Isles of Scilly eelgrass bed voluntary monitoring programme

2016 Annual Survey

A report for Natural England, prepared by Drs James Bull and Emma Kenyon

In association with Project Seagrass

http://www.projectseagrass.org

Contents

1. ABSTRACT

In this report, we present novel data from an ongoing, spatially replicated, annual study of a comparatively un-impacted temperate eelgrass habitat, based around the Isles of Scilly, UK. Five sites were assessed: Broad Ledges Tresco, Higher Town Bay, Little Arthur, Old Grimsby Harbour, and West Broad Ledges. Metrics include eelgrass (*Zostera marina*) shoot density, number of leaves per shoot, maximum shoot length, as well as semi-quantitative recording of signs of wasting disease and epiphyte cover on a leaf-by-leaf basis. Findings from the 2016 survey, as well as their place in continuous time series from 1996, are presented primarily in graphical form. **This represents twenty-one years of continuous annual monitoring around the Isles of Scilly.** Additionally, we use Generalised Linear Modelling to test a series of hypotheses on spatial and temporal trends.

Overall, eelgrass was present at all five survey sites around the Isles of Scilly. The 2014 and 2015 surveys did not find significant variation in shoot density between survey sites. In contrast, the 2016 survey did find significant variation between sites, **with Old Grimsby Harbour having the lowest density.** Longer-term trends reveal significant declines in average shoot density at two out of five surveyed sites: since Special Area of Conservation designation in 2005, **Higher Town Bay has declined 21%** and Little Arthur 14%.

Consistent with 2015, canopy height was found to differ between sites with shorter plants, on average, recorded at Old Grimsby Harbour and Broad Ledges Tresco during the 2016 survey. In particular, Broad Ledges Tresco was found to have substantially reduced canopy height compared to all previous years surveyed, apart from 2000, although this was offset by unusually high shoot density for this site in 2016.

Shoot density and canopy height were combined into a measure of Leaf Area Index (LAI - estimating total photosynthetic area per unit ground). We did not find significant differences in LAI between the five survey sites on the 2016 survey. It appears that shoot density is generally offset by canopy height, indicating a possible compensatory mechanism by which seagrass achieves resilience.

The 2016 results also showed differences between survey sites in levels of eelgrass ‘patchiness’; time series analysis showed that over time there has been a significant decline in the proportion of quadrats with eelgrass present at Old Grimsby Harbour. This has reduced to less than 25% of the coverage reported at the start of this monitoring (1996) and a **drop of over 50% since SAC designation in 2005 at Old Grimsby Harbour.**

Differences in wasting disease and epiphyte coverage scores were evident between survey sites although long term trends in these are not investigated in this report. Broad Ledges Tresco, Little Arthur and West Broad Ledges had higher levels of disease evident than at other sites; and Broad Ledges Tresco had had lower than average epiphyte abundance. Finally, we continue to see *Sargassum muticum*, an invasive species of brown seaweed known as wireweed, at all surveyed sites in the Isles of Scilly. While this is not formally quantified, no obvious changes in abundance or distribution were evident.

While the synthesis of these findings indicates particular concerns for the state of *Zostera marina* at Higher Town Bay and Old Grimsby Harbour, in fact only West Broad Ledges doesn’t show a decline in at least one metric assessed. The real value of this survey is the part it forms in what is now **the longest continuous, detailed annual survey of eelgrass in the world**, as far as we are aware.

2. INTRODUCTION

2.1 Eelgrass

Seagrasses are globally dispersed along coastlines, covering approximately 0.3 to 0.6 million km^2 (Duarte & Chiscano 1999, Duarte 2002). Much of the value of seagrass meadows lies in their high levels of primary productivity, acting as a carbon and nutrient sink, providing a shelter for invertebrates or juveniles of fish species and protecting shorelines via wave attenuation and stabilisation of sediments (Costanza et al. 1997, Duarte & Chiscano 1999, Gillanders 2007). However, seagrasses are currently in rapid decline worldwide, due to a range of anthropogenic impacts, disease and climate change (Orth et al. 2006, Waycott et al. 2009). As a result, there is considerable interest in understanding the drivers of seagrass population dynamics and a general appreciation that multiple spatial scales are important (for example, local density at the sub-metre scale (Olesen & Sand-Jenson 1994a, 1994b, Bull et al. 2012), the influence of clonal expansion over tens of metres (Reusch et al. 1999, Kendrick et al. 2005, Zipperle et al. 2011), or even metapopulation processes spanning oceans (Rozenfeld 2008).

Seagrass population dynamics have typically been studied through measuring allometric relationships between specific life history components and shoot density or biomass, within a season (Olesen & Sand-Jensen 1994a, b). Whilst these studies are necessary to identify mechanisms contributing to seagrass turnover, it has been rare for investigators to look at natural populations across many years. By repeating annual surveys at the same point in each growing season, to control for within-season variation, the longer-term effects of biological or environmental drivers of population dynamics can be quantified.

The focal seagrass species of this report is eelgrass, *Zostera marina*, the predominant seagrass species of the north Atlantic.

2.2 Wasting disease

In the 1930s, a 'wasting disease' (*Labyrinthula zosterae*) substantially reduced populations of eelgrass. Along the Atlantic coasts of Europe and North America, up to 90% loss was estimated (Muehlstein 1989), with dramatic knock-on effects to fishing industries and waterfowl populations (Orth et al. 2006). Wasting disease continues to affect eelgrass beds, but with no outbreaks as dramatic as the epidemic of the 1930s (Short et al. 1988). Various theories have been put forward to explain the occurrence of wasting disease (review in den Hartog 1987). In particular, environmental stresses, especially high summer temperatures, have been suggested as a likely trigger for epidemics (Rasmussen 1977).

Wasting disease was reported to have reappeared around the Isles of Scilly in the early 1990s, and this was a key motivation for monitoring reported in this study (Fowler 1992). We quantified signs of disease by its characteristic leaf lesions (den Hartog 1989; Burdick et al. 1993). We did not test for the presence of the causative agent directly (for example, by culturing or polymerase chain reaction). However, results from population dynamic modelling of this system are entirely consistent with these signs of disease being caused by an infectious agent (Bull et al. 2012).

2.3 Epiphytes

In this survey, we did not attempt to identify specific epiphytes as this would require a level of expertise and time that is beyond the scope of this project. Rather, we treated all visible epiphytes as a functional group, likely to have a similar effect on seagrass growth by restricting light reaching the photosynthetic surface of leaves. In reality, the epiphytic community of *Zostera marina* is typical of many seagrasses, dominated by algae but comprising a range of invertebrate species as well (Borowitzka 2007). There is known to be substantial spatial and temporal heterogeneity in epiphyte distributions on the leaves of *Z. marina* (Cullinane et al. 1985, Johnson et al. 2005); a phenomenon also found in other seagrass genera, such as *Amphibolis* (Lethbridge et al. 1988) and *Posidonia* (Piazzi & Cinelli 2000). This diversity in epiphytic species is likely to be structured by rich and, as yet, uncharted population dynamics.

2.4 Isles of Scilly

One of the main surviving eelgrass habitats around the UK is located in the shallow, relatively sheltered waters between the numerous islands and rocks that make up the Isles of Scilly, UK. Lying approximately 25 miles south west from Land's Ends, Cornwall, the Isles of Scilly are to the extreme west of the United Kingdom (Figure 1). They comprise an archipelago of approximately 200 granite islands and rocks, separated by shallow sea. The five main islands (St. Mary's, St. Martin's, Tresco, St. Agnes and Bryher) are permanently inhabited, supporting tourism, fishing and small scale farming.

The Isles of Scilly SAC was designated in 2005 and is protected for the following features (and sub-features):

1) Sandbanks which are slightly covered by sea water all the time (subtidal seagrass beds, subtidal coarse sediment, subtidal sand, subtidal mixed sediments),
2) reefs (intertidal rock, infralittoral rock, circalittoral rock),
3) mudflats and sandflats not covered by seawater at low tide (intertidal sand and muddy sand),
4) grey seals (*Halichoerus grypus*),
5) shore dock (*Rumex rupestris*).

Natural England has a duty to report on the condition of the eelgrass bed communities sub-feature every six years. This commitment, in part, motivated the support provided by Natural England for the current volunteer monitoring project.

In this report, we present novel data from an ongoing, spatially replicated, annual study of a comparatively un-impacted temperate eelgrass habitat (Jones & Unsworth 2016). In this sub-tidal environment, there are no large grazing species, such as the geese that affect inter-tidal seagrass populations (Zipperle et al. 2010, van der Teide et al. 2012), or the marine turtles and sirenians of tropical seagrass habitats (Thayer et al. 1984, Fourqurean et al. 2012). In addition, our survey location is an archipelago with little industrial or agricultural impact or urbanisation (Figure 2). Here, eelgrass grows substantially as a natural monoculture and we are able to make rare baseline observations of a seagrass ecosystem not previously thought to be in serious overall decline.

2.5 Survey site descriptions

There have been no major developments close to any of the five eelgrass survey sites. However, there has been substantial work to extend the main quay in Hugh Town, St. Mary's. The amount of associated traffic and disturbance is unknown.

The following section is included for completeness and is much as reported in the 2014 and 2015 Annual Reports (adapted from Cook 2011).

Broad Ledges Tresco. Broad Ledge lies on the southern edge of Tresco and, together with Crab Ledge, Tobaccoman's Ledge and Green Island to the east, forms part of the large intertidal area that fringes the southern coast of Tresco. There is a small jetty that allows access to the island from the sea and is used by tourist boats when the tide permits. The bay is used on an occasional basis as an anchoring point for smaller yachts. The area is open to the prevailing southwesterly winds and weak tidal streams. The seabed here comprises coarse sand, mixed with small gravel, pebbles and some cobbles, as well as some *Sargassum muticum* plants and small macro algae, found attached to the small material. The site does have yachts anchoring but this is infrequent due to the more exposed nature of the location. The bed is close to the works that took place in 2008 to repair and extend the pier at Carn Near.

Higher Town Bay. The bay is situated on the southern edge of St. Martin's and is bounded by Cruther's Point to the west and English Point to the east. A small stone harbour, which acts as one of the main access points to the island from the sea, is situated at the western end of the bay. The bay is also used as an anchorage for a number of small vessels and the fringing beach and dune system are a popular destination for tourists. The eelgrass bed lies at the eastern end of the bay and runs from English Island along the edge of the bay. Strong tidal streams flow across the bay and the bed is also exposed to the prevailing southwesterly winds. The sea floor here comprises medium sands which, given the strong tidal streams, is liable to erosion. This sediment movement and erosion is prevented in some places, however, by the eelgrass rhizomes that help bind the sand and also promote accretion to the extent that the eelgrass forms prominent platforms that stand up to 30cm above the surrounding sea floor. The strong tidal streams bring large fronds of loose macro algae from the rocky ground of the Eastern Isles and although there are very few other species growing here, there are large loose fronds of transported material that overlie the eelgrass.

Little Arthur. This bed lies in the Eastern Isles and to the east of Little Arthur, where it is sheltered from the prevailing southwesterly winds and strong currents that flow round the islands. The Eastern Isles are also home to a colony of grey seals (*Halichoerus grypus*) that attract boats of tourists who come to view them. Few of these boats, however, anchor here and impact the eelgrass bed. The majority of the substrate within the islands comprises bedrock and large boulders that are covered by dense growths of macro algae. The eelgrass bed, however, lies in a small patch of medium sand and, despite the surrounding macro algae, the eelgrass bed is relatively free from any covering plants. This is one of the deepest beds surveyed in the islands and although small in area, exists as a complete single bed with few significant patches of sand.

Old Grimsby Harbour. The bed lies along the southern edge of the natural harbour formed by the small bay on the eastern side of Tresco that forms one of the main access points to the island from the sea. Although this access is dependent on the state of the tide, a large number of boats use the stone quay situated in the centre of the western side of the bay. The bay is found on the eastern side of the island and it provides shelter for both the visiting boats that anchor on the edge of the bay and local boats that use the permanent mooring buoys in the bay, from the prevailing southwesterly winds. These moorings are anchored to base weights by means of a heavy sinker chain with a large buoy on the surface. The chains have to be long enough to allow for the rise and fall of the tide, which means that at low water there is a large amount of chain lying on the sea floor and over the eelgrass shoots. As the direction of the wind and current changes the moorings move round causing the chains to be dragged over the plants. This can cause plants to be dislodged and even for the rhizomes to be damaged. The presence of exposed and dislodged rhizomes within the arc of the chains movement confirms this theory. The seabed is mainly medium sand overlaid with eelgrass, intermixed with some overlying loose macro algae. It should also be noted that during the 2010 survey, large quantities of green and brown algal masses were recorded across the site and no eelgrass was found. Time series presented in the current report show zero eelgrass for this site in 2010. However, a limited number of quadrat records were made that year at an adjacent site (c. 100m away), which could be used for comparisons.

West Broad Ledges. West Broad Ledge lies on the southwestern edge of St. Martin’s and on the southern edge of the channel between St. Martin’s and the island of Tean. This channel is used by pleasure boats navigating between the islands but not often as an anchoring point as boats generally choose to anchor further to the north of the access jetty. The seabed comprises medium and coarse sand with small gravel and pebbles on which some fronds of *S. muticum* and other species of small macro algae are present. The eelgrass bed covers a wide area but is highly patchy in nature. The bed is also swept by strong tidal currents, especially on spring tides.

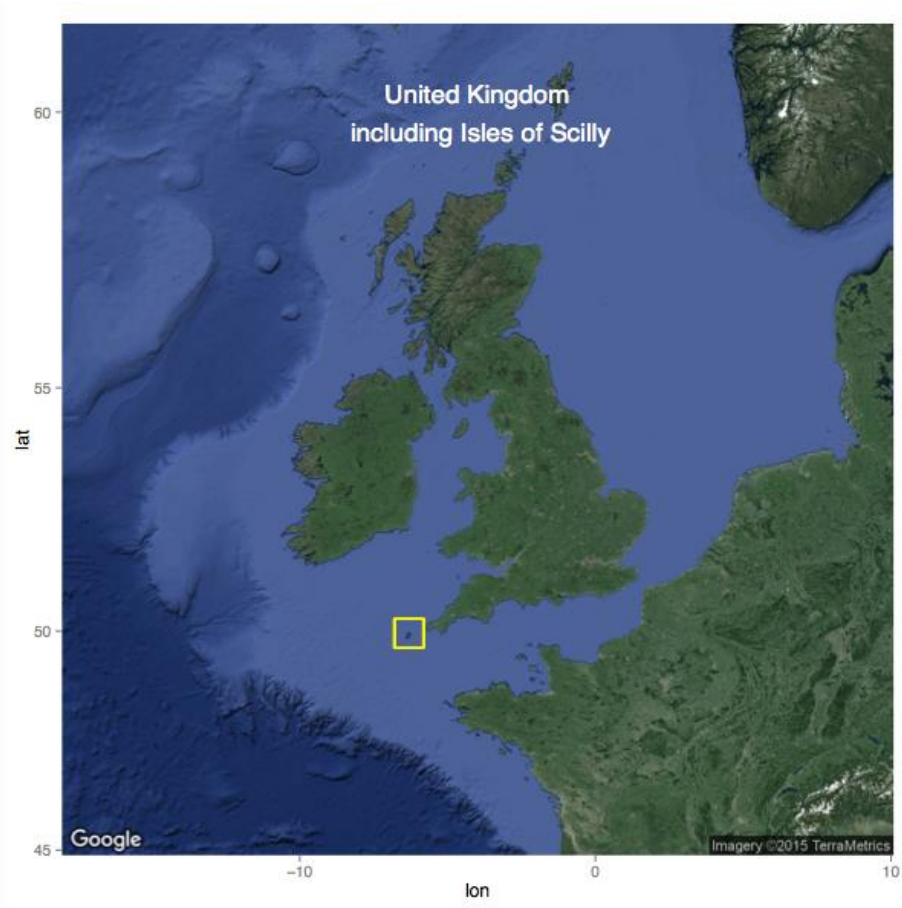


Figure 1 - Location of the Isles of Scilly in relation to the rest of the United Kingdom. Yellow square surrounds the Isles of Scilly.

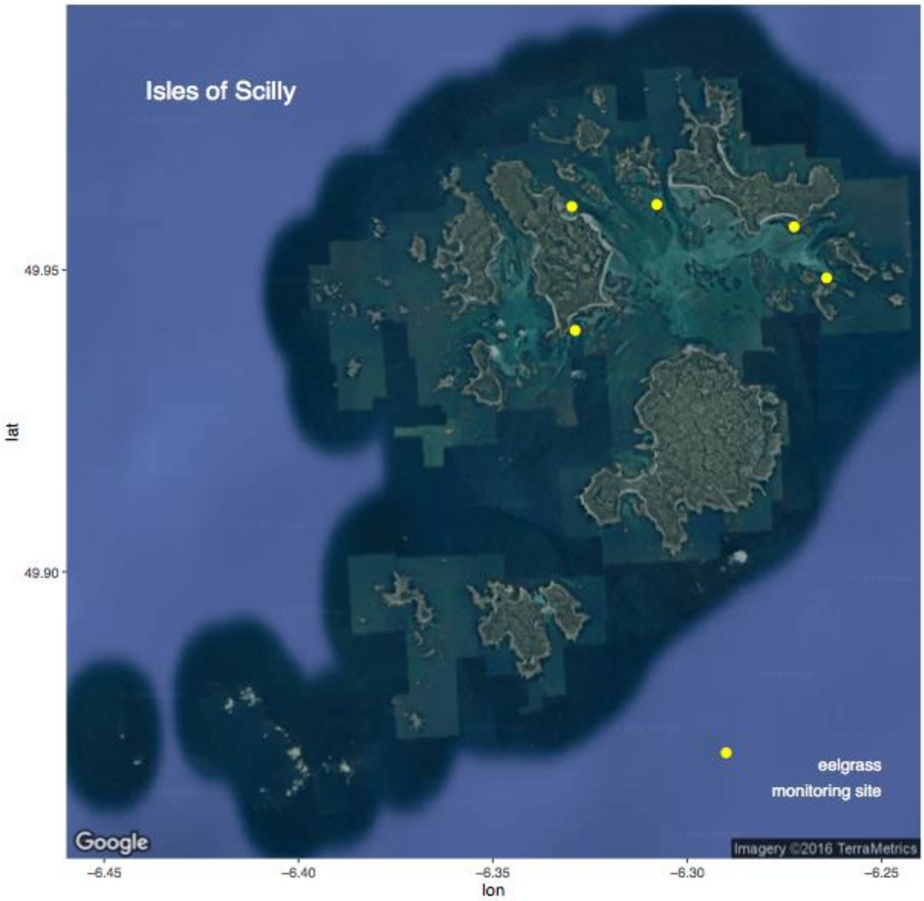


Figure 2 - Locations of the five survey sites around the Isles of Scilly in 2016. Solid yellow circles indicate sites. Clockwise from bottom-left: Broad Ledges Tresco (blt), Old Grimsby Harbour (ogh), West Broad Ledges (wbl), Higher Town Bay (htb) and Little Arthur (la).

2.6 Survey aims

Some form of monitoring of the Isles of Scilly eelgrass beds has been undertaken since the 1980s. This early work made numerous valuable contributions to our understanding of these beds, including the discovery of the signs of wasting disease in the archipelago, that was observed to be coincident with deterioration of the eelgrass. In the early 1990s, efforts were made to establish annual surveys, following consistent methodology. The current survey is a direct continuation of this process, with records that we regard as comparable beginning in 1996.

The aims of the annual Isles of Scilly eelgrass survey are to record:

1) the **density** (shoot counts per quadrat) of eelgrass at five sites around the archipelago,
2) the **number of leaves** per shoot of eelgrass,
3) the maximum **shoot length**,
4) the amount of **infection** on eelgrass leaves, thought to indicate wasting disease,
5) the amount of **epiphyte** cover on leaves.

Additionally, notes are taken on the presence and distribution of the non-native species, *Sargassum muticum*.

3. METHODS

3.1 Survey methods

Survey team. The team for the 2016 Isles of Scilly eelgrass survey comprised Olle Åkesson (Sussex Wildlife Trust), James Bull (Swansea University), Kevan Cook (Natural England), Fiona Crouch (Marine Biological Association), Emma Kenyon (Sussex University), Cyril Nicholas (formerly Natural England and long-time Islander) and Trudy Russell (Natural England). Whilst professional affiliations are given here, it must be stressed that all participants did so as volunteers and did not receive payment for their contributions to the survey (indeed in all cases, volunteers contributed to survey costs). The survey vessel was the RIB, 'Calypso', a 5.5m vessel with 90bhp four-stroke outboard engine, carrying VHF/DSC marine radio equipment, flares, 1st aid kit and emergency oxygen. Volunteers have appropriate training in these through approved agencies such as BSAC and RYA.

Survey location. As far as possible, surveys were carried out at the same five locations as in previous years (Figure 2 and Table 1). These have become known as 'Broad Ledges Tresco' (blt), 'Higher Town Bay' (htb), 'Little Arthur' (la), 'Old Grimsby Harbour' (ogh) and 'West Broad Ledges' (wbl). Once on site, the vessel was manoeuvred to the target coordinates for the survey. Final placement of the anchor was based on finding a sandy patch, devoid of eelgrass, as close as possible to the target. This was done to minimise the impact of the survey on the eelgrass. The resulting central datum for each survey was typically within 10-20m of the target coordinates and the actual coordinates were recorded.

Table 1. Survey site locations for Isles of Scilly eelgrass surveys, 2016.

Site	Latitude	Longitude	Depth (chart datum)	Date surveyed
Broad Ledges Tresco (blt)	49°56.376′N	06°19.818′W	0.2m	24 / 07 / 2016
Higher Town Bay (htb)	49°57.481′N	06°16.503′W	+0.5m	24 / 07 / 2016
Little Arthur (la)	49°56.913′N	06°15.921′W	1.0m	26 / 07 / 2016
Old Grimsby Harbour (ogh)	49°57.606′N	06°19.769′W	0.6m	25 / 07 / 2016
West Broad Ledges (wbl)	49°57.418′N	06°18.260′W	0.6m	27 / 07 / 2016

Quadrat placement. Quadrat-based shoot counts were replicated 25 times at each of the five survey sites. To achieve this, pairs of random rectangular ('x' and 'y') coordinates were generated before the study. These were translated into polar coordinates ('distance' and 'bearing'). Any polar coordinates with distance components greater than 30m were discarded. This process continued until 25 sets of polar coordinates within the maximum survey radius of 30m were assigned to each survey site. The rectangular-polar conversion method ensures even sampling of a circular survey area, guarding against over sampling of the centre that would result from generating random polar coordinates.

Since the full survey includes measurements of eelgrass 'health' (disease and epiphytes), which is not possible *in situ*, shoots were removed at the level of the substrate, paying particular attention to not disturb or damage the rhizomes or roots, for further assessment *ex situ*. This is consistent with current Natural England eelgrass survey methodology (Kevan Cook, pers. comm.).

Shoot counts. Shoot counts were made in 25 x 25cm quadrats and shoot density was presented per quadrat. Although tempting to extrapolate to 'per square metre' simply by multiplying quadrat counts by 16, for easy comparison with other global studies presented at the metre scale, this was not done here as it would imply knowledge of spatial heterogeneity at a different scale to that measured.

Shoot parameters. In addition to shoot density, the number of leaves was recorded on every shoot. Furthermore, the length of the longest leaf on every shoot was recorded, from a point at the base of the shoot, where leaves separate from the stem, to the leaf tip.

Wasting disease. Proportions of individual leaves showing signs of wasting disease (lesions characterised by black spots and streaks, den Hartog 1989) were scored for all leaves, based on an accepted categorisation: [a = 0%], [0% < b < 2%], [2% < c < 25%], [25% < d < 50%], [50% < e < 75%] and [75 < f < 100%] (Burdick et al. 1993 - see Figure 1 therein for a diagrammatic representation of the categories).

Epiphytes. In this survey, we did not attempt to identify specific epiphytes, but rather treated all visible epiphytes as a functional group, likely to have a similar effect on eelgrass growth by restricting light reaching the photosynthetic surface of leaves. This is because identification of many epiphyte species, especially algae, is a highly specialised and time-consuming task, beyond the scope of this project. Here, we recorded the proportion of each eelgrass leaf covered in epiphytes of any type using the same percentage cover brackets as used for recording signs of wasting disease (Burdick et al. 1993).

3.2 Analytical methods

We present a brief set of initial analyses based on a series of questions about differences between the five survey sites in 2016, as well as on temporal trends through the whole period of the current Isles of Scilly eelgrass survey, 1996 - 2016. In all cases, we adopt the simple approach of:

1) identifying the quantitative question to be focused on,
2) graphically presenting the observation that answers the question,
3) presenting statistical analysis to assess the probability observed trends occurred by chance.

Throughout, the Generalised Linear Model framework is ideal. This form of regression analysis is sufficiently flexible to model all the different types of data that we have recorded, rather than being limited by the assumption of 'Normally-distributed residuals' (here, we encounter 'count data', 'presence / absence data', 'continuous data with a lower boundary of zero' and 'proportion data').

Shoot counts. Differences in shoot counts were assessed using either over-dispersed Poisson GLMs or negative binomial GLMs, as appropriate.

Presence / absence. A number of quadrats at each site were found to include no eelgrass shoots. This information is important and was retained. As can be seen from satellite photos of the survey sites (Figure 2 and Appendix 1), eelgrass meadows form remarkable patterns of vegetation, separated by bare sand. In the current study, this presence / absence data was modelled using binomial GLMs.

Mixture models. Statistical models are underpinned by biological assumptions and statistical analysis is limited by the insight of the biologists conducting the analysis. We identify two reasons why individual quadrats might contain no eelgrass shoots: 1) rhizomes are present beneath the sand but no shoots have emerged within the quadrat area, and 2) no rhizomes are present, either through biological or environmental processes. A third possibility that shoots are missed through observer error seems unlikely to us but cannot be ruled out. Since we cannot be certain which process accounts for individual zero count records, we combine our 'shoot count' and 'presence / absence' data into 'mixture models' that simultaneously answer questions on counts and binomial outcomes without relying on explicit understanding, and partitioning, of the causes of zero counts.

Continuous data. Leaf length data is continuous but with a lower boundary of zero. This results in ‘skewed’ data distributions with increasing variance-mean ratios (i.e variability in leaf lengths is greater amongst sets of longer leaves). We model this type of bounded data using gamma GLMs.

Ordinal data. Wasting disease and epiphyte scores are recorded as percentage cover brackets. Here we converted these (0-5) to ‘proportion data’ (0-1), first by averaging raw infection scores across quadrats, then dividing through by five. Here, we modelled ‘proportion data’ by logit-transforming (where, $logit[p] = ln[p / (1-p)]$) the proportions with Gaussian (Normal) GLMs.

All statistical analyses were undertaken using R version 3.1 (R Core Team, 2014).

4 RESULTS

4.1 2016 Survey findings

Shoot counts. Distributions of shoot counts across quadrats, at each of the sampling locations, are presented in Figure 3. We ask the question whether there is a significant difference in mean shoot density between survey sites (Table 2). This is assessed as a two part mixture model, combining a binomial model of presence / absence in quadrats with a negative binomial count model. As 2015, we find that the first null hypothesis of equal proportions of occupied quadrats <u>is</u> rejected ($\chi^2 = 28.93$, df = 4, $p < 0.001$). However, in contrast to 2014 and 2015, we also find that the second null hypothesis of equal shoot densities across survey sites can be rejected ($\chi^2 = 12.26$, df = 4, $p = 0.016$).

Table 2a. Quadrat occupancy summary output.

Site	Estimate	Std. Error	z value	Pr(>|z|)
Intercept (blt)	0.0800	0.4003	0.200	0.842
htb	0.3254	0.5718	0.569	0.569
la	2.362	0.8389	2.816	0.005
ogh	-1.415	0.6426	-2.202	0.028
wbl	0.0000	0.5661	0.000	1.000

Table 2b. Shoot density summary output.

Site	Estimate	Std. Error	z value	Pr(>|z|)
Intercept (blt)	2.777	0.1440	19.28	<0.001
htb	-0.4651	0.2033	-2.287	0.0222
la	-0.6107	0.1869	-0.327	0.0011
ogh	-0.7866	0.3018	-2.607	0.0091
wbl	-0.3679	0.2091	-1.759	0.0785

The statistical summary indicates the lowest quadrat occupancy was at Old Grimsby Harbour, and highest quadrat occupancy at Little Arthur (Table 2a). Additionally, the lowest shoot density (excluding empty quadrats) was at Old Grimsby Harbour, and the highest at Broad Ledges Tresco (Table 2b).

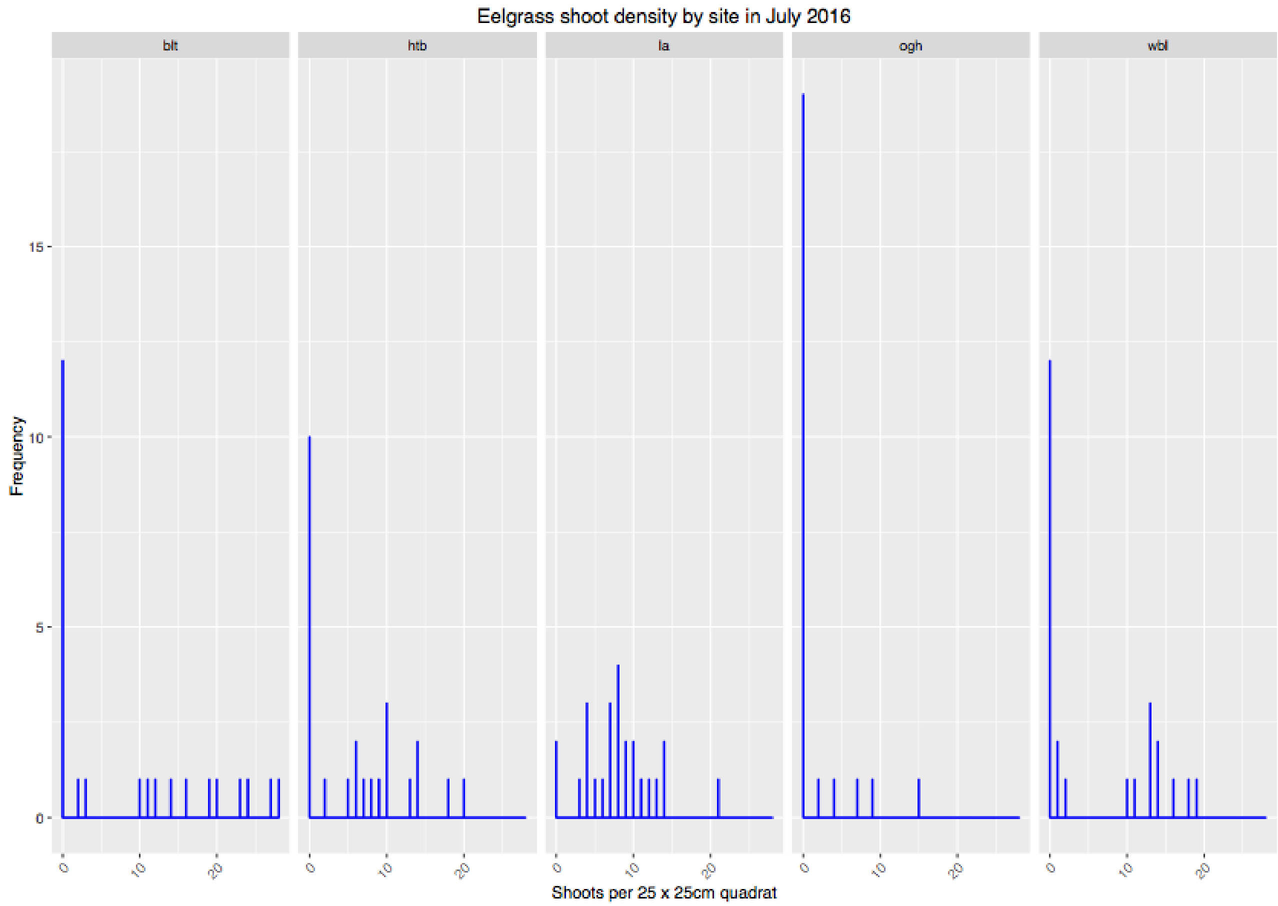


Figure 3 - Frequency histogram of the number of eelgrass shoots recorded per 25 x 25cm quadrat at each of the five survey locations.

We conclude that, within the limits of our survey, spatial heterogeneity is evident between sites at the level of eelgrass ‘patchiness’, which is consistent with 2014 and 2015. Also consistent with recent years, Old Grimsby Harbour shows the lowest patch occupancy, as part of a long-term decline.

However, in contrast to 2014 and 2015, we also saw significant spatial heterogeneity in shoot density between sites. This difference, compared to last year, is driven by unusually high shoot density at Broad Ledges Tresco.

Canopy height. Here we define the 'canopy height' as the median value of the lengths of the longest leaf on each shoot in a given quadrat. Distributions of canopy heights across quadrats, at each of the sampling locations, are presented in Figure 4. We ask the question whether there is a significant difference in mean (non-zero quadrat) canopy heights between survey sites (Table 3). This is assessed using a generalised linear model with gamma errors. We find that the null hypothesis of equal canopy heights across survey sites is rejected ($F = 29.3$, $df = 4$, $p < 0.001$).

Table 3. Canopy height summary output (note inverse link function so -ve estimate indicates higher canopy).

Site	Estimate	Std. Error	z value	Pr(>|z|)
Intercept (blt)	0.0322	0.0020	16.09	< 0.001
htb	-0.0108	0.0024	-4.590	< 0.001
la	-0.0171	0.0021	-8.074	< 0.001
ogh	-0.0006	0.0037	-0.153	0.879
wbl	-0.0097	0.0024	-3.993	< 0.001

As in 2015, the statistical summary indicates similar canopy heights at Broad Ledges Tresco and Old Grimsby Harbour and significantly higher canopy heights at Higher Town Bay, Little Arthur and West Broad Ledges.

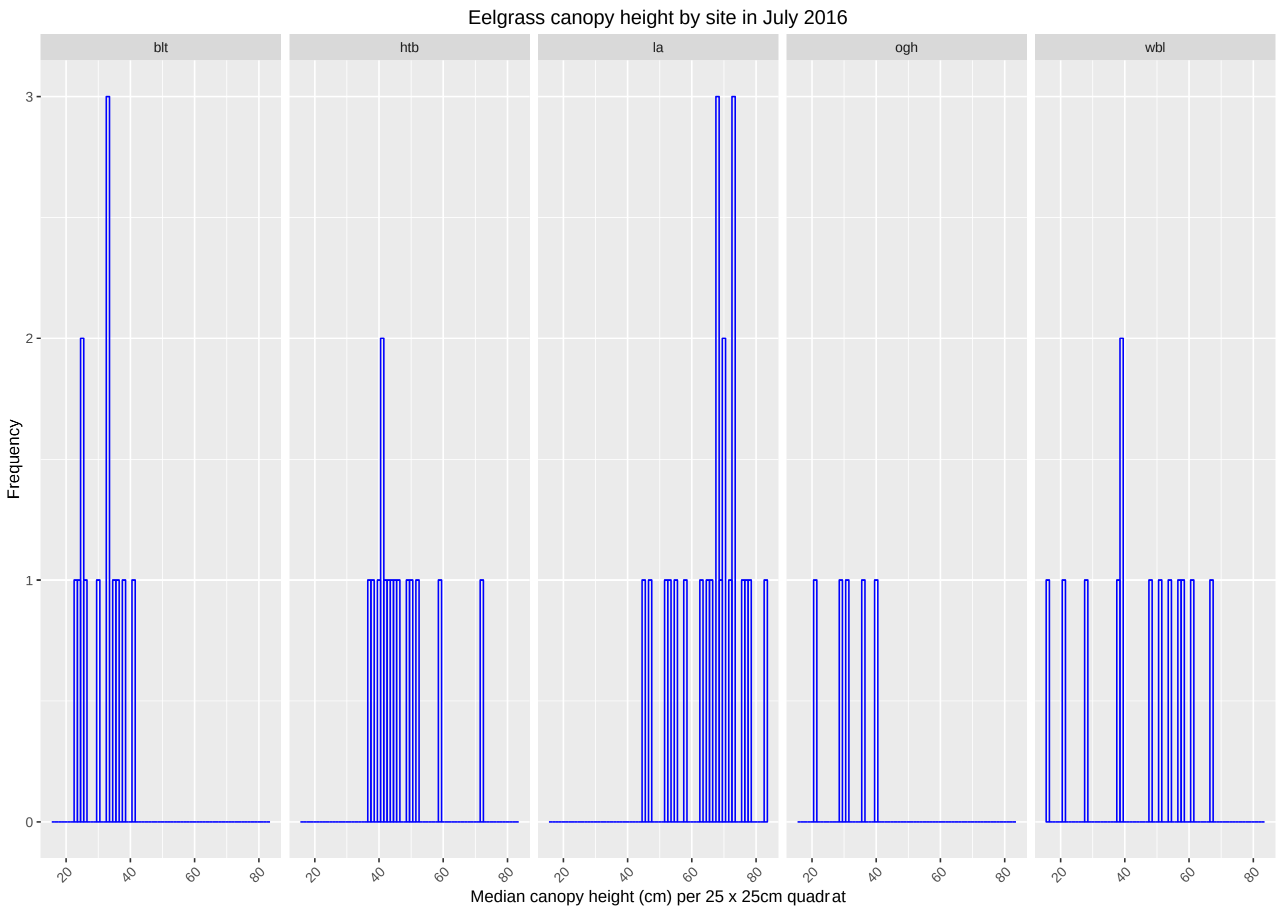


Figure 4 - Frequency histogram of the 'canopy height' (cm) of eelgrass shoots recorded per 25 x 25cm quadrat at each of the five survey locations.

This year's survey is consistent with the typical finding of the longest leaves, so greatest canopy height, being at Little Arthur. Both Old Grimsby Harbour and Broad Ledges Tresco have substantially lower canopy heights than the other survey sites.

Leaf analysis. Leaf area index (LAI) is the area of leaf per unit area of ground. Here, we estimate LAI by multiplying the length of the longest leaf on a given shoot by the number of leaves on that shoot, and summing over all shoots in a given quadrat. Distributions of LAIs across quadrats, at each of the sampling locations, are presented in Figure 5. We ask the question whether there is a significant difference in mean (non-zero quadrat) LAI between survey sites (Table 4). This is assessed using a generalised linear model with gamma errors. We find that the null hypothesis of equal LAI across survey sites is not rejected (F = 1.634, df = 4, p = 0.177).

Table 4. Leaf area index summary output (note inverse link function so -ve estimate indicates higher LAI).

Site	Estimate	Std. Error	z value	Pr(>|z|)
Intercept (blt)	4.669e-04	7.519e-05	6.210	< 0.001
htb	5.351e-05	1.084e-04	0.494	0.623
la	-6.396e-05	8.963e-05	-0.714	0.478
ogh	5.424e-04	2.726e-04	1.989	0.051
wbl	-2.823e-05	1.032e-04	-0.274	0.785

While the statistical summary indicates that leaf area index is not significantly lower at Old Grimsby Harbour than other sites, it is the least productive site by this metric, adding to a picture of concern for this site.

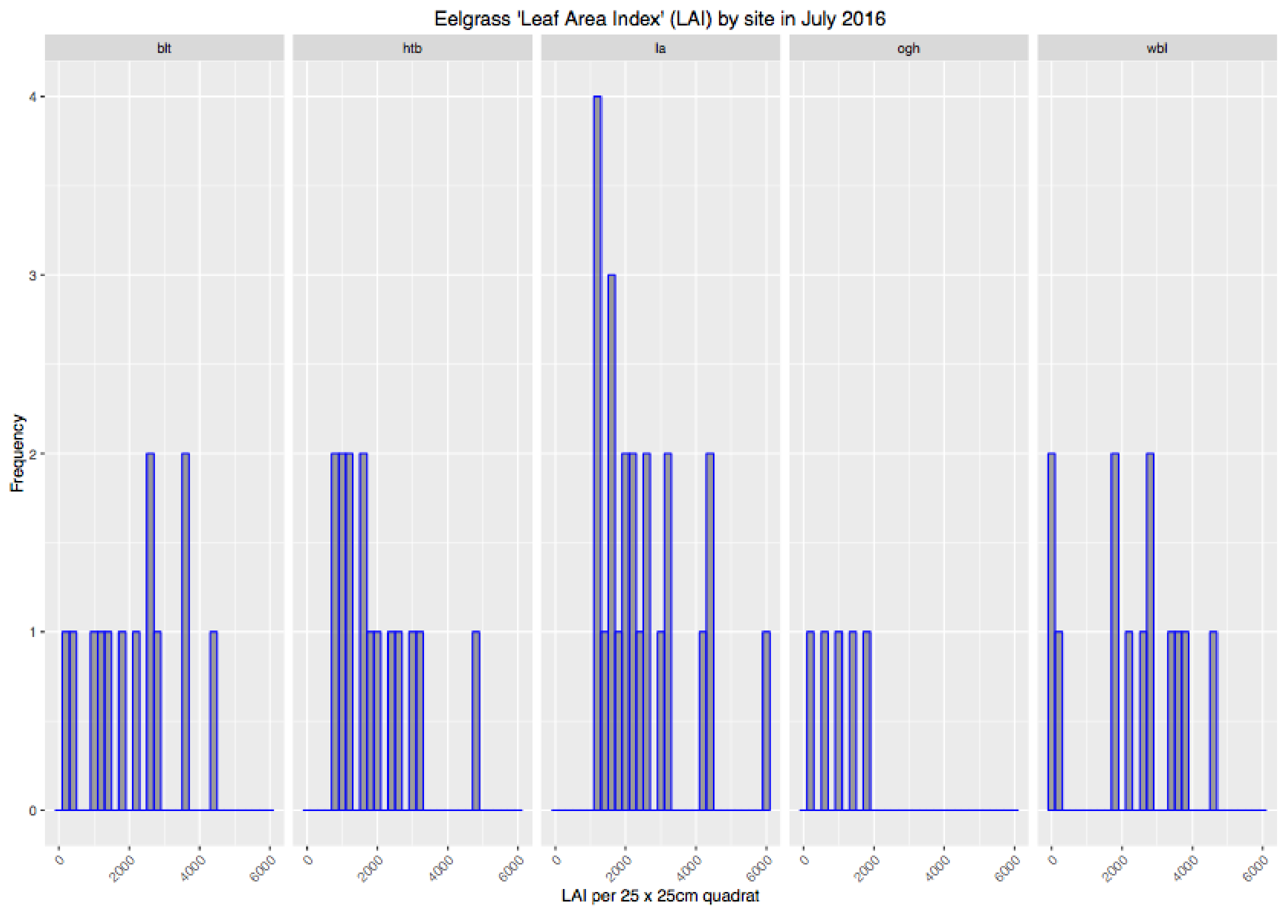


Figure 5 - Frequency histogram of the 'Leaf Area Index' (LAI) of eelgrass recorded per 25 x 25cm quadrat at each of the five survey locations.

4.2 Time series analysis, 1996 - 2016

Shoot counts. Time series of shoot counts throughout the monitoring period, at each of the sampling locations, are presented in Figure 6. We ask the question whether mean (non-zero quadrat) shoot density changes through time (Table 5). This is assessed using a generalised linear model with over-dispersed Poisson errors. We find that the null hypothesis of a zero gradient through time is rejected at Higher Town Bay (t = 4.95, p < 0.001) and Little Arthur (t = 2.83, p = 0.0047). In both cases, there is a significant decline in mean shoot density through time.

Table 5. Shoot count time series (1996-2016) summary output.

Site	Estimate	Std. Error	t value	Pr(>|t|)
blt	-7.838e-03	4.976e-03	-1.575	0.115
htb	-2.073e-02	4.186e-03	-4.951	< 0.001
la	-1.376e-02	4.857e-03	-2.833	0.0047
ogh	6.141e-03	6.321e-03	0.971	0.33
wbl	8.661e-04	5.585e-03	0.155	0.877

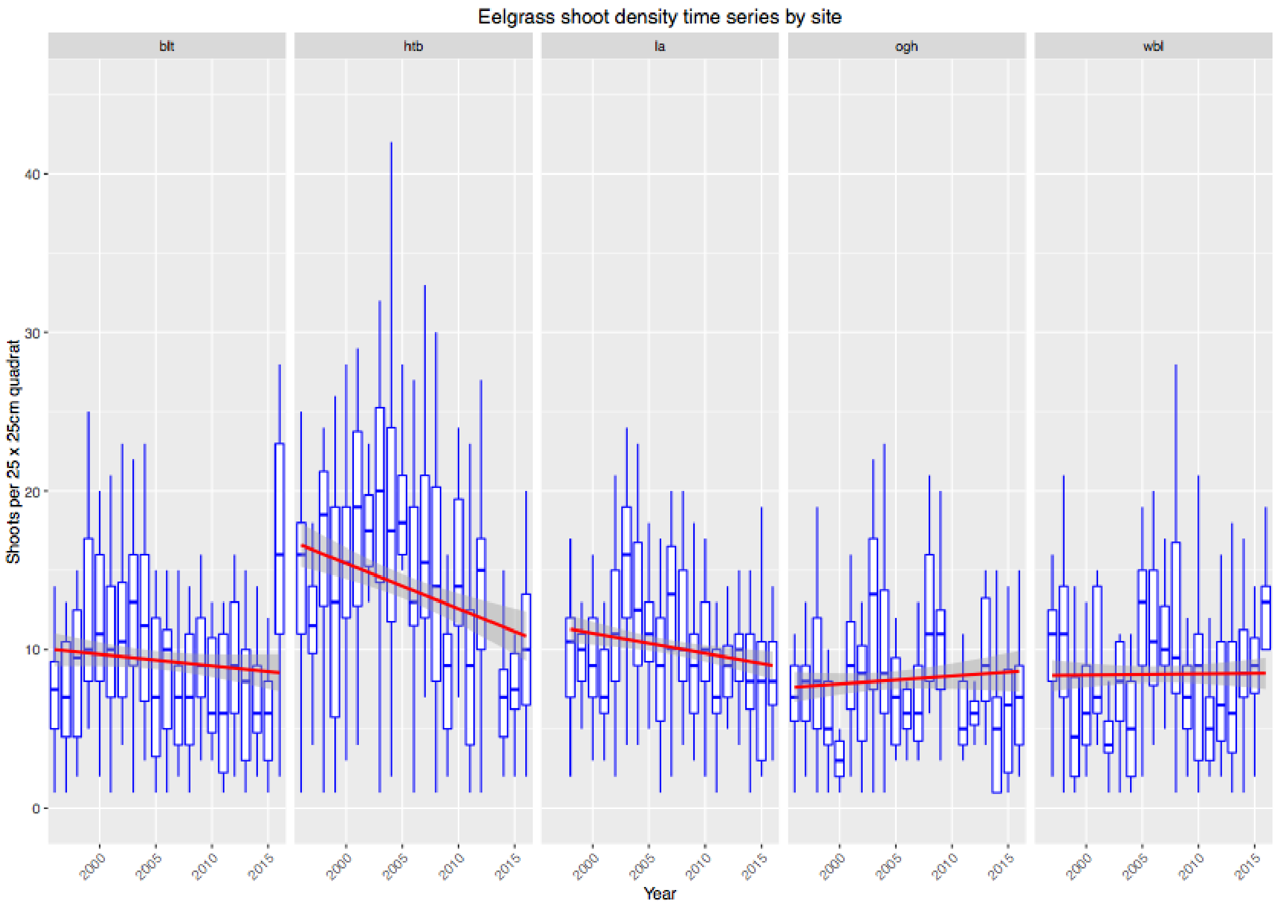


Figure 6 - Time series of eelgrass shoot densities for all quadrats at each of the five survey sites, from 1996 to 2016. Box-whisker plots show median (centre line), interquartile range (box) and an additional 1.5 x interquartile range (whiskers), with outliers not shown for clarity. Red lines show overall temporal trends (Generalised Additive Model smooth, using cubic splines). Trend lines are surrounded by 95% confidence envelopes in grey. Quadrats in which no eelgrass was recorded are excluded here.

The long-term decline reported at Broad Ledges Tresco in 2014 and 2015 (using time series from 1996 onwards) has been overturned by unusually high shoot density at this site in 2016. We have no explanation for this and it will be interesting to see whether it continues in 2017 onwards.

Canopy height. Here we define the 'canopy height' as the median value of the lengths of the longest leaf on each shoot in a given quadrat. Time series of canopy heights throughout the monitoring period, at each of the sampling locations, are presented in Figure 7. We ask the question whether mean (non-zero quadrat) canopy height changes through time (Table 6). This is assessed using a generalised linear model with gamma errors. We find that the null hypothesis of a zero gradient through time is rejected at Little Arthur ($t = 3.38$, $p < 0.001$) and Old Grimsby Harbour ($t = 2.23$, $p = 0.026$). In both cases, a decline is reported.

Table 6. Canopy height time series (1996-2016) summary output (note +ve estimate indicates decline).

Site	Estimate	Std. Error	t value	Pr(>|t|)
blt	-9.219e-05	7.000e-05	-1.317	0.188
htb	3.593e-05	6.434e-05	0.558	0.577
la	1.199e-04	3.551e-05	3.378	<0.001
ogh	1.806e-04	8.095e-05	2.231	0.0258
wbl	-2.279e-05	5.300e-05	-0.430	0.667

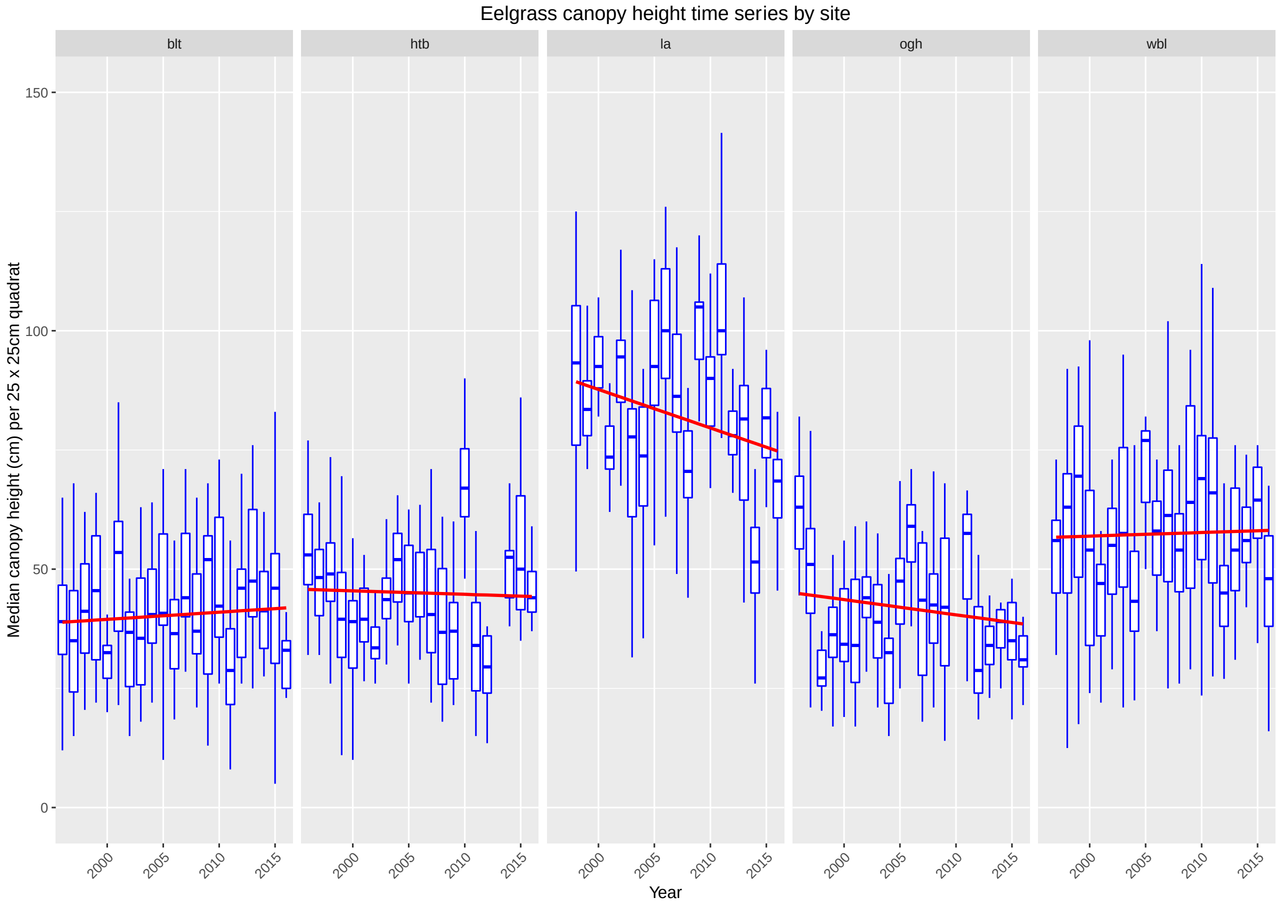


Figure 7 - Time series of eelgrass 'canopy heights' for all quadrats at each of the five survey sites, from 1996 to 2016. Box-whisker plots show median (centre line), interquartile range (box) and an additional 1.5 x interquartile range (whiskers), with outliers not shown for clarity. Red lines show overall temporal trends (Generalised Additive Model smooth, using cubic splines). Trend lines are surrounded by 95% confidence envelopes in grey. Quadrats in which no eelgrass was recorded are excluded here.

While long-term declines continue at Little Arthur and Old Grimsby Harbour, one of the most striking features of 2016 is the sudden drop in canopy height at Broad Ledges Tresco.

Leaf analysis. Leaf area index (LAI) is the area of leaf per unit area of ground. Here, we estimate LAI by multiplying the length of the longest leaf on a given shoot by the number of leaves on that shoot, and summing over all shoots in a given quadrat. Time series of LAIs throughout the monitoring period, at each of the sampling locations, are presented in Figure 8. We ask the question whether mean (non-zero quadrat) leaf area index changes through time (Table 7). This is assessed using a generalised linear model with gamma errors. We find that the null hypothesis of a zero gradient through time <u>is</u> rejected at Higher Town Bay ($t = 4.12$, $p < 0.001$) and Little Arthur ($t = 3.73$, $p = 0.002$). In both cases, there is a significant <u>decline</u> in mean LAI through time.

Table 7. Leaf area index time series (1996-2016) summary output (note +ve estimate indicates decline).

Site	Estimate	Std. Error	t value	Pr(>|t|)
blt	1.879e-06	3.510e-06	0.535	0.593
htb	9.181e-06	2.228e-06	4.121	< 0.001
la	6.155e-06	1.649e-06	3.732	< 0.001
ogh	3.791e-06	4.670e-06	0.812	0.417
wbl	-6.582e-07	2.900e-06	-0.227	0.820

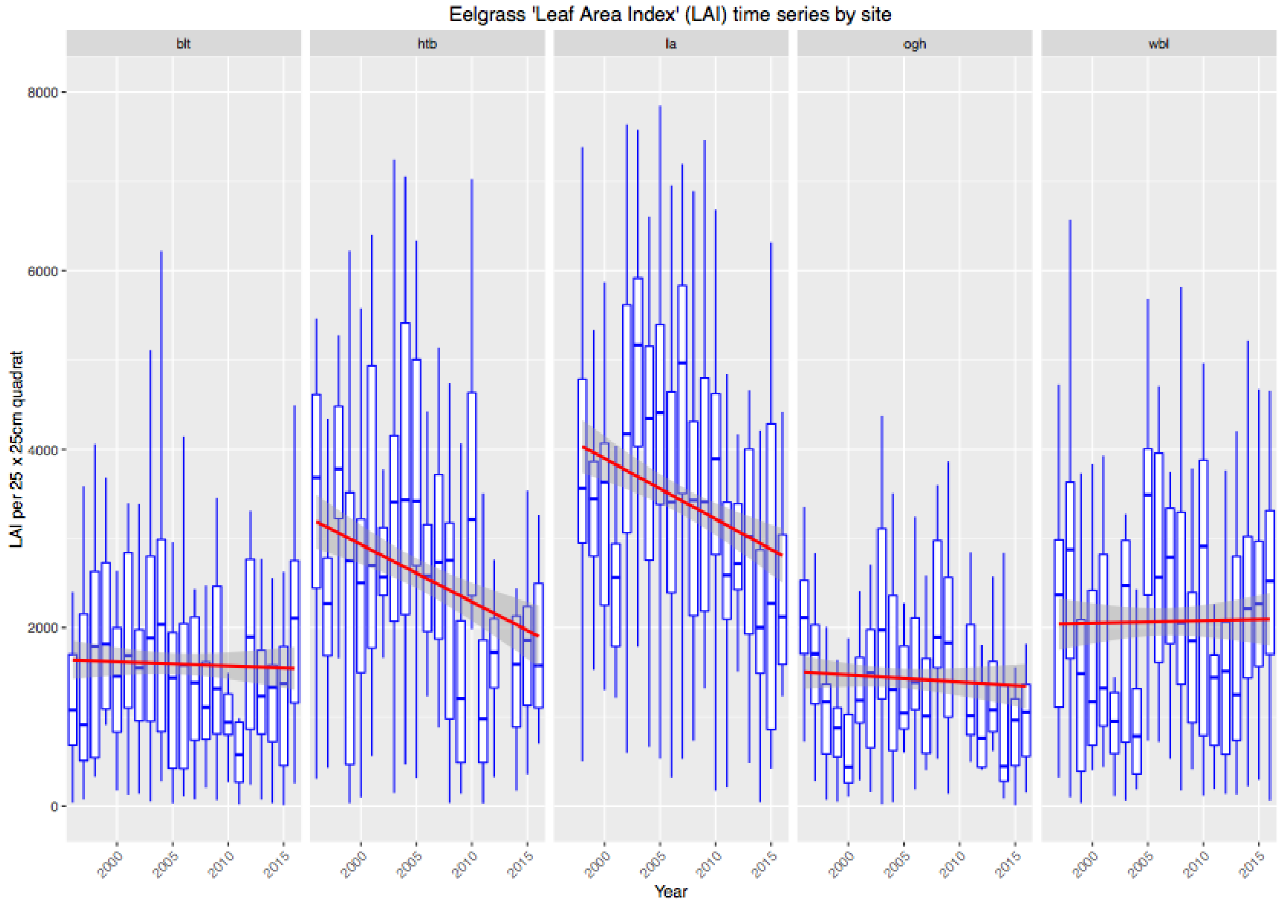


Figure 8 - Time series of the 'Leaf Area Index' (LAI) of eelgrass for all quadrats at each of the five survey sites, from 1996 to 2016. Box-whisker plots show median (centre line), interquartile range (box) and an additional 1.5 x interquartile range (whiskers), with outliers not shown for clarity. Red lines show overall temporal trends (Generalised Additive Model smooth, using cubic splines). Trend lines are surrounded by 95% confidence envelopes in grey. Quadrats in which no eelgrass was recorded are excluded here.

Eelgrass 'patchiness'. Time series of quadrat occupancies throughout the monitoring period, at each of the sampling locations, are presented in Figure 9. We ask the question whether the proportion of occupied (non-zero shoot density) quadrats changes through time (Table 8). This is assessed using a generalised linear model with over dispersed binomial errors. We find that the null hypothesis of a zero gradient through time is only rejected at Old Grimsby Harbour (t = 4.69, p < 0.001). Here, there has been a significant decline in the proportion of quadrats with eelgrass present.

Table 8. Quadrat occupancy time series (1996-2016) summary output.

Site	Estimate	Std. Error	t value	Pr(>|t|)
blt	-0.0502	0.0276	-1.82	0.0726
htb	-0.0254	0.0297	-0.856	0.394
la	-0.0324	0.0536	-0.605	0.547
ogh	-0.1380	0.0294	-4.686	< 0.001
wbl	0.00488	0.0285	0.171	0.865

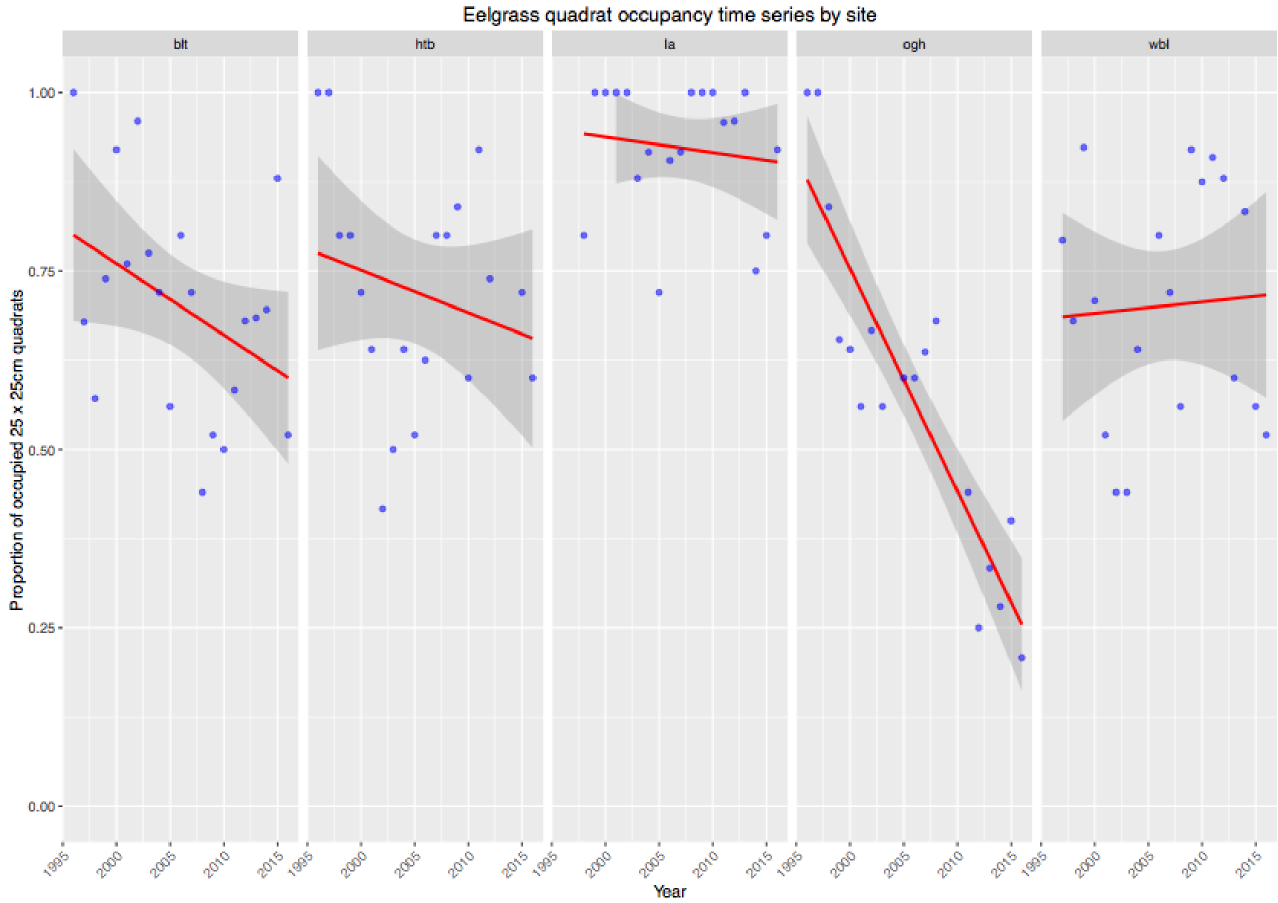


Figure 9 - Time series of the proportion of occupied quadrats at each of the five survey sites, from 1996 to 2016. Solid blue circles indicate proportions of quadrats occupied at each site. Red lines show overall temporal trends (Generalised Additive Model smooth, using cubic splines). Trend lines are surrounded by 95% confidence envelopes in grey.

The 2016 survey found a continuation of the substantial decline in eelgrass coverage at Old Grimsby Harbour, with the lowest level ever recorded (since 1996). There is now less than 25% of the eelgrass coverage reported in the early years of the survey and a reduction of more than 50% since SAC designation in 2005.

Wasting disease. Distributions of disease burdens across quadrats, at each of the sampling locations, are presented in Figure 10. We ask the question whether there is a significant difference in mean infection scores between survey sites (Table 9). This is assessed using a generalised linear model with Gaussian errors. We find that the null hypothesis of equal infection scores across survey sites is rejected ($F = 17.27$, $df = 4$, $p < 0.001$).

Table 9. Wasting disease summary output.

Site	Estimate	Std. Error	z value	Pr(>|z|)
blt	-1.415	0.0437	-32.40	< 0.001
htb	-1.967	0.0758	-25.96	< 0.001
la	-1.526	0.0493	-30.92	< 0.001
ogh	-1.914	0.1242	-15.41	< 0.001
wbl	-1.396	0.0514	-27.14	< 0.001

In particular, Broad Ledges Tresco, Little Arthur and West Broad Ledges have higher than average infection scores, while Higher Town Bay and Old Grimsby Harbour have lower than average infection scores.

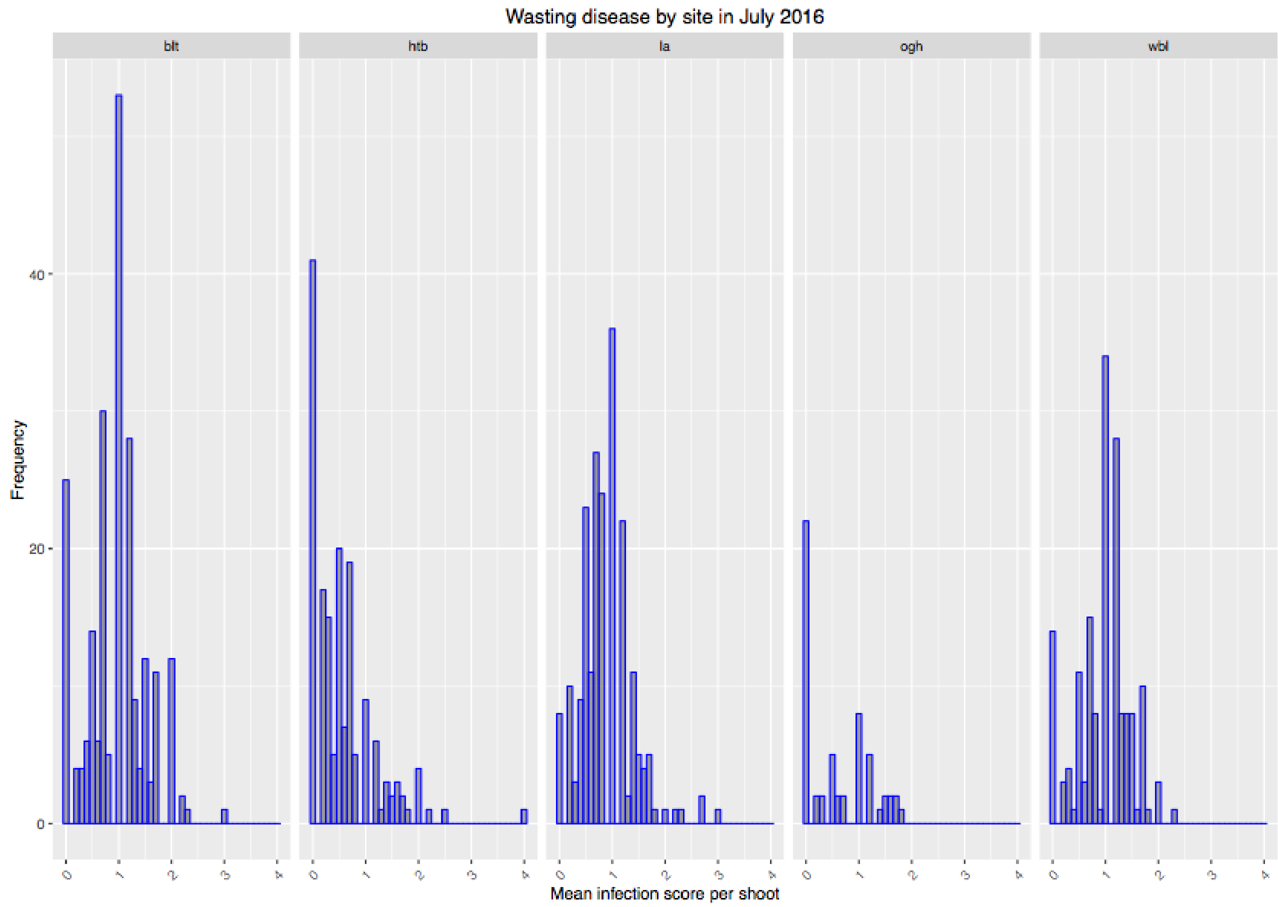


Figure 10. - Signs of wasting disease in each of the five survey sites in 2016. Here, we present average infection scores (0-5) per shoot.

Comparing the 2016 findings with those reported in the 2014 and 2015 Annual Reports, there is clearly considerable inter-annual fluctuation in wasting disease levels (and see Bull et al. 2012 for long time series from the Isles of Scilly). However, in these latest three years, Old Grimsby Harbour has had the lowest levels of wasting disease each year.

Epiphytes. Distributions of epiphyte loads across quadrats, at each of the sampling locations, are presented in Figure 11. We ask the question whether there is a significant difference in mean epiphyte scores between survey sites (Table 10). This is assessed using a generalised linear model with Gaussian errors. We find that the null hypothesis of equal epiphyte scores across survey sites is rejected (F = 60.1, df = 4, p < 0.001).

Table 10. Epiphyte summary output.

Site	Estimate	Std. Error	z value	Pr(>|z|)
blt	-2.331	0.0786	-29.66	< 0.001
htb	-1.233	0.0431	-28.57	< 0.001
la	-1.865	0.0576	-32.37	< 0.001
ogh	-1.247	0.0742	-16.81	< 0.001
wbl	-1.567	0.0529	-29.59	< 0.001

In particular, Broad Ledges Tresco has lower than average epiphyte scores than the other sites.

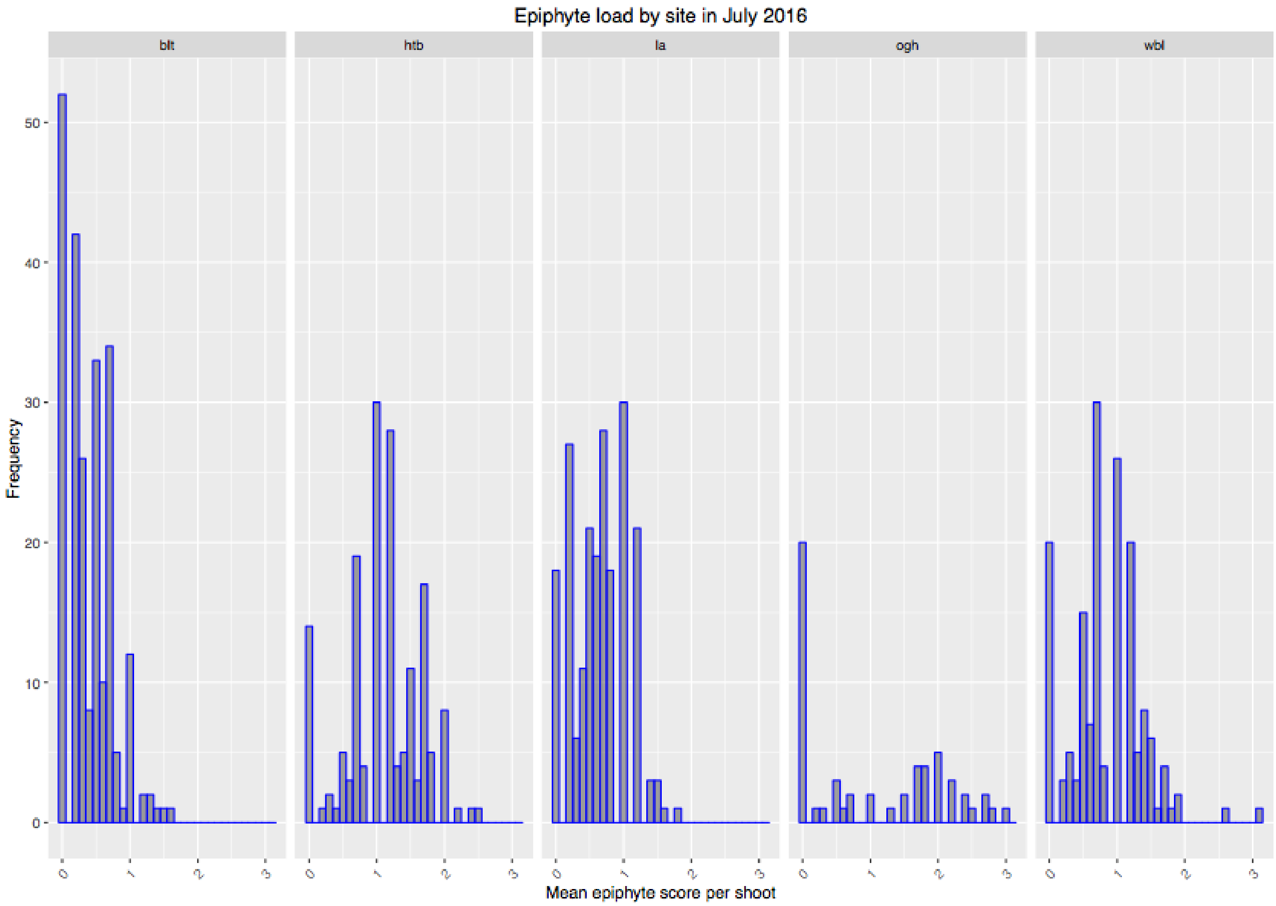


Figure 11. - Eelgrass epiphyte scores in each of the five survey sites in 2016. Here, we present average epiphyte scores (0-5) per shoot.

A fuller investigation of the role of epiphytes in the community dynamics of eelgrass over the life of this survey has been published by some of the authors of this report (Lobelle et al., 2013).

5. CONCLUSIONS

5.1 Key findings

The core metric recorded in this survey is shoot density, which is by far the most common measurement of density (as opposed to extent) used worldwide. Annual change was quantified through log-linear regression, with long-term average annual changes reported in table 5. The decline since a given number of years in the past can be calculated using the formula $N = N_0(1 + r)^t$, where N is the shoot density today, N_0 is the shoot density in the starting year, r is the annual change 'Estimate' from table 5, and t is the number of years elapsed. Special Area of Conservation status was designated in 2005, giving eleven annual time steps to present (t = 11). Based on this estimation, overall percentage changes at each of the site monitoring sites since designation are:

Broad Ledges Tresco: 8.3% <u>decline</u>, **Higher Town Bay: 20.6% <u>decline</u>**, Little Arthur: 14.1% <u>decline</u>, Old Grimsby Harbour: 7.0% <u>increase</u>, West Broad Ledges: 1.0% <u>increase</u>. In the 2015 Annual Report, we identified Higher Town Bay and Little Arthur as the most concerning in terms of shoot density, predicting 20% declines by 2018 and 2017, respectively. In fact, Higher Town Bay has now passed that threshold, two years ahead of our prediction.

The other key estimator of eelgrass abundance is 'patch occupancy', measured as the proportion of sampling quadrats with eelgrass, as opposed to bare sand. Here, the site that has shown substantial cause for concern for some years is **Old Grimsby Harbour, which has now dropped to less than 25% of the coverage** recorded in the early years of this monitoring.

5.2 Individual site summaries

Broad Ledges Tresco. 2016 was a highly unusual one at this site. Exceptionally high shoot density was only partially offset by lower than typical canopy height, resulting in a reprieve from the substantial drop in productivity (as measured by Leaf Area Index, LAI). It is important to continue to closely monitor this site to see if this is transient, especially as no obvious cause for this high shoot density is apparent.

Higher Town Bay. This site continues to show a serious decline in shoot density, now having exceeded a 20% reduction since SAC designation in 2005. This site typically has shorter plants than other sites, which is consistent with it being the shallowest site and is not, in itself, a cause for concern. As a result, a significant decrease in shoot density over the years underpins a decrease in productivity (LAI). Coupled with a decline in coverage, as measured by 'patch occupancy', this site is one of two (the other being Old Grimsby Harbour) that is thought to be particularly in trouble.

Little Arthur. Whilst 'patch occupancy' remains very high here, this is the only site to show declines in both shoot density and canopy height. This site is the other of our five monitored sites to show a sustained and statistically significant decrease in productivity, as measured by LAI. It is important not to overlook the fact that this site is showing serious decline in terms of productivity (LAI) , despite the high occupancy/patch coverage.

Old Grimsby Harbour. Trends at ogh are strikingly different to all other monitored locations around the Isles of Scilly. This site has not shown a significant decrease in shoot density, canopy height or LAI over the years. This is not a cause for celebration as it has consistently had amongst the lowest levels of all these metrics for the entire twenty year study. Even more worrying, unlike all other monitored sites around the Isles of Scilly, ogh is showing a sustained and significant decline in coverage, as measure by the proportion of quadrats found to have no eelgrass in them (occupancy proportion, or 'patchiness'). Here, patch occupancy has now dropped by over 75% since the survey began.

West Broad Ledges. This site is the only site to show no statistically significant decline in any of the metrics records in the twenty-one year study and this year showed amongst the highest recorded shoot density at this site.

Disease and epiphytes. It is interesting that wasting disease has remained evident at relatively low but persistent levels, suggesting an endemic state. Wasting disease is notable for periodic large scale epidemic outbreak. In order to understand this conflicting situation, further research beyond the remit of this study would be needed. Epiphytic cover may be both a sign of a diverse community, or a result of eutrophication and disturbance. Again, further in-depth research would be needed to understand the relationship between eelgrass and epiphytes in the Isles of Scilly.

Sargassum muticum. This invasive species has spread along the south and west coasts of the UK and has been a regular feature of the Isles of Scilly eelgrass survey for several years. We do not formally quantify distributions of *S. muticum* as part of this project but can report that the species was present at all surveyed sites but was not strikingly more prevalent than in previous years. It is debatable how much of an impact this invasive is likely to have on eelgrass: while shading might negatively impact on eelgrass, direct competition for space between the two species seems unlikely as *S. muticum* requires a hard substrate to establish.

5.3 Synthesis

Twenty-one years of continuous monitoring represents a globally important long-term dataset. This length and intensity of monitoring is necessary to uncover sustained trends in abundance and distribution of populations and biological communities. Worryingly, the picture for eelgrass around the Isles of Scilly is one of decline in four out of five of monitored sites. Despite its envious position far from sources of pollution and many other direct human impacts, there is serious cause for concern about the status of *Zostera marina* in the Isles of Scilly Special Area of Conservation.

6. ACKNOWLEDGMENTS

We are very grateful to Natural England for their major contribution to essential survey costs this year. More than ever, we are indebted to Lisa at The Bylet for putting us up and putting up with us. As usual, Island Carriers went the extra mile in helping us move kit and launch (and recover!) our rib. We are also grateful to Dave McBride of Dive Scilly and Jolene Williams of Moonshadow Diving for their assistance with air fills and allowing us to leave cylinders at their air station. Every year financial and logistical constraints present serious challenges to the continuation of this survey and we are always indebted to the many residents of the Isles of Scilly who help us overcome these issues and make the survey a success.

7. REFERENCES

Borowitzka MA, Lavery P, van Keulen M (2007) Epiphytes of seagrasses. In: Larkum AWD, Orth RJ, Duarte CM, editors. Seagrasses: Biology, ecology and conservation. Dortrecht: Springer, pp. 441-461.

Bull JC, Kenyon EJ, Cook KJ (2012) Wasting disease regulates long-term population dynamics in a threatened seagrass. Oecologia 169: 135-142.

Burdick DM, Short FT, Wolf J (1993) An index to assess and monitor the progression of wasting disease in eelgrass *Zostera marina*. Mar. Ecol. Progress. Ser. 94: 83-90.

Cook KJ (2011) Isles of Scilly *Zostera marina* monitoring: 2011 Expedition Report. Report to Natural England.

Costanza R, d'Arge R, de Groot R, Farber S, Grasso M, et al. (1997) The value of the world's ecosystem services and natural capital. Nature 387: 253-260.

Cullinane JJ, Mahoney O, Whelan P (1985) Algal epiphytes of subtidal *Zostera marina* L. on the south coast of Ireland. Cryptogam Algol 6: 239-251.

den Hartog C (1987) Wasting disease and other dynamics phenomena in *Zostera* beds. Aquat. Bot. 27: 3-14.

den Hartog C (1989) Early records of wasting disease-like damage patterns in eelgrass *Zostera marina*. Dis. Aquat. Organ. 7: 223-226.

Duarte CM (2002) The future of seagrass meadows. Envir. Cons. 29: 192-206.

Duarte CM, Chiscano CL (1999) Seagrass biomass and production: A reassessment. Aquat. Bot. 65: 159-174.

Fowler SL (1992) Marine monitoring in the Isles of Scilly: Report to Natural England.

Fourqurean JW, Manuel S, Coates KA, Kenworthy WJ, Smith SR (2010) Effects of excluding sea turtle herbivores from a seagrass bed: overgrazing may have led to a loss of seagrass meadows in Bermuda. Mar. Ecol. Progr. Ser. 419: 223-232.

Gillanders BM (2007) Seagrasses, fish and fisheries. In: Larkum AWD, Orth RJ, Duarte CM, editors. Seagrasses: Biology, ecology and conservation. Dortrecht: Springer, pp. 503-536.

Johnson MP, Edwards M, Bunker F, Maggs CA (2005) Variation in assemblage structure from individual leaves to regional scale. Aquat. Bot. 82: 12-26.

Jones BL, Unsworth RK (2016). The perilous state of seagrass in the British Isles. Roy. Soc. Open Sci. 3(1), 150596.

Kendrick GA, Duarte CM, Màrba N (2005) Clonality in seagrasses, emergent properties and seagrass landscapes. Mar. Ecol. Progr. Ser. 290: 291-296.

Lethbridge RC, Borowitzka MA, Benjamin K (1988) The development of an artificial *Amphibolis*-like seagrass of complex morphology and preliminary data on its colonization by epiphytes. Aquat. Bot. 31: 153-168.

Lobelle D, Kenyon EJ, Cook KJ, Bull JC (2013) Local and metapopulation processes drive seagrass-epiphyte population dynamics. PLoS ONE 8: e57072.

Muehlstein LK (1989) Perspectives on the wasting disease of eelgrass *Zostera marina*. Dis. Aqua. Organ. 7: 211-221.

Olesen B, Sand-Jensen K (1994a) Biomass-density patterns in the temperate seagrass *Zostera marina*. Mar. Ecol. Progr. Ser. 109: 283-291.

Olesen B, Sand-Jensen K (1994b) Demography of shallow eelgrass (*Zostera marina*) populations: shoot dynamics and biomass development. J. Ecol. 82: 379-390.

Orth RJ, Carruthers TJB, Dennison WC, Duarte CM, Fourqurean JW (2006) A global crisis for seagrass ecosystems. Biosci. 56: 987-996.

Piazzi L, Cinelli F (2000) Effects of the spread of the introduced Rhodophyceae *Antithamnion preissii* and *Womersleyella setacea* on the macroalgal community of *Posidonia oceanica* rhizomes in the western Mediterranean Sea. Cryptogam. Algol. 21: 291-300.

Potouroglou M, Kenyon EJ, Gall A, Cook KJ, Bull JC (2014) The roles of flowering, overwinter survival and sea surface temperature in the long-term population dynamics of *Zostera marina* around the Isles of Scilly, UK. Marine Pollution Bulletin 83: 500-507.

R Core Team (2014). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

Rasmussen E (1977) The wasting disease of eelgrass (*Zostera marina*) and its effects on environmental factors and fauna. In: McRoy CP, Helfferich C (eds) Seagrass Ecosystems, a Scientific Perspective. Marcel Dekker. New York. pp1-51.

Reusch TBH, Stam WT, Olsen JL (1999) Microsatellite loci in eelgrass *Zostera marina* reveal marked polymorphism within and among populations. Mol. Ecol. 8: 317-322.

Short FT, Ibelings BW, den Hartog C (1988) Comparison of a current eelgrass disease to the wasting disease of the 1930s. Aquat. Bot. 30: 295-304.

Thayer GW, Bjorndal KA, Ogden JC, Williams SL, Zieman JC (1984) Role of larger herbivores in seagrass communities. Estuaries 7: 351-376.

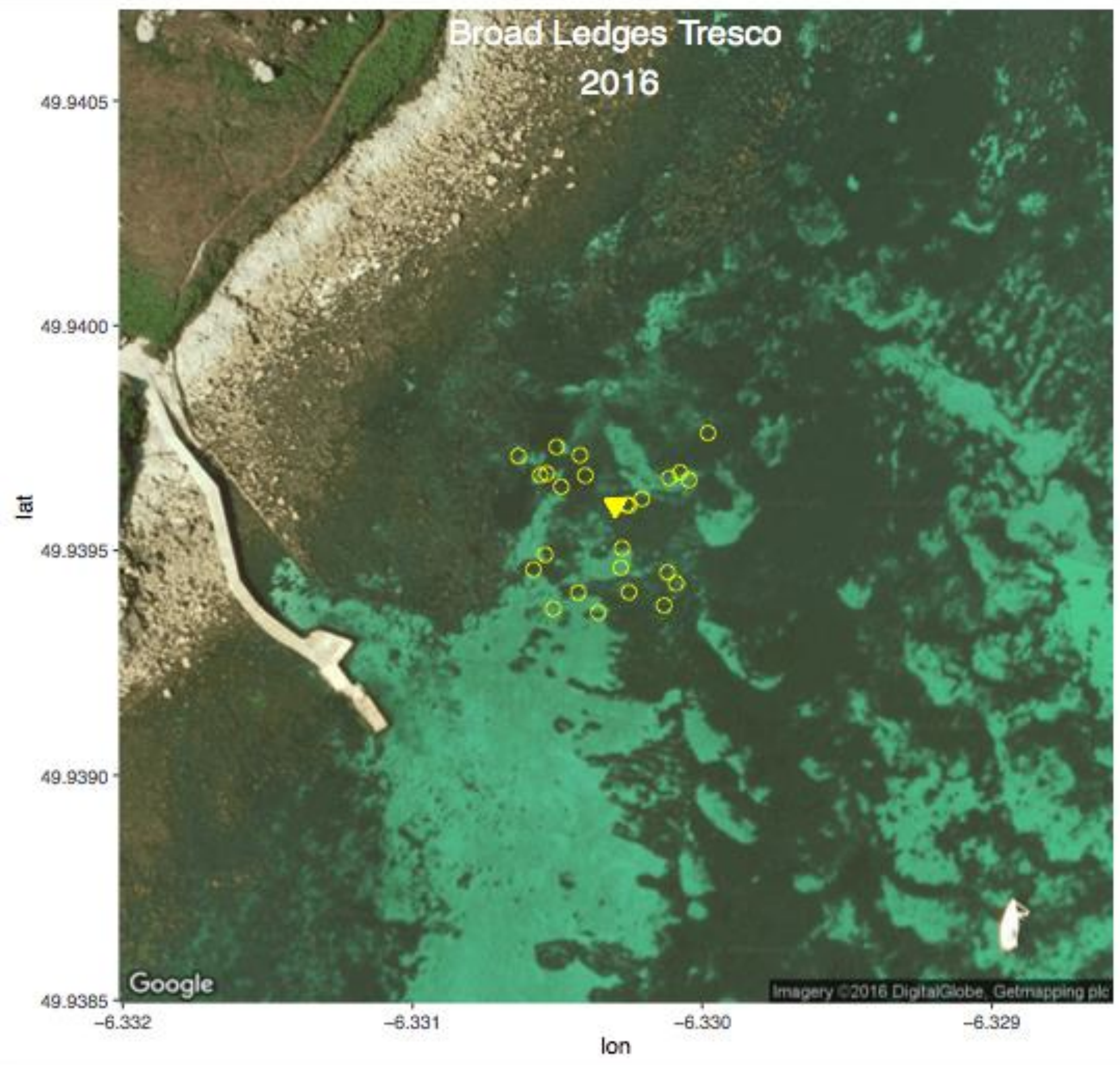
van der Heide T, Eklöf JS, van Nes EH, van der Zee EM, Donadi S, et al. (2012) Ecosystem engineering by seagrasses interacts with grazing to shape an intertidal landscape. PLoS ONE 7: e42060.

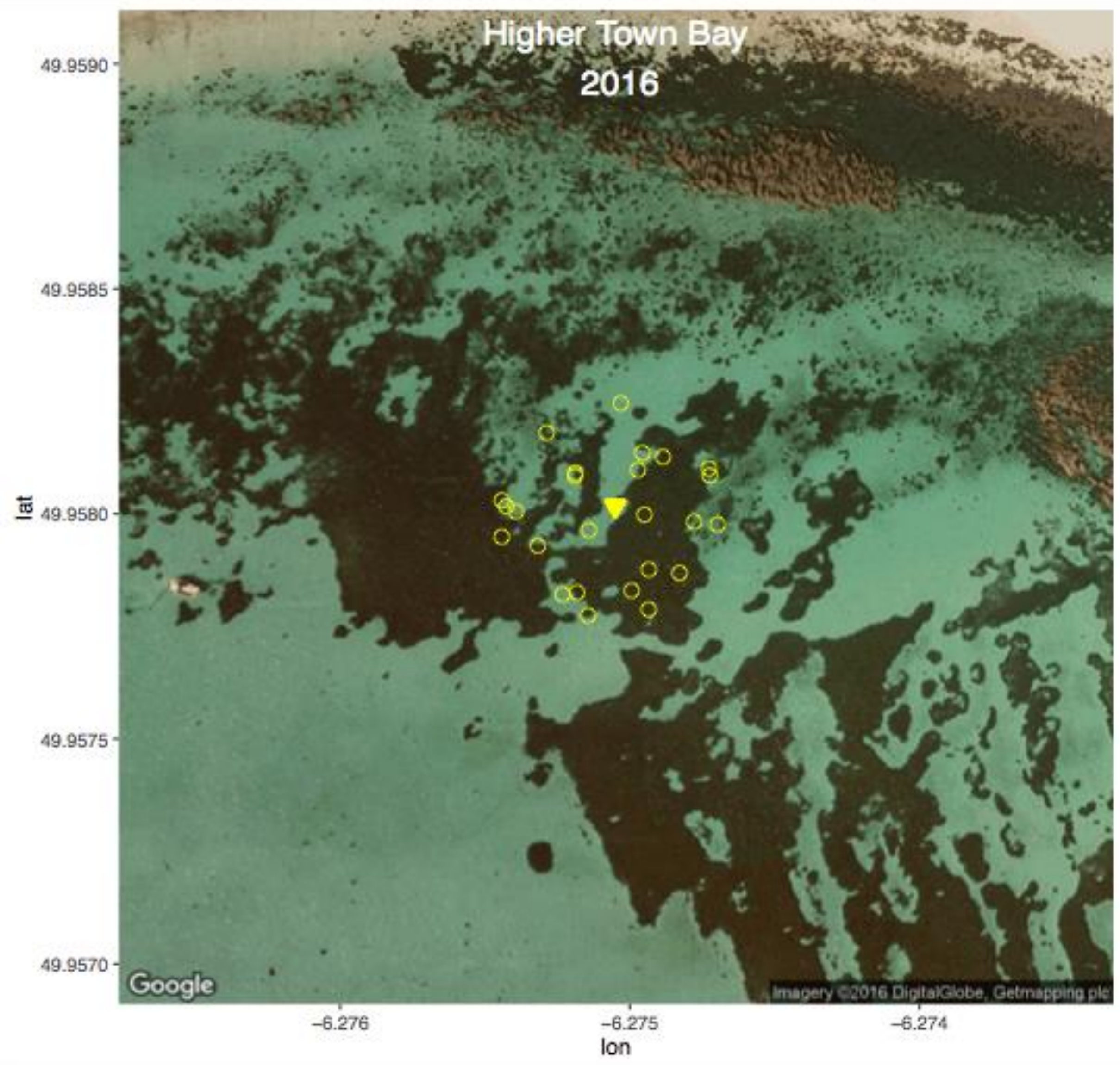
Waycott M, Duarte C, Carruthers T, Orth R, Dennison W, et al. (2009) Accelerating loss of seagrasses across the globe threatens coastal ecosystems. Proc. Natl. Acad. Sci. USA 106: 12377-12381.

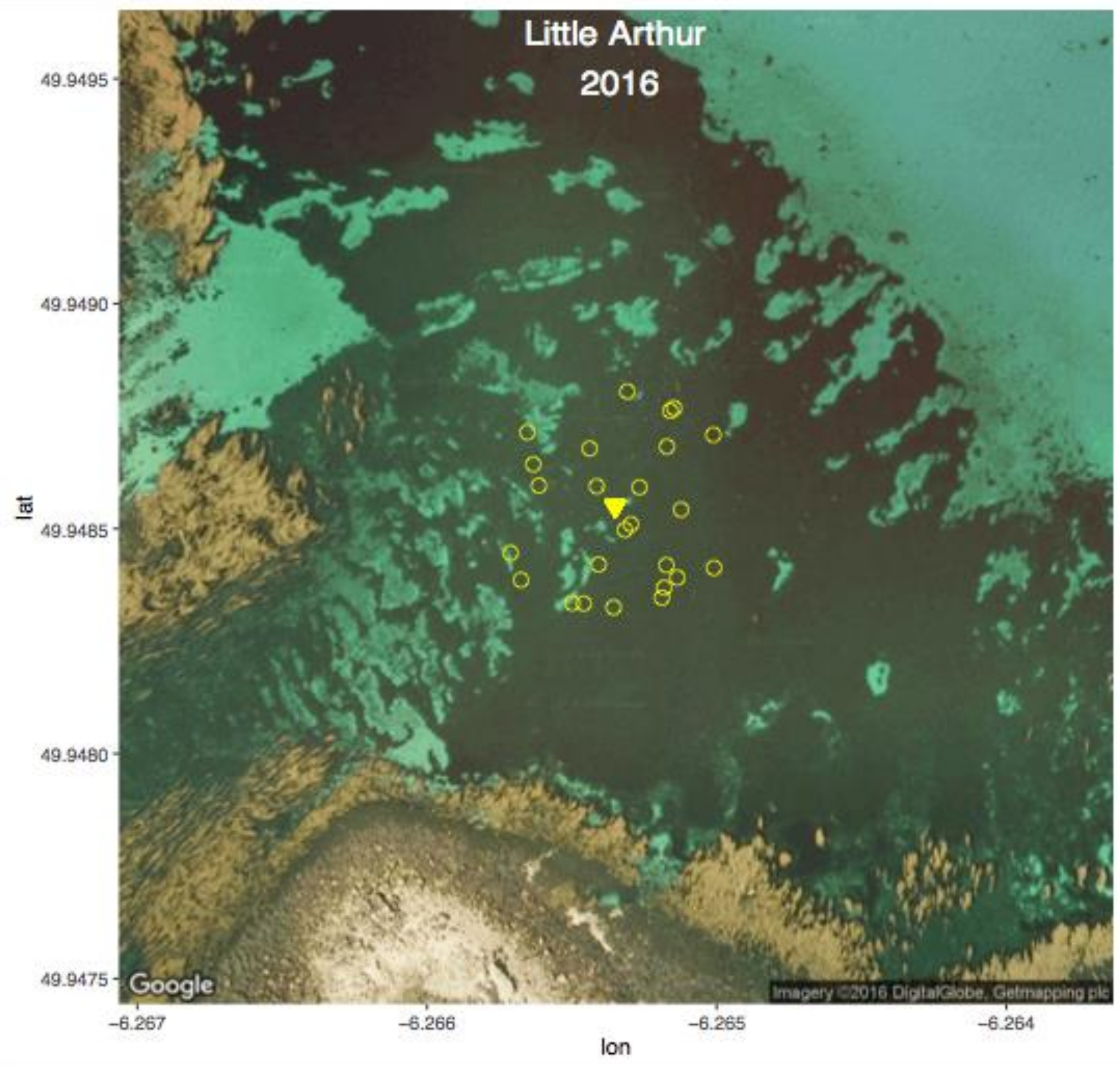
Zipperle AM, Coyer JA, Reise K, Stam WT, Olsen JL (2011) An evaluation of small-scale genetic diversity and the mating system in *Zostera noltii* on an intertidal sandflat in the Wadden Sea. Ann. Bot. 107: 127-133.

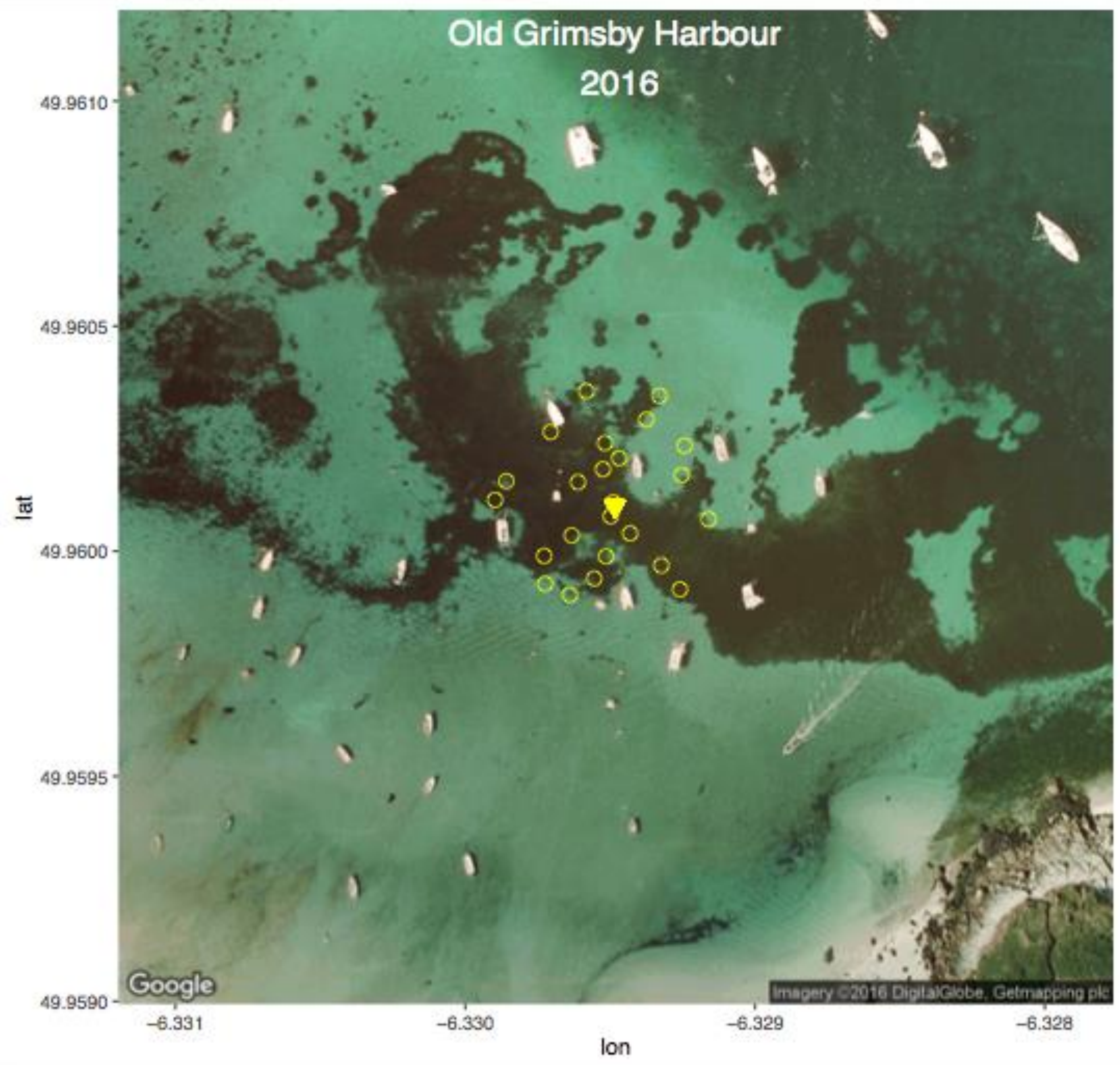
8. APPENDICES

Appendix 1 - Locations of quadrats used in the 2016 survey. Yellow triangles show the central datum (anchor) for each survey. Yellow circles show individual quadrats (not to scale, quadrats do not overlap). Google Earth images are from 2005 so these are primarily illustrative to give an indication of the spatial scale of seagrass patchiness in relation to our survey and care should be taken over interpretation. It should also be noted that not all the 'dark' patches in the photos necessarily represent seagrass. Kelp is also present at these locations and, to a lesser extent, submerged rocks.

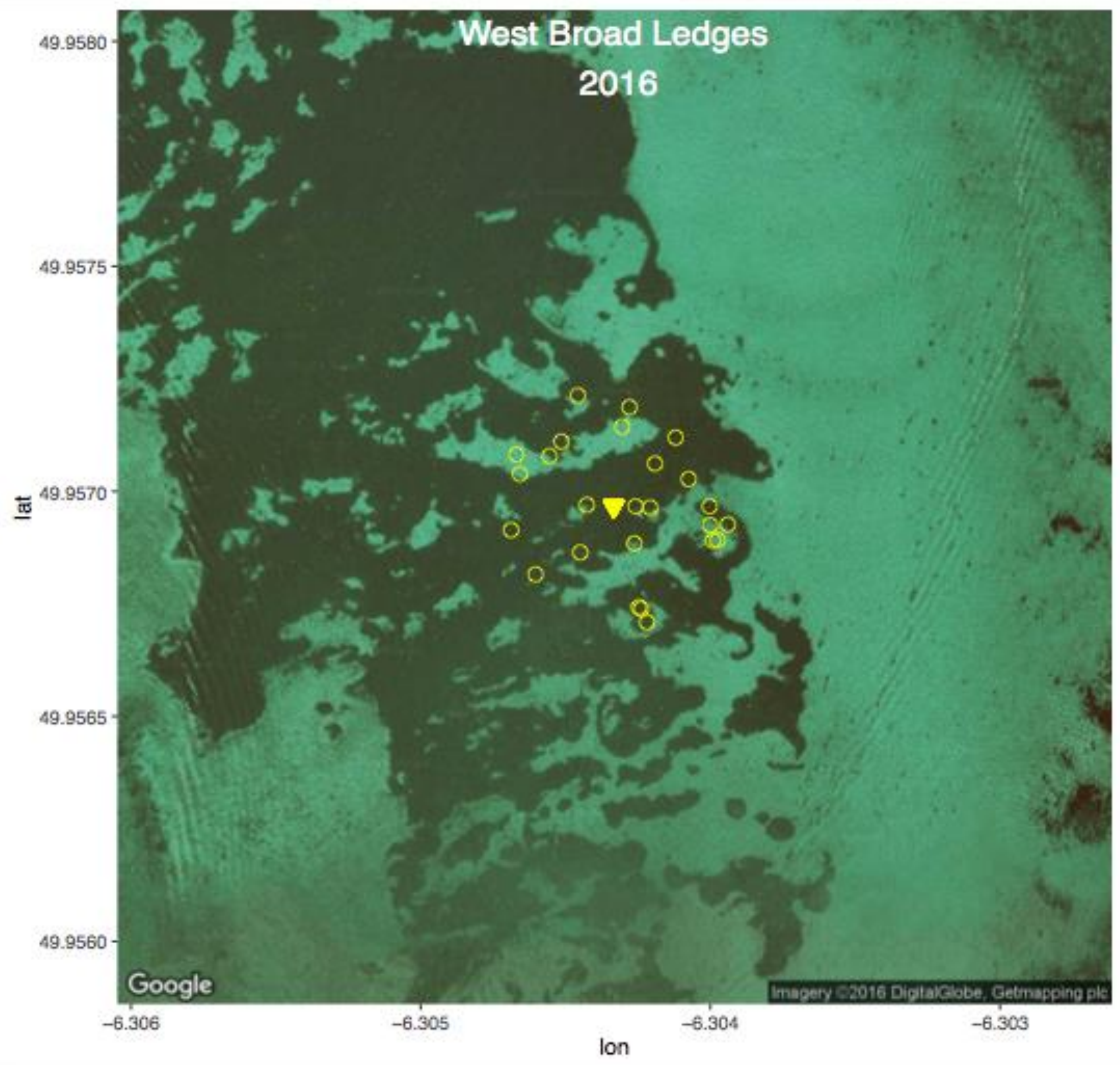

Broad Ledges Tresco
2016
49.9405
49.9400
49.9395
49.9390
49.9385
lat
−6.332
−6.331
−6.330
−6.329
lon
Google
Imagery ©2016 DigitalGlobe, Getmapping plc


Higher Town Bay
2016
49.9590
49.9585
49.9580
49.9575
49.9570
lat
Google
Imagery ©2016 DigitalGlobe, Getmapping plc
−6.276
−6.275
−6.274
lon


Little Arthur
2016
49.9495
49.9490
49.9485
49.9480
49.9475
lat
Google
Imagery ©2016 DigitalGlobe, Getmapping plc
−6.267
−6.266
−6.265
−6.264
lon



Old Grimsby Harbour
2016
49.9610
49.9605
49.9600
49.9595
49.9590
lat
−6.331
−6.330
−6.329
−6.328
lon
Google
Imagery ©2016 DigitalGlobe, Getmapping plc


West Broad Ledges
2016
49.9580
49.9575
49.9570
49.9565
49.9560
lat
Google
Imagery ©2016 DigitalGlobe, Getmapping plc
−6.306
−6.305
−6.304
−6.303
lon

Appendix 2 - Summary data.

Broad Ledges Tresco

quadrat	distance / m	bearing / deg	no. shoots	mean leaves	sd leaves	mean length	sd length	mean infection score	sd infection score	mean epiphyte score	sd epiphyte score
1	315	10.5	0	NA	NA	NA	NA	NA	NA	NA	NA
2	235	21.2	0	NA	NA	NA	NA	NA	NA	NA	NA
3	203	23.4	0	NA	NA	NA	NA	NA	NA	NA	NA
4	232	25.7	0	NA	NA	NA	NA	NA	NA	NA	NA
5	189	26.8	0	NA	NA	NA	NA	NA	NA	NA	NA
6	171	21.7	0	NA	NA	NA	NA	NA	NA	NA	NA
7	211	29.8	0	NA	NA	NA	NA	NA	NA	NA	NA
8	86	2.8	0	NA	NA	NA	NA	NA	NA	NA	NA
9	63	15	0	NA	NA	NA	NA	NA	NA	NA	NA
10	154	27.5	0	NA	NA	NA	NA	NA	NA	NA	NA
11	52	29.1	0	NA	NA	NA	NA	NA	NA	NA	NA
12	89	3.4	0	NA	NA	NA	NA	NA	NA	NA	NA
13	63	18	31	5.06	3.94	40.29	18.43	1.15	0.56	0.41	0.25
14	71	19.3	22	5.32	4.16	41	12.75	1.01	0.37	0.49	0.28
15	76	6.8	16	3.94	0.68	32.12	9.64	0.7	0.31	0.26	0.33
16	171	10.7	11	6.18	6.27	29.73	12.95	0.82	0.39	0.6	0.31
17	297	26.9	14	3.71	0.73	35	11.46	1.18	0.46	0.42	0.22
18	315	20.5	12	3.67	0.89	29.17	12.81	0.27	0.27	0.42	0.32
19	289	14.2	11	3.64	0.67	25.73	5.53	0.6	0.56	0.29	0.27
20	295	18.7	28	3.75	0.52	41.96	12.24	1.23	0.47	0.22	0.3
21	142	24.4	2	4	1.41	30.5	6.36	0.47	0.19	0.1	0.14
22	175	15.4	3	4.67	0.58	21.67	7.09	0.27	0.23	0.28	0.3
23	325	15.2	21	4.67	4.07	34.33	9.16	1.32	0.55	0.89	0.36
24	142	21	23	3.91	0.67	38.78	10.53	0.95	0.42	0.44	0.2
25	292	20	24	3.62	0.71	28.83	8.38	1.31	0.36	0.46	0.26

Higher Town Bay

quadrat	distance / m	bearing / deg	no. shoots	mean leaves	sd leaves	mean length	sd length	mean infection score	sd infection score	mean epiphyte score	sd epiphyte score
1	162	26.8	0	NA	NA	NA	NA	NA	NA	NA	NA
2	317	24.9	0	NA	NA	NA	NA	NA	NA	NA	NA
3	211	25.4	0	NA	NA	NA	NA	NA	NA	NA	NA
4	204	23.3	0	NA	NA	NA	NA	NA	NA	NA	NA
5	228	8.8	0	NA	NA	NA	NA	NA	NA	NA	NA
6	3	25.5	0	NA	NA	NA	NA	NA	NA	NA	NA
7	32	10.6	0	NA	NA	NA	NA	NA	NA	NA	NA
8	27	14.8	0	NA	NA	NA	NA	NA	NA	NA	NA
9	194	27.8	0	NA	NA	NA	NA	NA	NA	NA	NA
10	169	21.2	0	NA	NA	NA	NA	NA	NA	NA	NA
11	310	12.9	6	4	0.89	43.5	11.4	0.44	0.42	0.83	0.28
12	273	28.1	20	3.6	0.68	44.35	8.94	0.41	0.25	0.98	0.36
13	255	29.1	10	3.7	0.82	53.1	11.16	0.52	0.28	1.35	0.42
14	267	24.6	8	3.38	0.74	41	13.26	0.43	0.41	1.36	0.47
15	44	17	10	3.8	0.42	40.4	9.03	0.3	0.35	1.13	0.38
16	307	12.5	14	3.93	0.73	46.36	5.62	0.18	0.22	1.03	0.29
17	152	17.7	15	4.8	2.48	39	12.39	1.2	0.4	1.38	0.76
18	106	7.5	5	4.4	0.89	32	13.75	0.91	0.7	1.08	0.64
19	136	22.9	2	5.5	0.71	72	5.66	1.37	0.05	1.1	0.14
20	100	25.7	9	4	0.5	43.67	5.61	0.69	0.24	0.86	0.29
21	270	27	10	3.9	0.88	45.9	11.55	2.13	0.75	1.38	0.46
22	68	25	6	5	0.89	36.17	9.33	0.28	0.23	0.52	0.36
23	72	24.6	18	4.44	0.62	58.83	10.31	0.57	0.21	1.45	0.48
24	243	21.5	7	3.86	0.38	36.71	7.48	0.3	0.22	1.32	0.37
25	101	19.9	13	4.31	0.48	51.69	8.1	0.25	0.33	1.46	0.25

Little Arthur

quadrat	distance / m	bearing / deg	no. shoots	mean leaves	sd leaves	mean length	sd length	mean infection score	sd infection score	mean epiphyte score	sd epiphyte score
1	246	28.4	0	NA	NA	NA	NA	NA	NA	NA	NA
2	153	25.4	0	NA	NA	NA	NA	NA	NA	NA	NA
3	317	6.7	11	4.27	0.65	54.45	4.61	1.1	0.37	0.47	0.25
4	31	28.3	4	4.5	0.58	72.75	11.3	0.61	0.54	1.05	0.42
5	285	19.6	10	3.7	0.82	40.2	14.95	1	0.67	0.52	0.36
6	54	30	14	4.21	0.8	72.64	22.77	0.48	0.3	0.91	0.52
7	93	16.3	4	5.25	0.5	76	19.13	0.82	0.24	0.68	0.43
8	310	28.4	4	4.25	0.96	71	8.64	1.37	0.7	0.59	0.36
9	52	7.6	13	4.54	0.66	73.46	13.66	0.77	0.37	0.7	0.19
10	139	23.4	12	3.92	1	66	12.51	1.23	0.61	0.21	0.25
11	6	28.5	10	4.5	1.08	69.3	9.79	0.78	0.33	0.9	0.21
12	336	15.6	14	4.64	0.63	64.36	15.34	1.03	0.36	0.8	0.36
13	204	26.2	9	4.11	0.78	56.11	9.51	1.55	0.66	0.42	0.34
14	139	5.9	9	5	0.5	64.89	9.16	1.06	0.35	0.57	0.13
15	41	19.5	3	5	0	83	2	1.2	0.2	1.07	0.12
16	30	27.2	8	4	1.07	60.25	17.97	0.7	0.13	1.11	0.53
17	198	25.3	6	4	0.89	51.5	8.69	0.96	0.38	0.67	0.17
18	139	19.3	7	4.71	0.49	65.86	10.33	0.93	0.39	0.45	0.26
19	122	28.8	21	4.48	1.03	61.33	18.86	0.82	0.56	0.39	0.29
20	297	22.8	8	4.5	0.93	44.88	10.71	0.48	0.31	0.66	0.29
21	232	29.6	5	4.2	0.84	56.8	19.11	1.1	0.28	1.1	0.28
22	149	23.5	10	7.3	6.86	63.3	11.26	0.63	0.39	0.52	0.24
23	158	6.3	7	4.57	0.53	72.57	4.61	0.83	0.19	0.71	0.39
24	196	15	8	4.5	1.2	71.75	8.88	0.92	0.35	0.99	0.14
25	181	25	8	6.62	5.9	56.88	16.95	0.75	0.29	0.87	0.4

Old Grimsby Harbour

quadrat	distance / m	bearing / deg	no. shoots	mean leaves	sd leaves	mean length	sd length	mean infection score	sd infection score	mean epiphyte score	sd epiphyte score
1	235	21.4	0	NA	NA	NA	NA	NA	NA	NA	NA
2	319	24.3	0	NA	NA	NA	NA	NA	NA	NA	NA
3	196	18.6	0	NA	NA	NA	NA	NA	NA	NA	NA
4	273	29.7	0	NA	NA	NA	NA	NA	NA	NA	NA
5	22	29.4	0	NA	NA	NA	NA	NA	NA	NA	NA
6	236	12.9	0	NA	NA	NA	NA	NA	NA	NA	NA
7	222	25.8	0	NA	NA	NA	NA	NA	NA	NA	NA
8	151	7.7	0	NA	NA	NA	NA	NA	NA	NA	NA
9	283	27.6	0	NA	NA	NA	NA	NA	NA	NA	NA
10	346	29.3	0	NA	NA	NA	NA	NA	NA	NA	NA
11	207	24.6	0	NA	NA	NA	NA	NA	NA	NA	NA
12	65	18.2	0	NA	NA	NA	NA	NA	NA	NA	NA
13	303	10.9	0	NA	NA	NA	NA	NA	NA	NA	NA
14	142	18.6	0	NA	NA	NA	NA	NA	NA	NA	NA
15	190	12.6	0	NA	NA	NA	NA	NA	NA	NA	NA
16	5	11.9	0	NA	NA	NA	NA	NA	NA	NA	NA
17	142	26.1	0	NA	NA	NA	NA	NA	NA	NA	NA
18	203	2.7	0	NA	NA	NA	NA	NA	NA	NA	NA
19	342	9.6	0	NA	NA	NA	NA	NA	NA	NA	NA
20	20	22.8	15	3.93	0.88	29.47	9.3	0.65	0.37	2.12	0.6
21	337	1	9	3.67	1.12	37.78	14.55	1.09	0.68	1.49	0.77
22	98	23.4	4	4.5	0.58	30.75	5.12	0.95	0.25	0.59	0.31
23	49	22.8	7	4	0.82	36.14	14.17	1.14	0.51	1.57	0.78
24	351	15.8	2	3.5	0.71	21.5	9.19	0.92	0.82	0.71	0.06

West Broad Ledges

quadrat	distance / m	bearing / deg	no. shoots	mean leaves	sd leaves	mean length	sd length	mean infection score	sd infection score	mean epiphyte score	sd epiphyte score
1	273	6.7	0	NA	NA	NA	NA	NA	NA	NA	NA
2	298	27.3	0	NA	NA	NA	NA	NA	NA	NA	NA
3	108	27	0	NA	NA	NA	NA	NA	NA	NA	NA
4	42	22.9	0	NA	NA	NA	NA	NA	NA	NA	NA
5	342	28.8	0	NA	NA	NA	NA	NA	NA	NA	NA
6	6	19.8	0	NA	NA	NA	NA	NA	NA	NA	NA
7	216	14.1	0	NA	NA	NA	NA	NA	NA	NA	NA
8	164	29.8	0	NA	NA	NA	NA	NA	NA	NA	NA
9	166	25.7	0	NA	NA	NA	NA	NA	NA	NA	NA
10	257	26.1	0	NA	NA	NA	NA	NA	NA	NA	NA
11	165	26.2	0	NA	NA	NA	NA	NA	NA	NA	NA
12	9	24.8	0	NA	NA	NA	NA	NA	NA	NA	NA
13	229	25.6	1	4	NA	16	NA	1	NA	1.25	NA
14	92	9	13	4.08	0.76	51.85	15.54	1.15	0.29	0.91	0.37
15	151	10.5	11	5.27	5.93	49.64	20.39	0.94	0.46	0.79	0.5
16	99	28.6	19	4.16	1.01	39.68	11.86	1.25	0.49	0.59	0.25
17	101	24.3	18	3.94	0.87	62.33	18.86	1.2	0.52	0.86	0.37
18	321	20.6	2	3.5	2.12	28	18.38	1.2	0.28	0.2	0.28
19	289	24.6	13	4	0.58	53.54	12.51	1.03	0.29	0.69	0.17
20	44	14.7	14	4.21	0.89	36.21	11.72	0.78	0.26	0.88	0.55
21	70	19.7	16	3.75	1.06	59.5	10.62	1.25	0.24	1.06	0.44
22	109	26	1	4	NA	21	NA	0.25	NA	1.5	NA
23	90	5.4	16	5.31	3	59.56	17.57	0.92	0.47	1.35	0.41
24	308	20.2	11	4.18	0.75	39	9.4	1.24	0.34	0.78	0.27
25	90	23.7	15	5.33	4.98	53.27	25.09	0.81	0.4	1.23	0.76

Further information

Natural England evidence can be downloaded from our **Access to Evidence Catalogue**. For more information about Natural England and our work see **Gov.UK**. For any queries contact the Natural England Enquiry Service on 0300 060 3900 or e-mail **enquiries@naturalengland.org.uk** .

Copyright

Report number RP02939
ISBN 978-1-78354-384-7