 1 m^2 quadrat of each image. The percent cover was estimated by counting the number of squares, to the nearest half square, that were covered by seagrass/macroalgae. Full covered squares are counted as 4 % each, half squares as 2 %.

An assessment of visibility and presence of seabed litter were also noted. No particle size analysis samples were collected during the survey, but the seabed substrate type was categorised by eye into 'gravel', 'rock', 'sand' and 'gravelly sand/sandy gravel'.

Table 1. Visibility assessment scale of still images collected during the Salcombe to Kingsbridge Estuary SSSI subtidal seagrass survey.

1 - **Good visibility** Although may not be perfectly clear, can still identify all features and species on the seabed.		
2 - Moderate visibility Some turbidity or slightly out of focus. Can identify % cover, other algae, detail on leaf blades.		
3 - Poor visibility Possible to identify substrate, algae, if seagrass is present / 100% cover). Possibly considerable green tinting if sampled at low tide.		
4 – Very poor visibility Not possible to ID any species present. Can possibly ID if seagrass is present or not. Camera out of focus.		

The images were analysed by trained Environment Agency officers. 10 % of the images were selected and re-analysed by the project manager.

Seagrass extents were mapped using ArcGIS. The bed extent was defined using threshold identified by OSPAR (2009); beds only include areas that were ≥ 5 % cover of *Zostera marina*. The data points of still image percentage cover were interpolated to form an extent using the Natural Neighbour tool in ArcGIS Spatial Analyst, and the resulting interpolation clipped to the mean low water line.

2.5. Echosounder Analysis

The echosounder data was analysed using the macrophyte package within the Sonar5Pro software (Balk and Lindem 2015). Seagrass roots and canopy detection thresholds were set at -40 dB and -60 dB respectively, and features with a canopy height < 10 cm were assumed to be close-cropping macroalgae and removed from the analysis. Pings were aggregated into 20-ping sampling units for calculating metrics.

Two metrics were calculated from the echosounder data: Percentage Volume Inhabited (PVI) is considered a proxy for seagrass percentage cover; Mean Bioheight measures the mean seagrass canopy height above the seabed over 20 pings. More detail on the metrics and analysis can be found in Green (2018).

2.6. Aerial photography

The Southwest Coastal Programme undertook aerial photograph flights over Salcombe to Kingsbridge Estuary SSSI in between July and November 2017. The photography was acquired from the Channel Coastal Observatory, and compared to the drop-camera assessment of seagrass extent.

3. Results

3.1. South Sands

268 still images were collected from 89 stations in South Sands in 2017. 95 of the 268 images contained *Zostera*, and 75 contained *Zostera* that were > 5% cover. No images were collected in 2018.

The substrate at South Sands was observed to be predominately sand to the west of the bay, transitioning to sandy gravel to the east (**Figure 5**). Kelp-dominated rock outcrops bordered the north and south of the Bay. Fifty moorings, separated into two groups, were recorded in South Sands Bay in 2017. This made surveying in the bay quite difficult, as the survey vessel had significantly restricted manoeuvrability

Zostera was present across the centre of the bay and was densest in the area between the two sets of moorings, and to the south-east of the southern area of moorings. The bed was generally limited to between 50 m and 150 m of the mean low water line.

Where *Zostera* was present, the mean percentage cover was 17.27 ± 2.02 % (**Figures 6, 7**). The mean percentage cover within a defined bed (> 5 % cover threshold) was 18.05 ± 3.81 %.

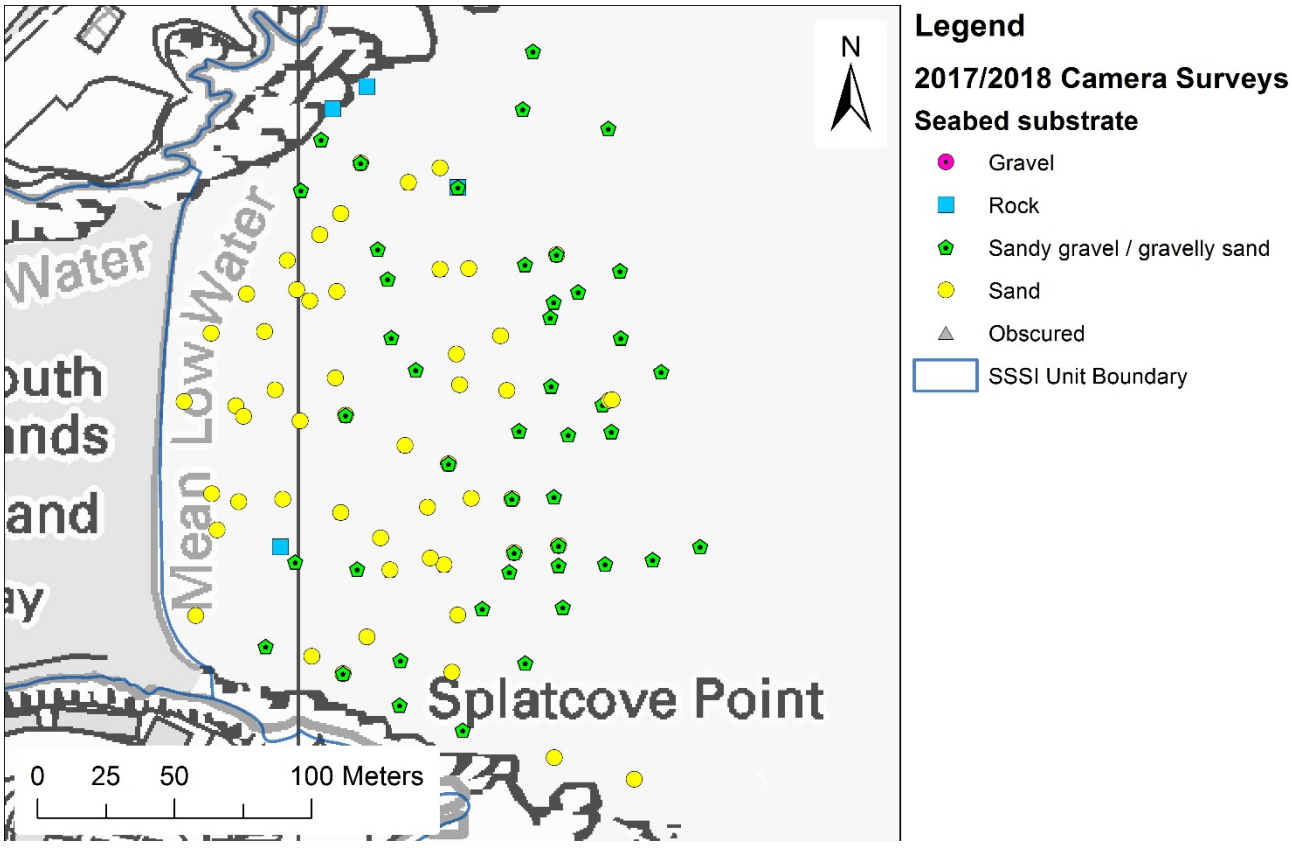


Figure 5. Observations of seabed substrate from still images collected at South Sands in 2017.

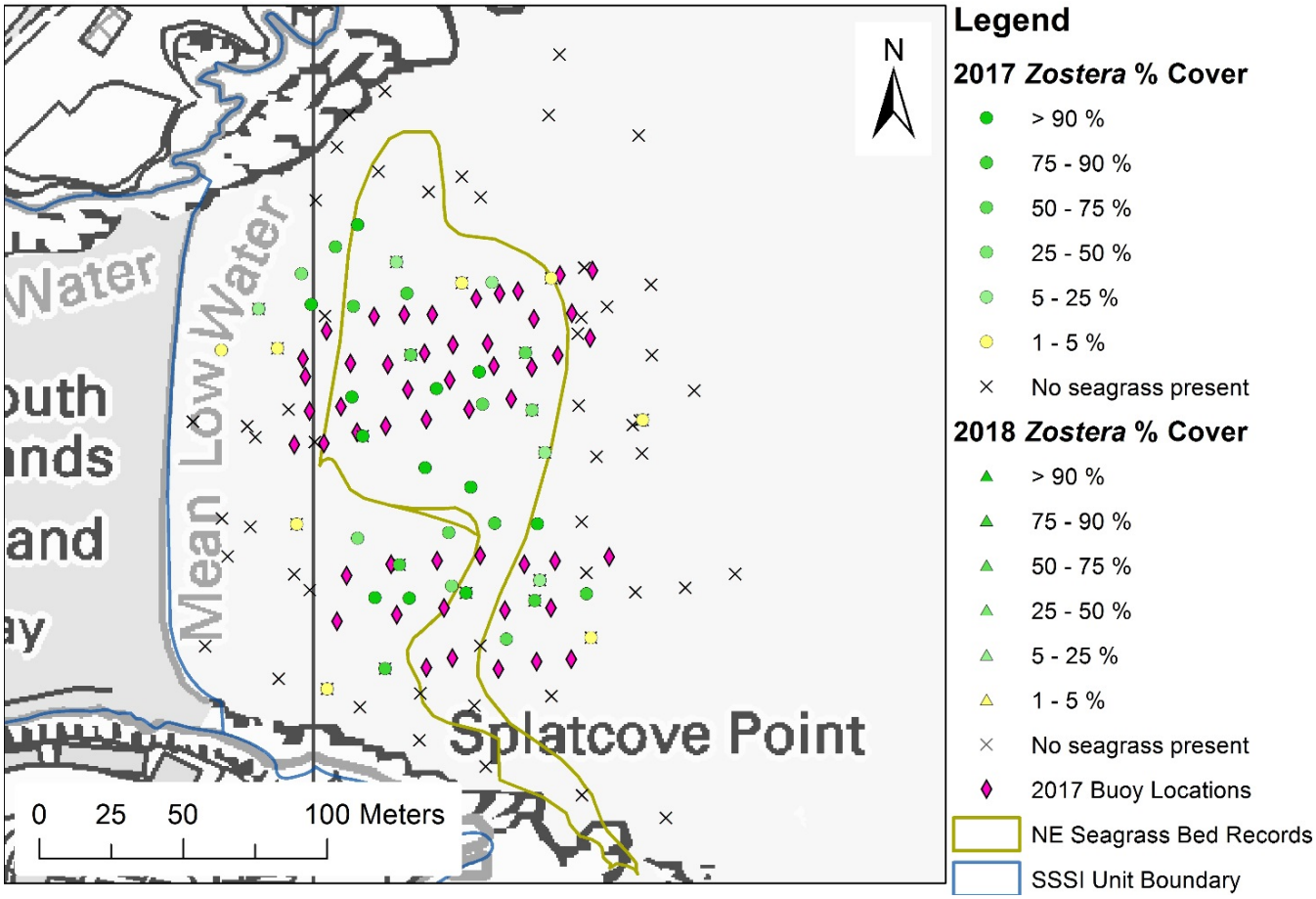


Figure 6. Percentage cover of *Zostera marina* assessed from still images collected in South Sands Bay in 2017. Swing mooring locations in 2017 and the historic extents of *Zostera* in the bay are also shown.

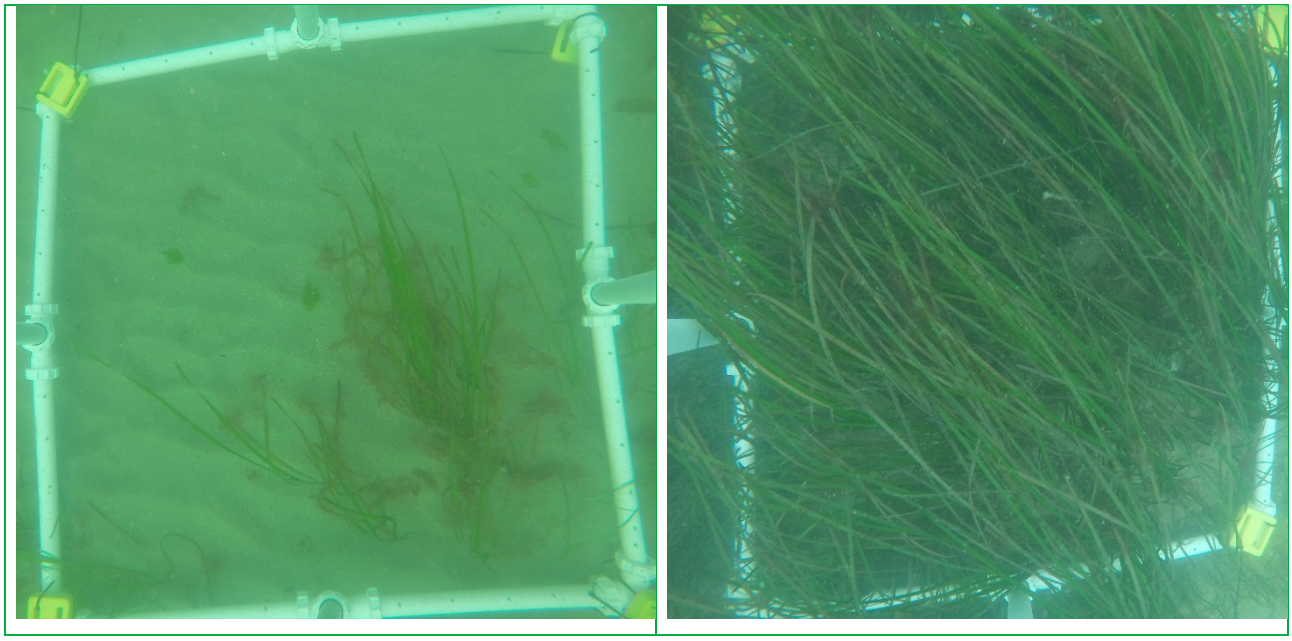


Figure 7. Example images of (left) sparse and (right) dense Zostera marina beds sampled at South Sands in 2017.

Following interpolation of the still image data, the total area of seagrass bed (>5 % cover) was estimated at **1.204 ha**, and the density with the largest area was 5 - 25 % cover. An additional 1.102 ha seabed had 1 - 5 % seagrass cover, and could be considered supporting habitat (**Table 2**).

The wireweed *Sargassum muticum* was found at 17 of the 89 stations sampled at South Sands (**Figure 9**).

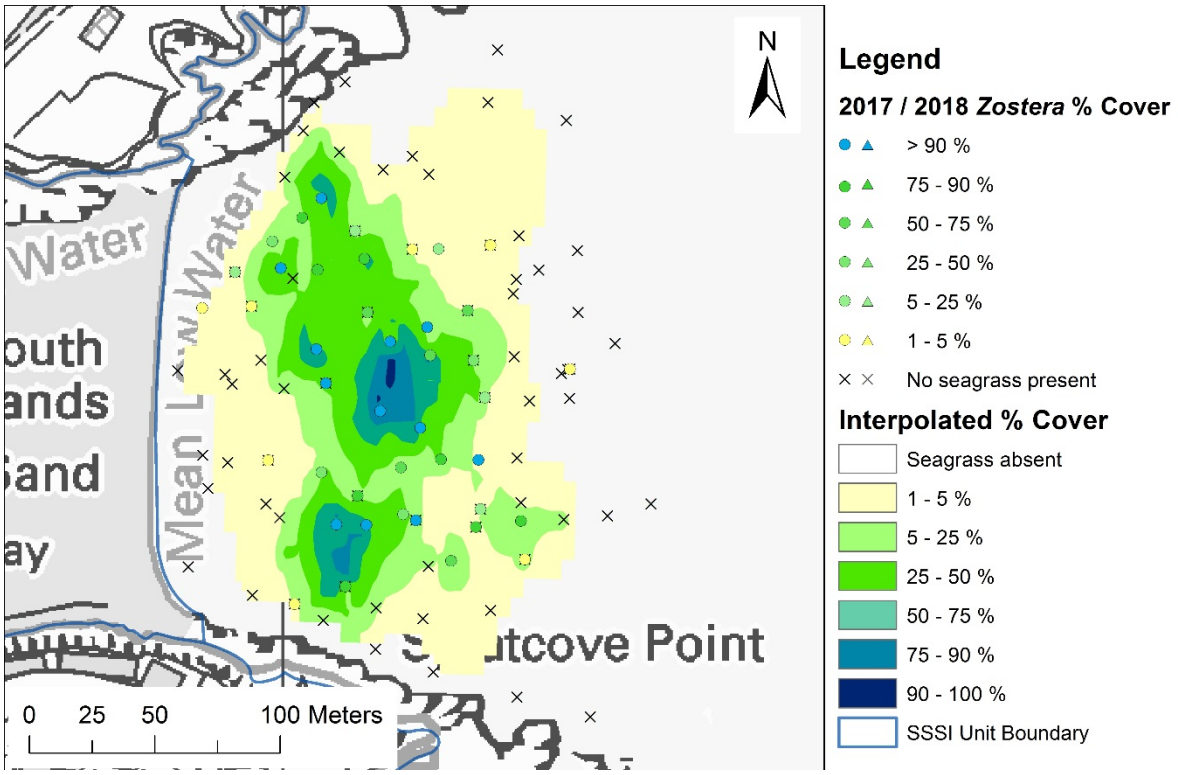


Figure 8. Interpolated map of seagrass density and extent from the 2017 drop-camera survey at South Sands.

Table 2. Interpolated *Zostera* bed extent values for percentage cover boundaries at South Sands.

Zostera % cover	South Sands extent (ha)	% of total extent
5 - 25 %	0.511	42.4 %
25 - 50 %	0.485	40.3 %
50 - 75 %	0.141	11.7 %
75 - 90 %	0.059	4.9 %
> 90 %	0.008	0.7 %

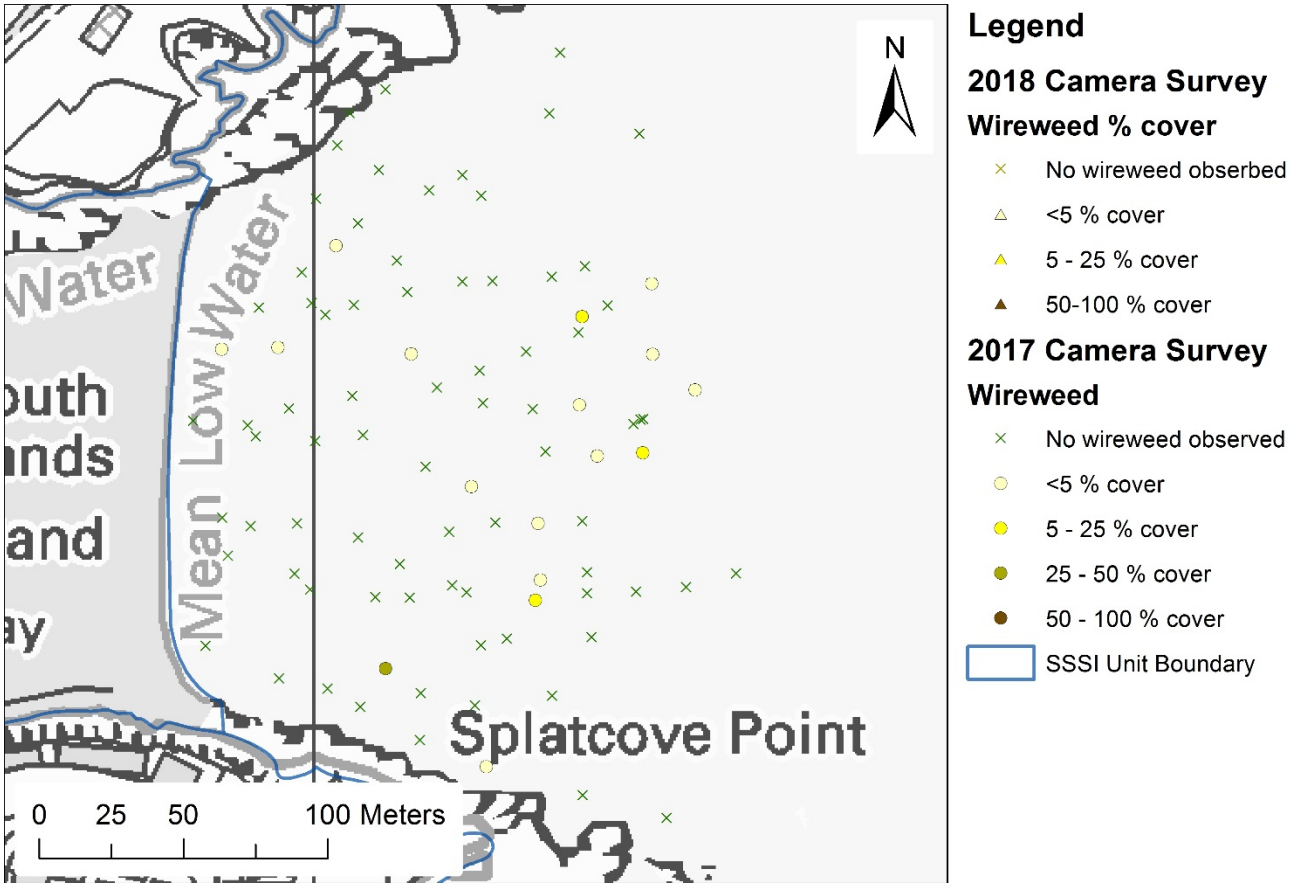


Figure 9. Wireweed (*Sargassum muticum*) presence from the 2017-18 drop-camera surveys in South Sands.

3.2. North Sands

17 still images from 9 stations were sampled at North Sands in 2017 (**Figures 10, 11**). Only two still images contained Zostera (92 % and 26 % cover). The seabed type was observed to be fine sand throughout.

No echosounder surveys were undertaken at North Sands.

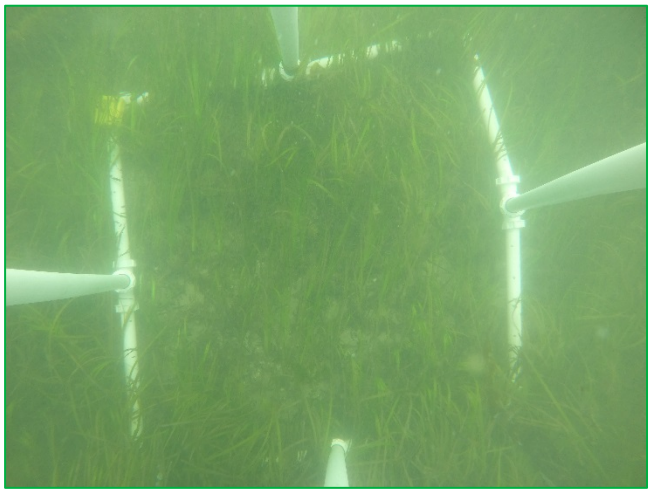


Figure 10. Example image of *Zostera marina* beds sampled at North Sands in 2017.

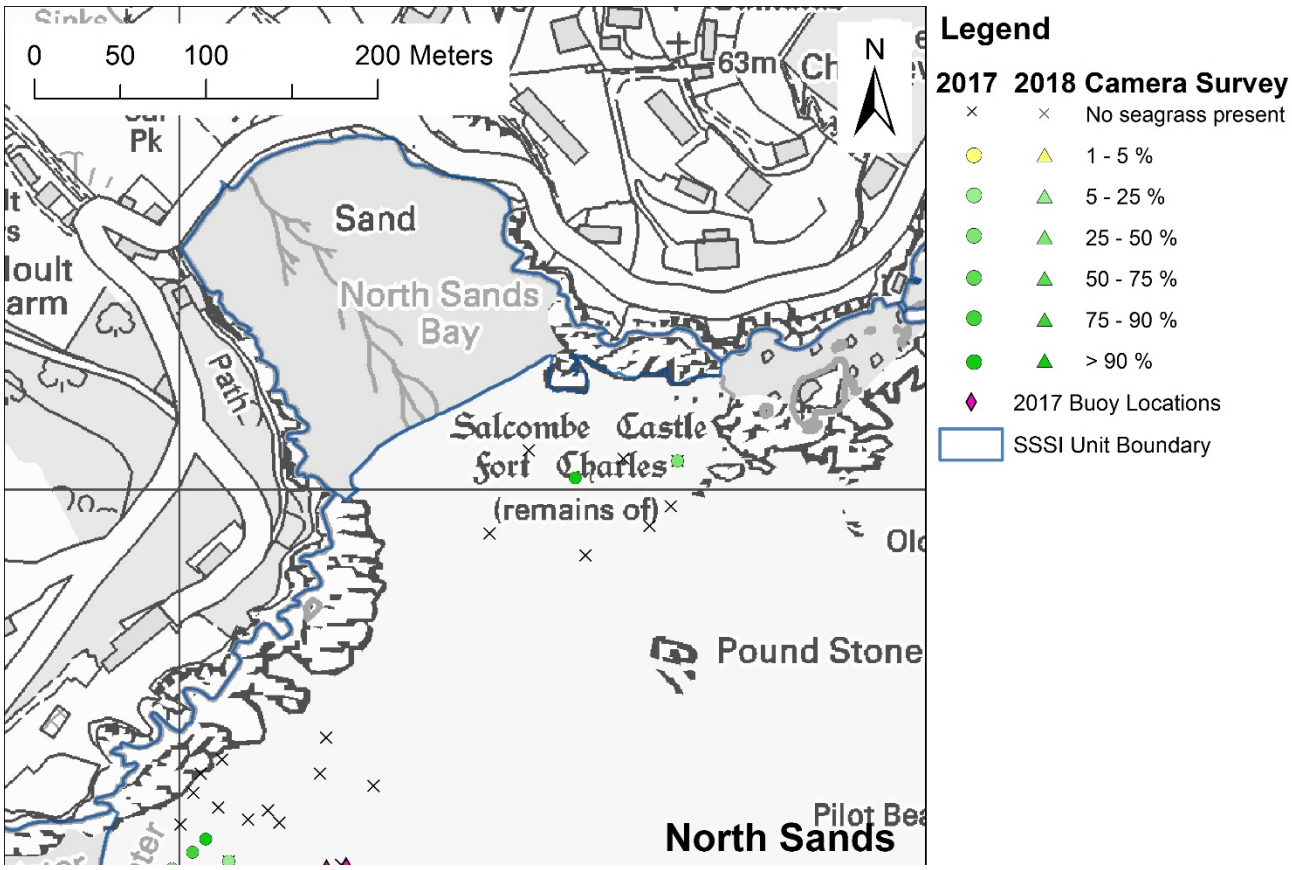


Figure 11. Percentage cover of *Zostera marina* assessed from still images collected in North Sands in 2017.

3.3. North and South Main Salcombe beds

The substrate in the southern part of the main bed (between North Sands and Woodville Rocks) was observed to be predominately gravelly sand/sandy gravel (with occasional patches of gravel closer to the shore) at the southern end of the bed, transitioning to sand closer to Woodville Rocks. The beds were fringed by kelp and fucoid-dominated rock outcrops. From Woodville Rocks to Batson Creek, the substrate was a mix of fine and gravelly sands, transitioning to muddy sand in the mouth of Batson Creek (**Figure 12**). The sediment closer to the estuary channel, outside of the seagrass beds was generally coarser than sediment observed inside the seagrass beds.

Sixty-two moorings/buoys were recorded in 2017 over the North and South Salcombe beds, 12 south of Woodville Rocks and 50 between Woodville Rocks and Batson Creek.

Where *Zostera* was present, the mean percentage cover was 67.11 ± 1.88 % (**Figure 13, 14**). The mean percentage cover within a defined bed (> 5 % cover threshold) was **74.76 ± 1.70 %** (**Table 3**).

Following interpolation of the still image data, the total area of seagrass bed (>5 % cover) was estimated at **7.523 ha**, and the density with the largest area was 25 - 50 % cover (**Figure 15**). An additional 2.6 ha of seabed had 1 - 5 % seagrass cover, and could be considered supporting habitat.

The wireweed *Sargassum muticum* was observed in 59 images, ranging from 4 - 100 % cover. The densest wireweed was present across at the northern end of bed, closest to Batson Creek, and just south of Woodville Rocks. The wireweed predominately occurred on gravelly sand substrate (**Figure 16**).

Table 3. Interpolated *Zostera* bed extent values for percentage cover boundaries for the main (North and South) Salcombe bed.

Zostera % cover	Salcombe Main Bed extent	Percentage of total extent
5 - 25 %	1.839 ha	24.4 %
25 - 50 %	2.108 ha	28.0 %
50 - 75 %	1.564 ha	20.8 %
75 - 90 %	0.839 ha	11.2 %
> 90 %	1.173 ha	15.6 %

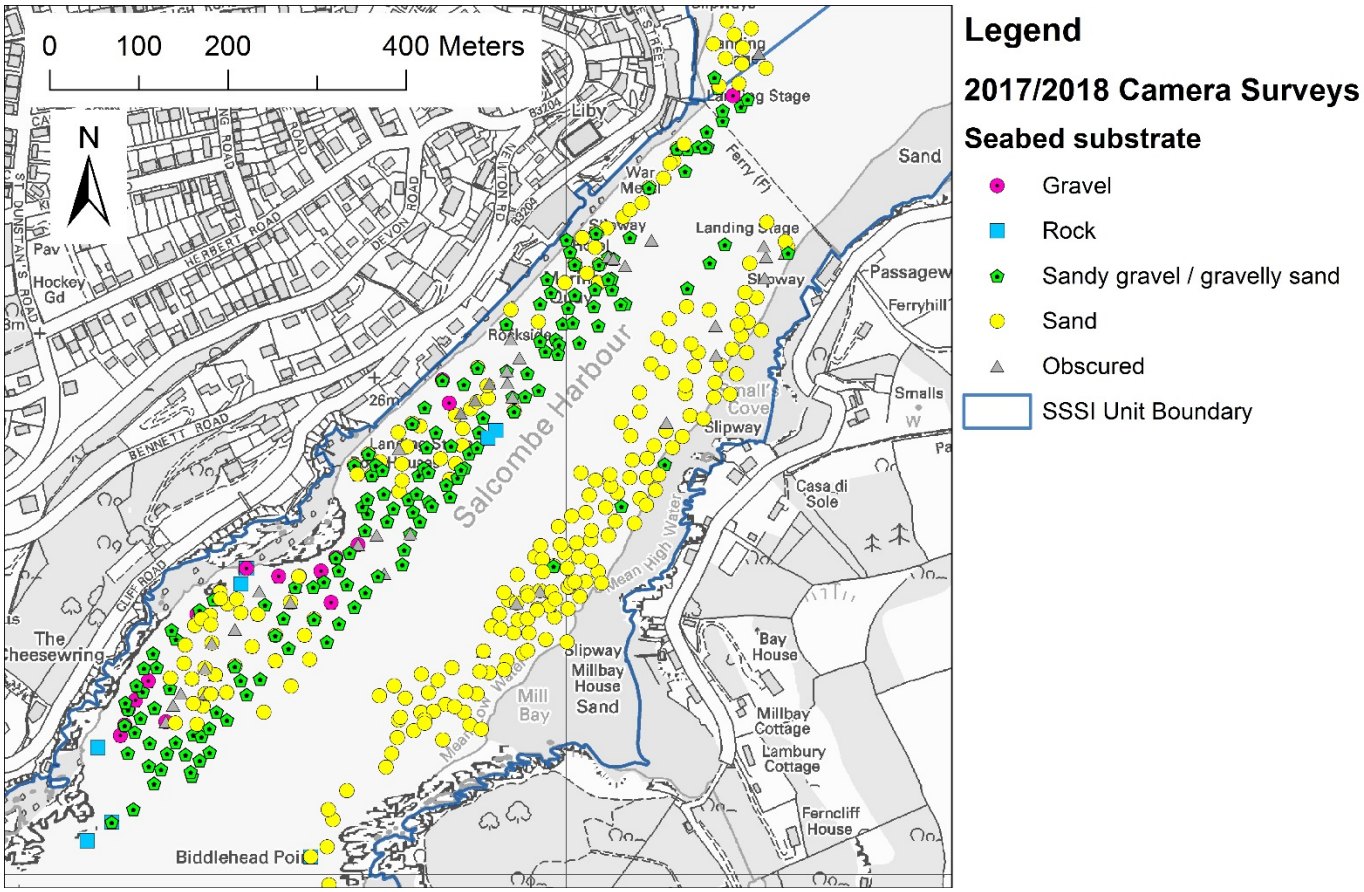


Figure 12. Observations of seabed substrate from still images collected at the main Salcombe Harbour bed and Mill Bay bed in 2017/18

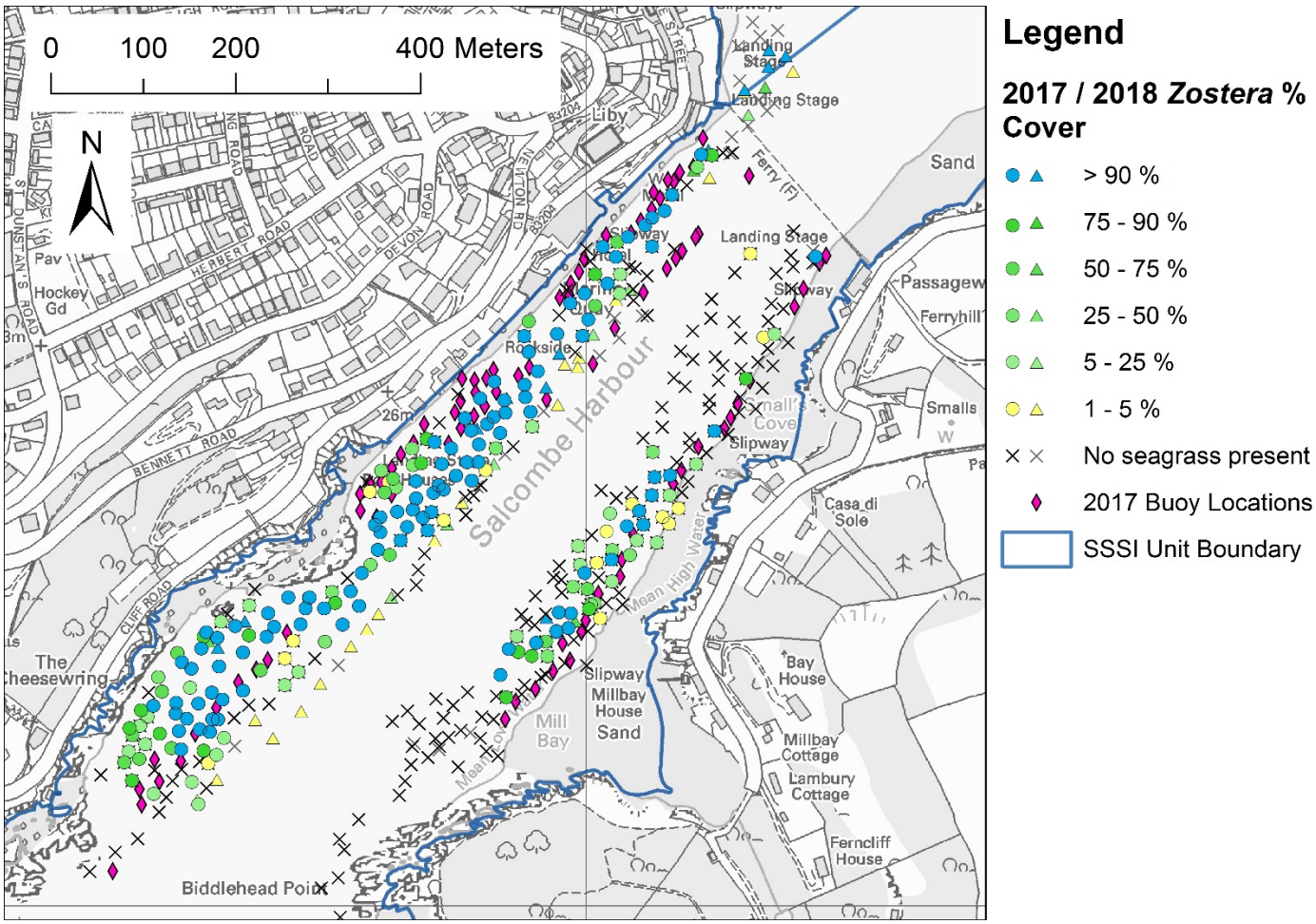


Figure 13. Percentage cover of *Zostera marina* assessed from still images collected in the main Salcombe Harbour bed and Mill Bay / East Portlemouth bed in 2017-18. Swing mooring locations recorded in 2017 are also shown.

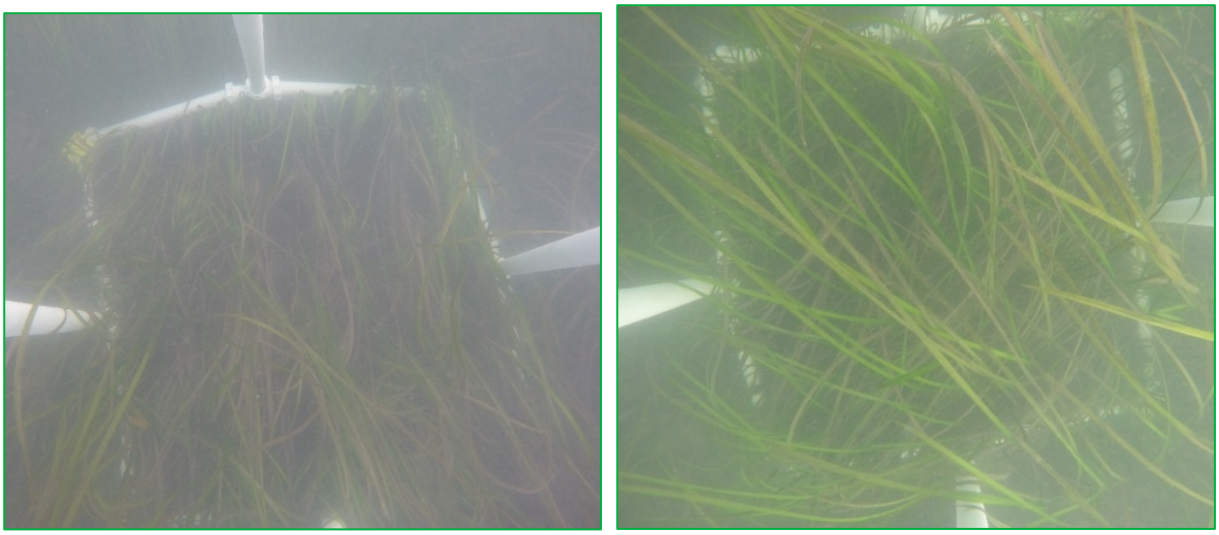


Figure 14. Example images of dense (90 - 100 % cover) *Zostera marina* beds sampled north of Woodville Rocks in 2017.

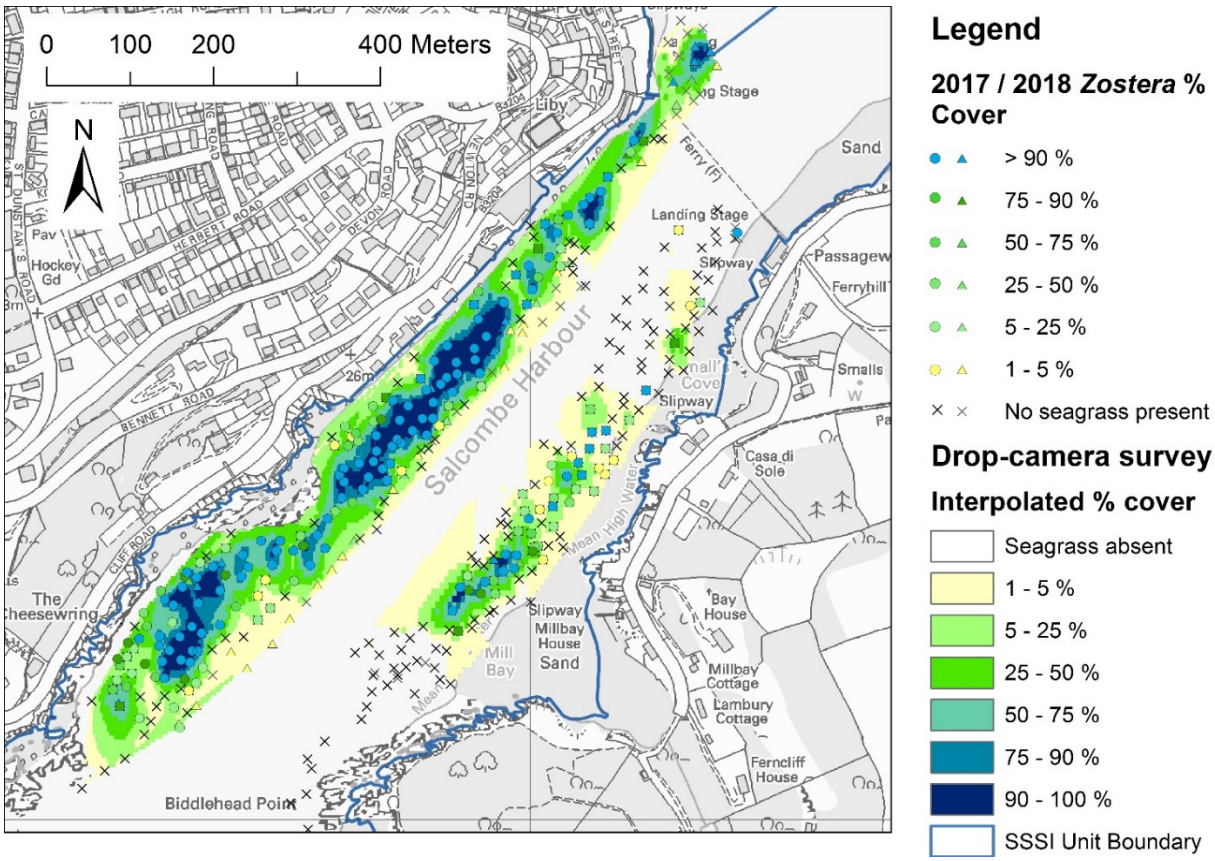


Figure 15. Interpolated map of seagrass density and extent from the drop-camera survey in the main Salcombe Harbour bed and Mill Bay / East Portlemouth bed in 2017-18.

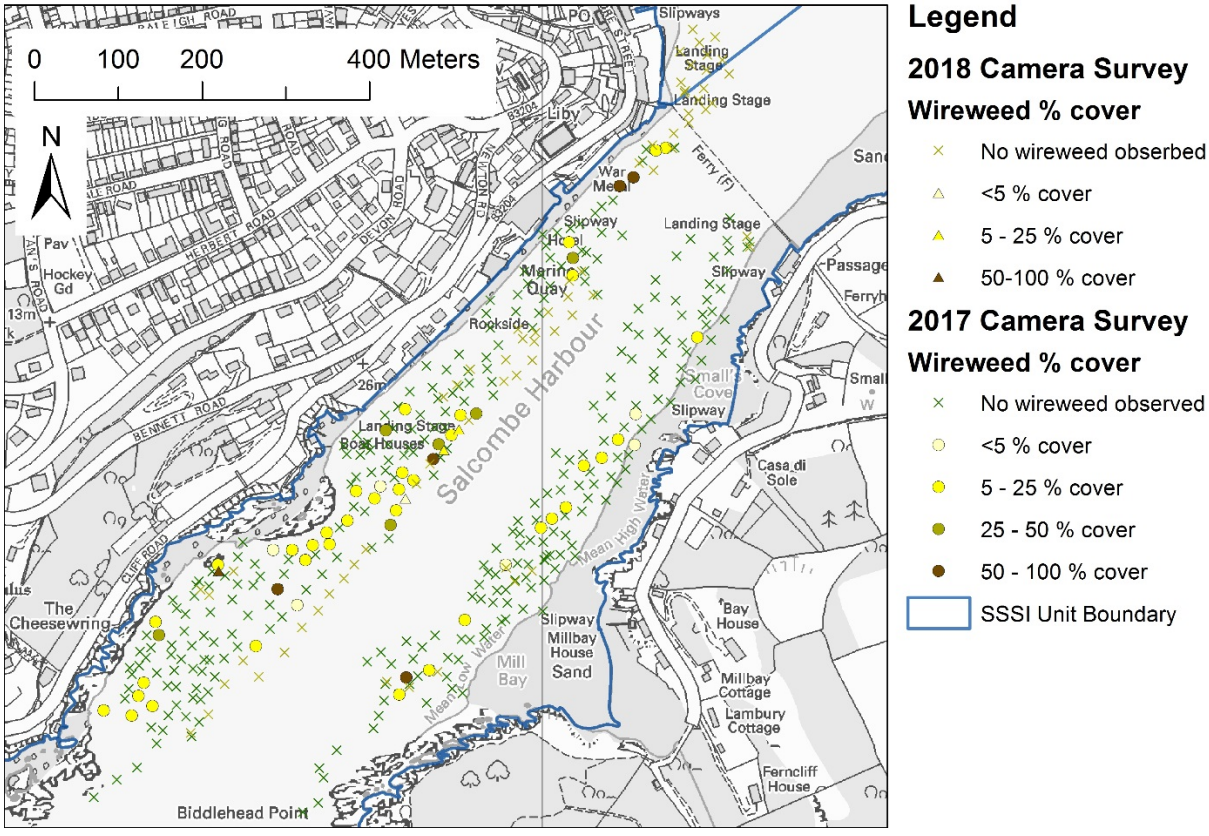


Figure 16. Wireweed (*Sargassum muticum*) presence from the 2017-18 drop-camera surveys in the main Salcombe Harbour seagrass bed and off Mill Bay / East Portlemouth.

3.4. Mill Bay / East Portlemouth

The sediment at East Portlemouth and Mill Bay was observed to be predominately sand along the full extent of the eastern side of the estuary channel. Occasional coarser gravelly sand patches were observed closer to the estuary channel.

The largest beds of seagrass were present off Mill Bay, with several smaller patches occurring along the coast to East Portlemouth.

Where *Zostera* was present, the mean percentage cover was 51.08 ± 4.15 % (Figure 6). The mean percentage cover within a defined bed (> 5 % cover threshold) was **61.48 ± 4.19 %** (**Figure 17**).

Following interpolation of the still image data, the total area of seagrass bed (>5 % cover) was estimated at **1.414 ha**. An additional 2.487 ha of seabed had 1 - 5 % seagrass cover, and could be considered supporting habitat (**Table 4**).

The wireweed *Sargassum muticum* was observed at 14 stations, including within the seagrass at Mill Bay.

Twenty-three moorings were recorded in the area of survey, most of which were positioned close to the mean low water line.

Table 4. Interpolated *Zostera* bed extent values for percentage cover boundaries for the Mill Bay / East Portlemouth bed.

***Zostera* Percentage cover**	**East Portlemouth / Mill Bay Bed extent (ha)**	**% of total extent**
5 - 25 %	0.639	45.2 %
25 - 50 %	0.437	30.9 %
50 - 75 %	0.218	15.4 %
75 - 90 %	0.085	6.0 %
> 90 %	0.035	2.5 %

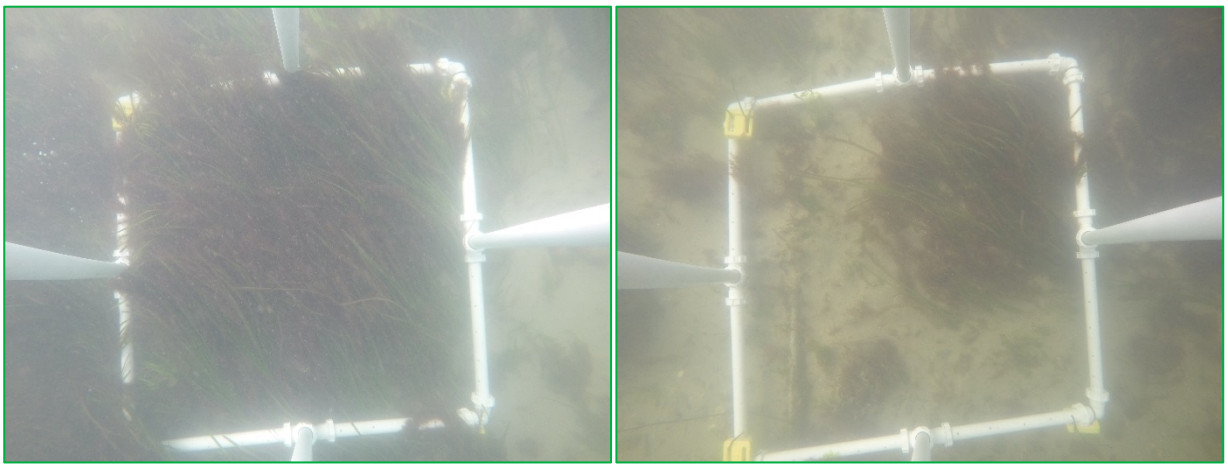


Figure 17. Example images of dense (90 - 100 % cover) and sparse (25 - 50 %) *Zostera marina* beds sampled at Mill Bay in 2017. These two images were sampled approximately 5 m apart, indicating the patchy nature of the Mill Bay beds.

3.5. Echosounder results

The echosounder survey was undertaken over the Main Bed, Mill Bay and South Sands beds. Over the main Salcombe bed, the echosounder assessment of density (the percent volume inhabited metric, PVI) and the visual assessment of density from the camera images broadly agreed (**Figure 18**). The seagrass canopy height (bioheight) was assessed by the echosounder to be > 0.75 m in the densest areas of the bed, and over 1.25 m in areas north of Woodville Rocks (**Figure 19**).

At South Sands, the echosounder density assessment broadly agreed with the distribution of seagrass. However, the presence of kelp and dense macroalgae to the north, south and at the seaward edge of the bed indicated areas that could be misinterpreted as seagrass if groundtruthing data was not available (**Figure 20**).

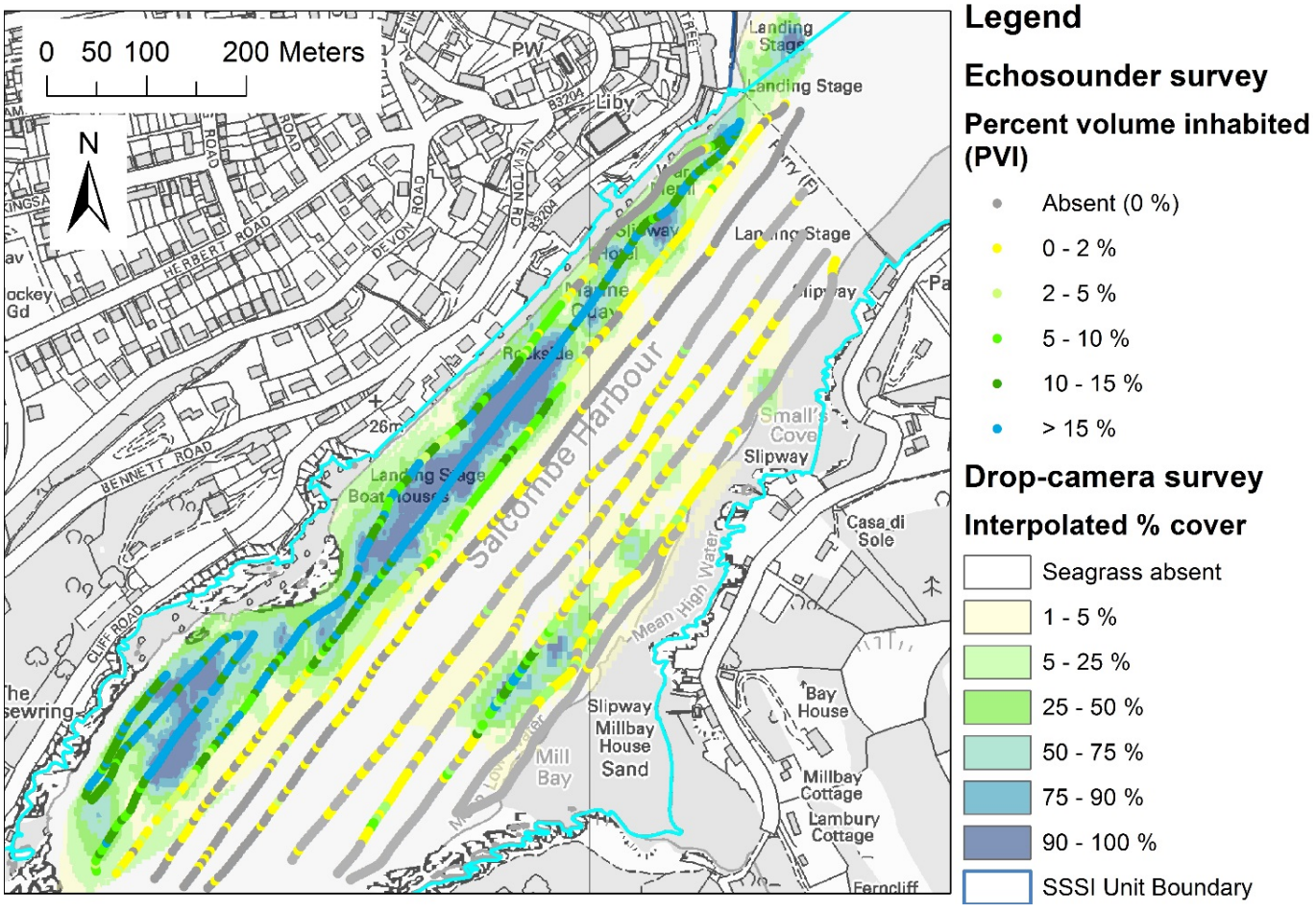


Figure 18. Percent Volume Inhabited (PVI) measurements of seagrass density using a singlebeam echosounder, overlaid over the seagrass extents determined from drop-camera surveys in the main Salcombe and Mill Bay / East Portlemouth beds.

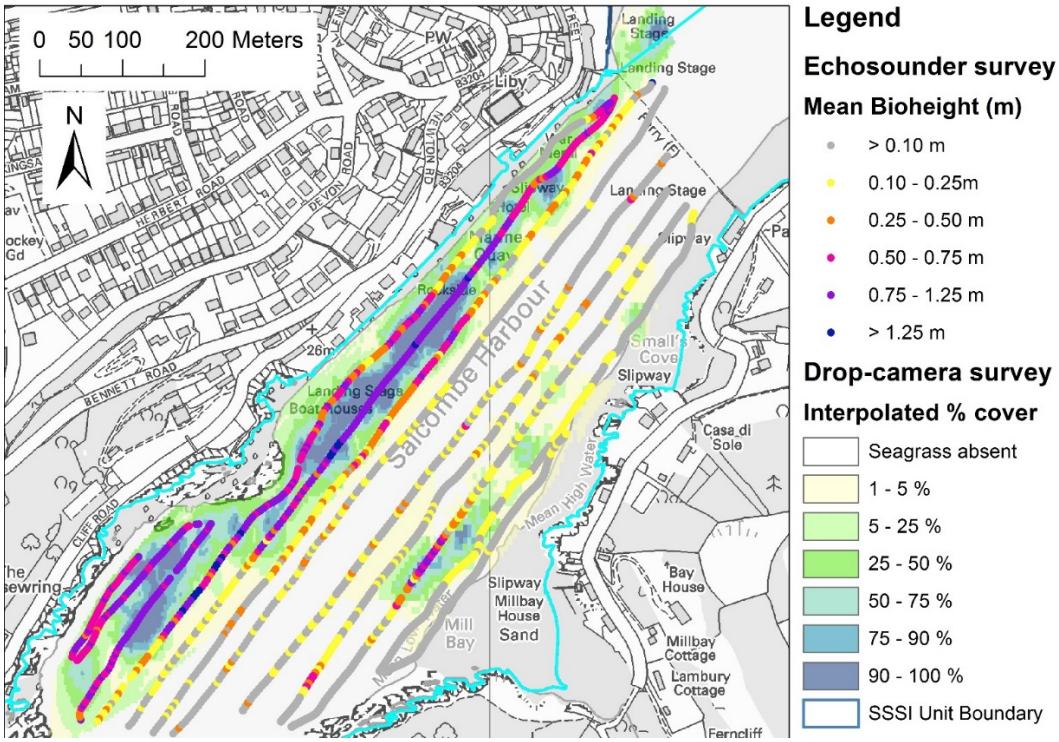


Figure 19. Mean bioheight measurements of seagrass canopy height using a singlebeam echosounder, overlaid over the seagrass extents determined from drop-camera surveys in the main Salcombe and Mill Bay / East Portlemouth beds.

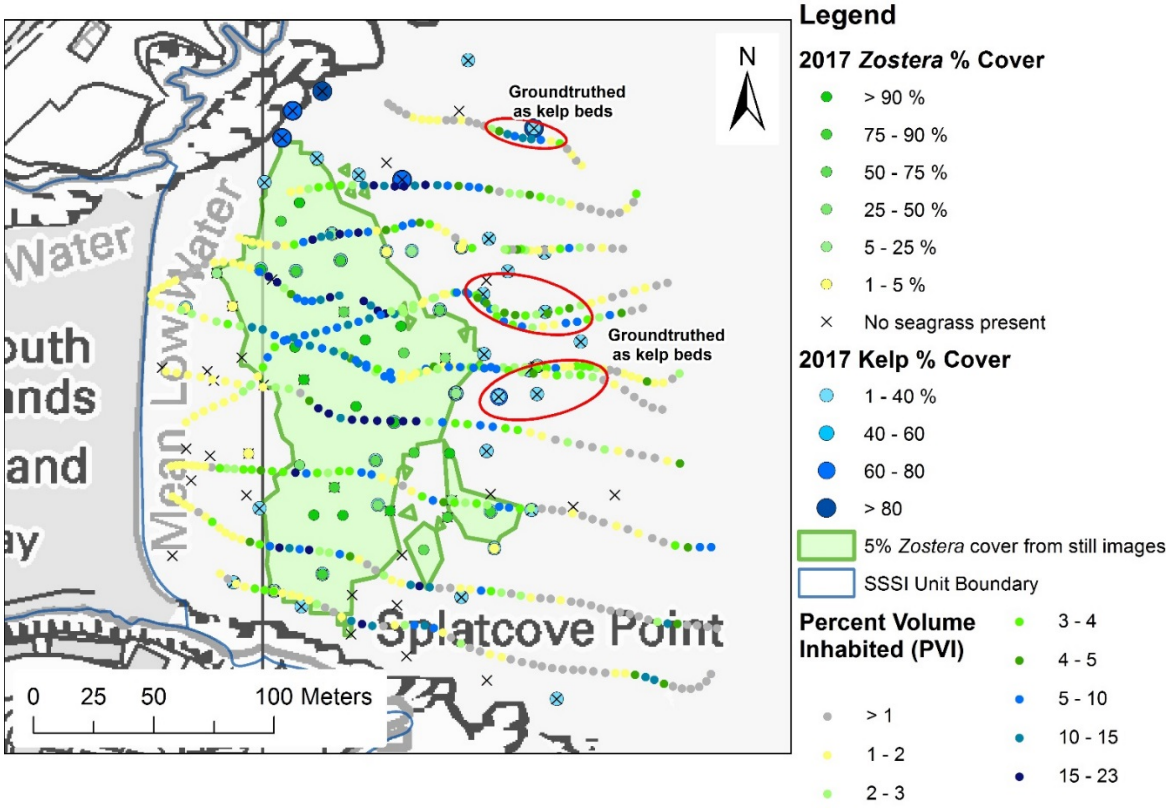


Figure 20. Percent Volume Inhabited (PVI) measurements of seagrass density using a singlebeam echosounder, overlaid over the seagrass extents determined from drop-camera surveys in the South Sands bed. Note areas circled in red that appeared to be dense areas of seagrass on the echosounder, but were actually groundtruthed as kelp beds.

3.6. Comparison to 2017 aerial photography

Aerial photography was flown in summer-autumn 2017. A visual assessment of seagrass in the aerial photos showed a varied alignment with the 2017-18 extents assessed by drop-camera. While the photography provided excellent information on the fine-scale detail of bed extents and the potential impact of mooring chains, there were notable differences to the camera-derived extent:

- Areas that appeared to be bare sediment on the aerial photography were shown to be low-density seagrass beds from the drop-camera survey (particularly notable at South Sands, **Figure 21**).
- Areas that appeared to be seagrass on the aerial photography were shown to be macroalgae or kelp beds from the camera survey (particularly notable at South Sands and Mill Bay / East Portlemouth, **Figures 22 & 23**).
- Seagrass beds were present in the camera survey in areas of deeper water that were not visible on the aerial photography (particularly notable in the Main Salcombe bed, **Figures 22 & 23**).

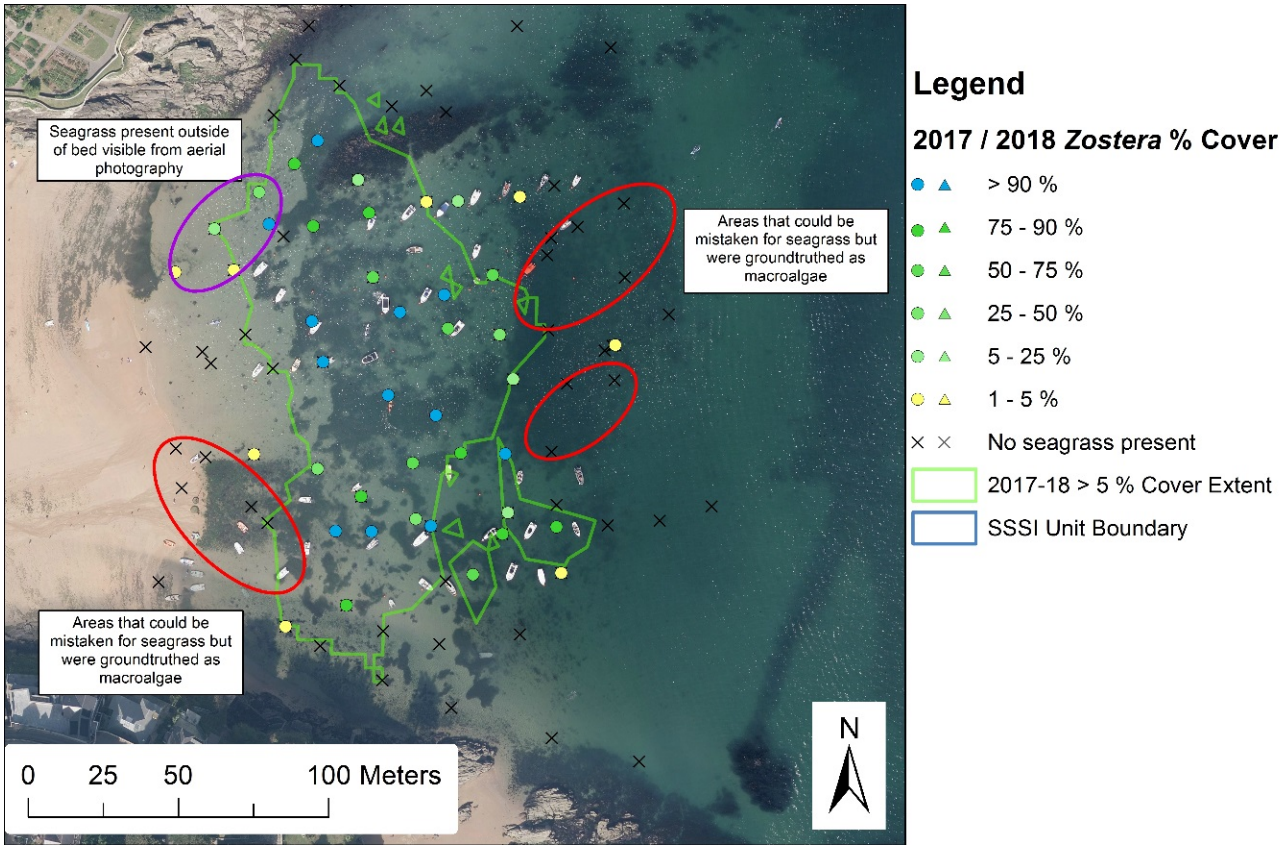


Figure 21. Seagrass bed extent derived from the 2017-18 drop-camera survey at South Sands, overlaid on aerial photography flown in summer 2017. Red and purple ovals highlight discrepancies between the two survey methods.

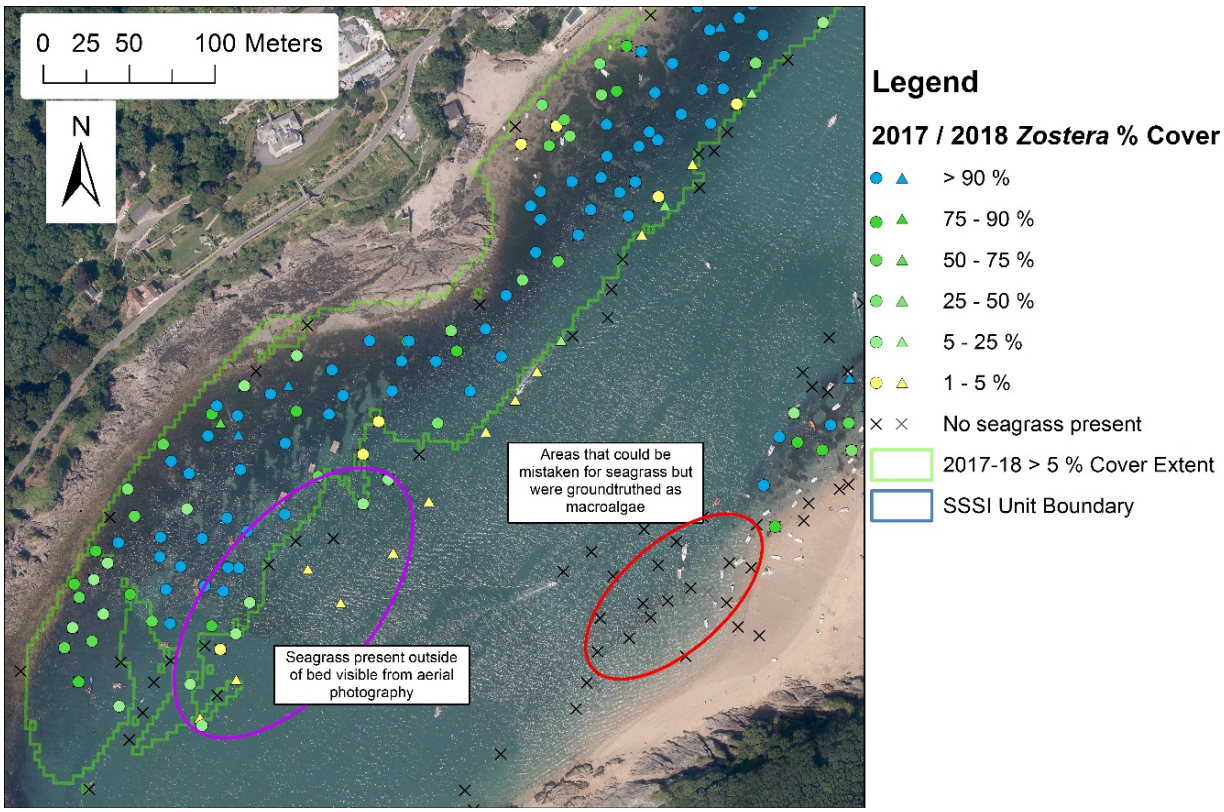


Figure 22. Seagrass bed extent derived from the 2017-18 drop-camera survey of the south main Salcombe bed, overlaid on aerial photography flown in summer 2017. Red and purple ovals highlight discrepancies between the two survey methods.

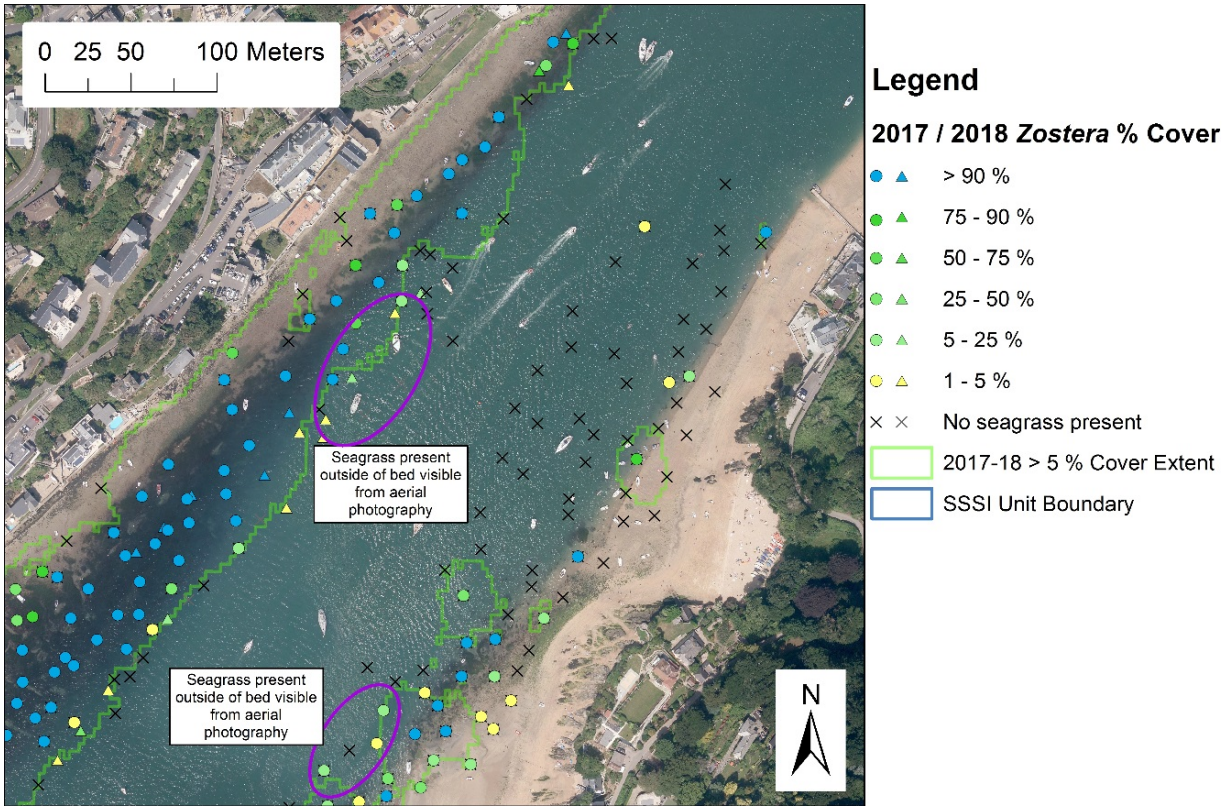


Figure 23. Seagrass bed extent derived from the 2017-18 drop-camera survey of the north main Salcombe bed, overlaid on aerial photography flown in summer 2017. Purple ovals highlight discrepancies between the two survey methods.

Additionally, 135 moorings were recorded over or close to the seagrass beds during the survey. Whilst no analysis of the association between moorings and seagrass percentage cover undertaken, there were areas that could be appeared to be 'gaps' in seagrass cover in the 2017 aerial photography that were closely located with mooring buoy locations georeferenced in 2017 (**Figure 24**).

Figure 24. Moorings (purple diamonds) recorded during the 2017 seagrass survey of the Salcombe main seagrass bed, overlaid on aerial photography flown in summer 2017, highlighting loss of seagrass bed areas close to moorings. The green line indicates interpolated 2017-18 bed extent.

4. Discussion

4.1. Comparison of extent and % cover to historic data

- The 2017-18 survey of the subtidal seagrass beds in the Salcombe to Kingsbridge Estuary SSSI recorded the total extent as 10.14 ha. The extent of the main Salcombe bed was 7.523 ha which is **almost 2.5 ha (35 %) bigger** than the extent recorded in 1997 by Mortimer, and slightly bigger than the combined (with Mill Bay) extent of Faithfull (2015), although not as big as the combined extent of the D&SIFCA (**Table 5**).
- The increased extent (**Figure 25**) of the Main Salcombe Bed was due to:
    - Seagrass was observed for the first time extending into the mouth of Batson Creek (unit 4 of the SSSI). This is further north than previously recorded, and in area that has not been previously surveyed.
    - Seagrass was recorded as extending further into the centre of the estuary than previously recorded, notably in areas south of Woodville Rocks.
- The extents of the fragmented beds in Mill Bay / East Portlemouth were larger than previously recorded by Mortimer (1997), and by Rhodes et al. (2006) (**Figure 25**). The beds at Mill Bay did not extent as far south as identified from the aerial photography by Rhodes (2006), but were interpolated to extend both further into the intertidal and into the estuary than compared to Mortimer (1997).
- The extent of the South Sands bed was 18 % larger than recorded using aerial photography by Rhodes et al. (2006), but the distribution of the beds recorded in this study is different. The Rhodes et al. (2006) beds have larger extents to the south west and south east of South Sands bay, whilst this study recorded more seagrass in the north east and north west of the bay (**Figure 26**).
- The small patches of seagrass at North Sands was recorded to the southwest of the extent derived using aerial photography by Rhodes et al. (2006) (**Figure 27**).
- Overall, between-year comparisons of extent will be of low confidence, due to the different survey methods used between each year.

Table 5. Historic seagrass extent records of the three main beds in Salcombe Harbour, compared to the extents recorded in this survey. Note that different survey methods were used for each survey.

Survey	Main bed (ha)	Mill Bay (ha)	South Sands (ha)
1985 (MNCR)	4.031	1.780	1.023
1997 (Mortimer)	4.911	0.186	0.014
2002 / 2004 (Rhodes et al.)	4.527	0.739	1.025
2009 (Bunker, intertidal only)	0.053	1.659	N/A
2014 (D&SIFCA)	9.699 (beds combined)		N/A
2015 (Faithfull, multibeam only)	7.265 (beds combined)		N/A
2017 / 18 (this survey)	7.523	1.414	1.204

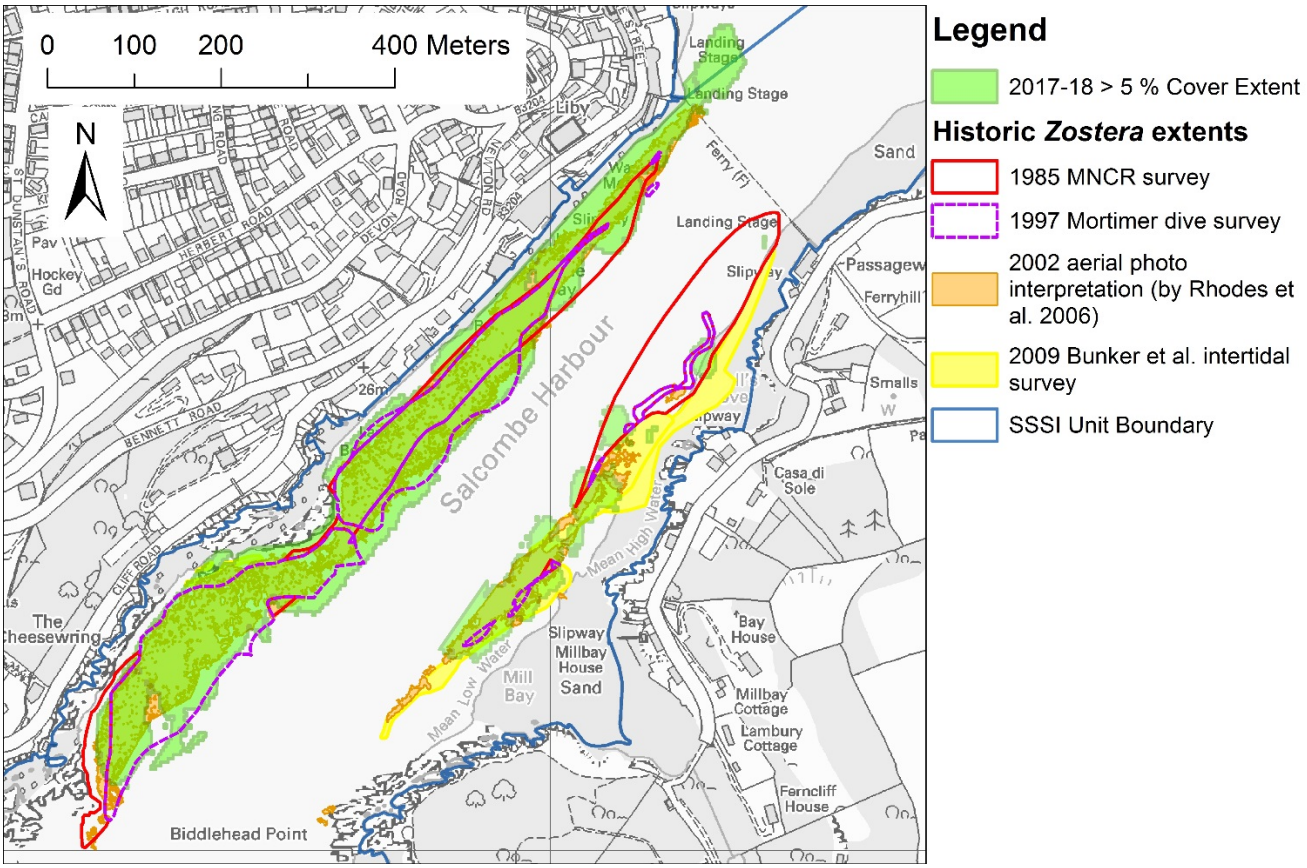


Figure 25. Seagrass bed extent derived from the 2017-18 drop-camera survey, compared to previous surveys from 1985-2009 in the Salcombe bed and Mill Bay/East Portlemouth.

- Only Field (2009) has previously recorded seagrass percentage cover, although sample numbers were low and restricted to the north of the main Salcombe bed. Field observed mean percentage cover of 34 % (pre-dredging of Batson Creek) and 50 % (post-dredging), which is lower than the mean 74.8 % cover observed in the main Salcombe bed in this study.
- Shoot density was assessed by divers in Axellson et al. (2015), who recorded the main Salcombe bed had lower mean shoot densities (12.8 and 13.8 shoots 0.25 m^{-2} for North and South of the main Salcombe bed respectively) than South Sands (16.4 shoots 0.25 m^{-2}) and Mill Bay / East Portlemouth (26.3 shoots 0.25 m^{-2}). The relative ratios of the Axellson et al. (2015) shoot densities between the beds differs to the ratios of percentage covers between the beds observed in this study, where South Sands had the far lowest percentage cover (18.1 %), compared to the main Salcombe (74.5) and Mill Bay / East Portlemouth (61.4 %) beds.
- Percentage cover of the main Salcombe and Mill Bay / East Portlemouth beds are relatively high compared to other recently recorded subtidal seagrass beds from the south coast of England, and equivalent density to beds sampled in Plymouth Sound, Solent and Yealm Estuary (**Table 6**).

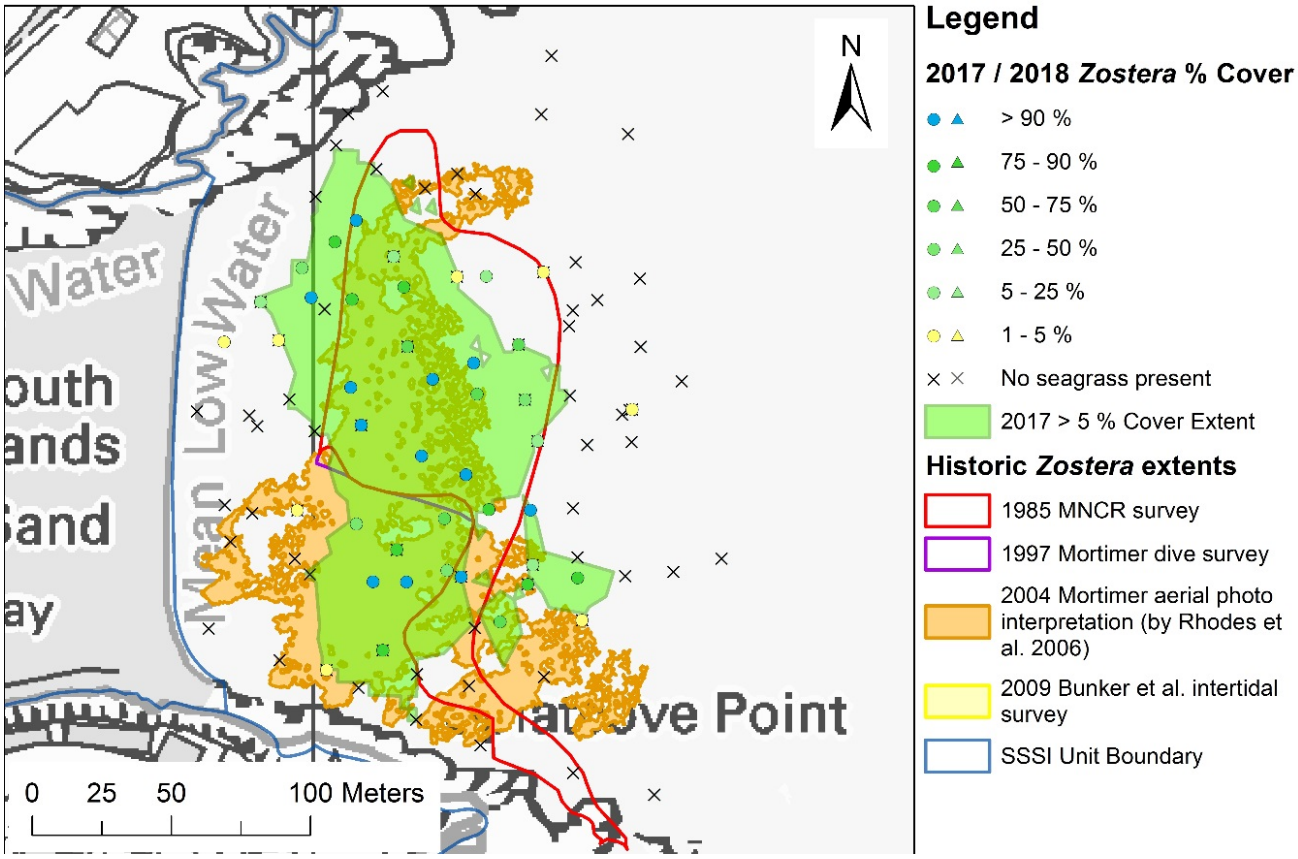


Figure 26. Seagrass bed extent derived from the 2017-18 drop-camera survey, compared to previous surveys from 1985-2009 at South Sands.

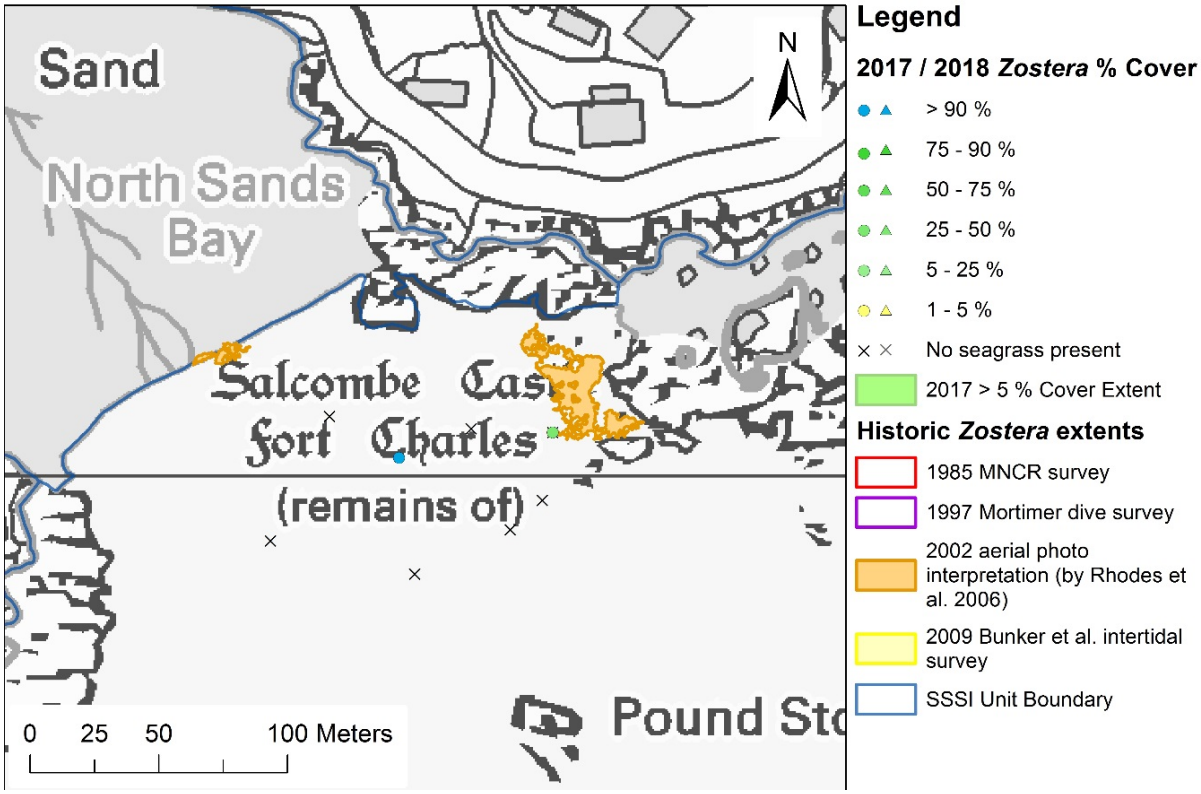


Figure 27. Seagrass bed extent derived from the 2017-18 drop-camera survey, compared to previous surveys from 2002 at North Sands.

Table 6. Examples of percentage cover of subtidal seagrass beds surveyed in this study and other beds surveyed in 2019. All the studies used the same drop-camera system.

Bed	Percentage cover (± S.E.)	Source
(North & South) Salcombe main bed	74.8 ± 1.7 %	This survey
Mill Bay / East Portlemouth	61.5 ± 4.2 %	This survey
South Sands	18.1 ± 3.8 %	This survey
Cawsand Bay (Plymouth Sound)	42.8 ± 1.5 %	Bunker & Green (2019)
Drakes Island (Plymouth Sound)	72.3 ± 4.0 %	Bunker & Green (2019)
Jennycliffe South (Plymouth Sound)	13.9 ± 2.3 %	Bunker & Green (2019)
Cellar Cove (Yealm Estuary)	69.2 ± 3.3 %	Bunker & Green (2019)
Yarmouth - Bouldnor (Solent)	75.8 ± 15.0 %	Green (2019)
Totland Bay (The Needles MCZ)	36.2 ± 0.8 %	Green (2019)
Colwell Bay (The Needles MCZ)	32.9 ± 1.2 %	Green (2019)

4.2. Methodology appraisal

- It should be noted that all the surveys that have attempted to estimate extent to date, have all used different survey methods - aerial photography, drop-camera, divers and echosounders. There are both advantages and drawbacks with each method when it comes to obtaining data that can be compared between sampling events.
- Aerial photography can provide excellent fine scale detail on seagrass distribution, and impact of moorings (as demonstrated by Rhodes et al. 2006), but without suitable groundtruthing, may not accurately map low density areas of seagrass and seagrass in deeper waters. It may also struggle to distinguish seagrass from patches of macroalgae.
- The echosounder technique used in 2018 generally gave good spatial patterns in seagrass density and canopy height, as there was sufficient groundtruthing to support avoid misinterpreting macroalgae as seagrass. Future surveys should ideally undertake the echosounder transects at every 20 m apart instead of every 50 m apart, in order to provide more fine-scale detail on seagrass density.
- The drop-camera technique used in this study provides a consistent, replicable, large scale and detailed picture of extent and percentage cover, but cannot provide the fine-scale detail of impacts from moorings (on patches that are definitively seagrass) as well as can be done through aerial photography or diver surveys.
- The quantification of extent from drop-camera stations will be subject to a level of variability due to the use of interpolation techniques to predict seagrass density in areas where it was not sampled. The Natural Neighbour interpolation method was used in this study, but other approaches (e.g. kriging) could give slightly different extent values.

4.3. Summary and conclusions

- The extent and density of seagrass in the Salcombe to Kingsbridge Estuary SSSI has shown an increase compared to previous records. However, confidence in comparison of extent between years is low (especially in the main Salcombe bed), as there have been several different survey methods used to measure extent since 1997.
- The results showed that South Sands had the lowest mean percentage cover of seagrass compared to the main Salcombe and Mill Bay / East Portlemouth beds.
- Aerial photography shows mixed results compared to extents determined by camera surveys, although it does provide fine scale evidence of impacts on seagrass beds by swing moorings. It should be interpreted with supporting groundtruthing.
- Future surveys should ideally repeat the methodology used in 2017/18 - echosounders can be used to quickly resurvey on an annual basis to understand between-year variability in seagrass extent, providing they are used in areas that have been previously groundtruthed to be seagrass. Additional groundtruthing would be required in fringing areas to confirm that seagrass is present. A detailed camera survey should be repeated every reporting cycle to confirm seagrass density.

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