Natural England Commissioned Report NECR178

Isles of Scilly eelgrass bed voluntary monitoring programme

2014 Annual Survey

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Foreword

Natural England commission a range of reports from external contractors to provide evidence and advice to assist us in delivering our duties. The views in this report are those of the authors and do not necessarily represent those of Natural England.

Background

This study was carried out to continue the long-standing annual survey effort on five main *Zostera* marina beds in the Isles of Scilly, for which data have been collected since 1992. The study covered *Zostera* shoot densities, numbers 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.

The results from this study, and their place in continuous time series of results dating from 1996, will enable any observed changes or possible trends to be monitored, thus informing site managers as to any adaptations that may need to be made to the future management of the Special Area of Conservation.

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Natural England Project Manager - Kate Sugar, Pydar House, Pydar Street, Truro, Cornwall, TR1 1XU
kate.sugar@naturalengland.org.uk

Contractor - Dr James Bull, Department of Biosciences, Swansea University and Dr Emma Kenyon, School of Life Sciences, University of Sussex

Keywords - eelgrass beds, Isles of Scilly, long term monitoring, marine ecology, Marine Protected Areas (MPA), seagrass, Special Areas of Conservation (SAC), volunteers, *zostera* marine

Further information
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Contents

1. ABSTRACT

Seagrasses are globally dispersed along coastlines, covering approximately 0.3 to 0.6 million km^2. However, seagrasses are currently in rapid decline worldwide, due to a range of anthropogenic impacts, disease and climate change. As a result, there is considerable interest in understanding the drivers of seagrass population dynamics. However, 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, in order to control for within-season variation, the longer-term effects of biological or environmental drivers of population dynamics can be quantified.

In this report, we present novel data from an ongoing, spatially replicated, annual study of a comparatively un-impacted temperate seagrass habitat, based around the Isles of Scilly, UK. Metrics include eelgrass (*Zostera marina*) shoot density, numbers 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 2014 survey, as well as their place in continuous time series from 1996, are presented primarily in graphical form. Additionally, we use Generalised Linear Modelling to test a series of hypotheses on spatial and temporal trends.

Despite severe winter storms in 2013 / 4, no catastrophic losses were reported. Overall, eelgrass was present at all five survey sites around the Isles of Scilly and, where eelgrass was found, the 2014 survey found no significant variation in shoot density between survey sites. Longer-term trends reveal gradual declines in average shoot density at three out of five surveyed sites (Higher Town Bay, Little Arthur and Broad Ledges Tresco). Canopy height was found to differ between sites with the greatest mean height in 2014 at West Broad Ledges, in contrast to previous years where Little Arthur typically had greatest canopy height. Time series analysis found increasing canopy height at Broad Ledges Tresco, but declines through time for Higher Town Bay and Little Arthur.

Shoot density and canopy height were combined into a measure of Leaf Area Index (estimating total photosynthetic area per unit ground). Here, declines in this index were found at Higher Town Bay and Little Arthur but the decline in shoot density at Broad Ledges Tresco was balanced by an increase in canopy height to result in on overall trend in Leaf Area Index at this survey site. The 2014 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.

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. Finally, we continue to see *Sargassum muticum* at all surveyed sites in the Isles of Scilly. While this is not formally quantified, no obvious changes in abundance or distribution were evident.

Conclusions from a single year of study can only be very limited, but we are able to report that growth was much reduced at the Little Arthur site, which usually supports the largest eelgrass shoots. Reasons for this are unknown but may result from disturbance to the water by storms earlier in the year. The real value of this survey is the part it forms in what is now the longest continuous, detailed annual survey of seagrass in the world, as far as we are aware. We look forward to continuing this remarkable feat in future years.

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, in order to control for within-season variation, the longer-term effects of biological or environmental drivers of population dynamics can be quantified.

2.2 Wasting disease

In the 1930s, a ‘wasting disease’ (*Labyrinthula zosterae*) substantially reduced populations of eelgrass, the predominant seagrass species of the north Atlantic. 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 seagrass 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 for the following features (and sub-features):

1) sub-tidal sandbanks (eelgrass bed communities, sand and gravel communities, mixed sediment communities);
2) reefs (rocky shore communities, vertical rock, kelp forest communities, sub-tidal rock & boulder communities, sub-tidal faunal turf communities);
3) intertidal mudflats and sand flats (sand communities);
4) grey seals (*Halichoerus grypus*); and
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 seagrass habitat. 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 currently thought to be in serious overall decline.

2.5 Survey site descriptions (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 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.

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 weight 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 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 is comprised of 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.

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; and
5) the amount of **epiphyte** cover on leaves.

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

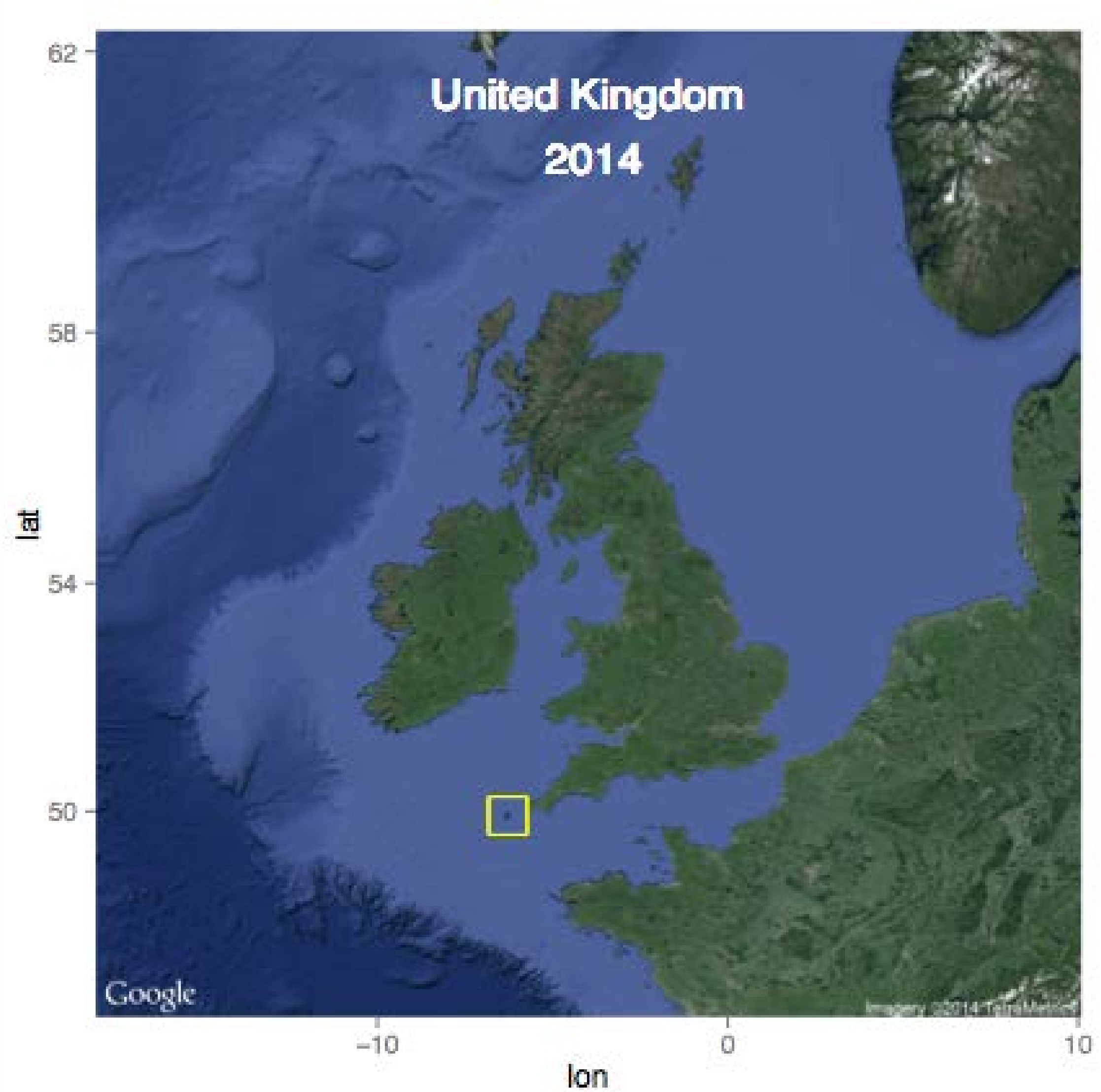

Figure 1 - Location of the Isles of Scilly in relation to the rest of the United Kingdom. Yellow square surrounds the Isles of Scilly.

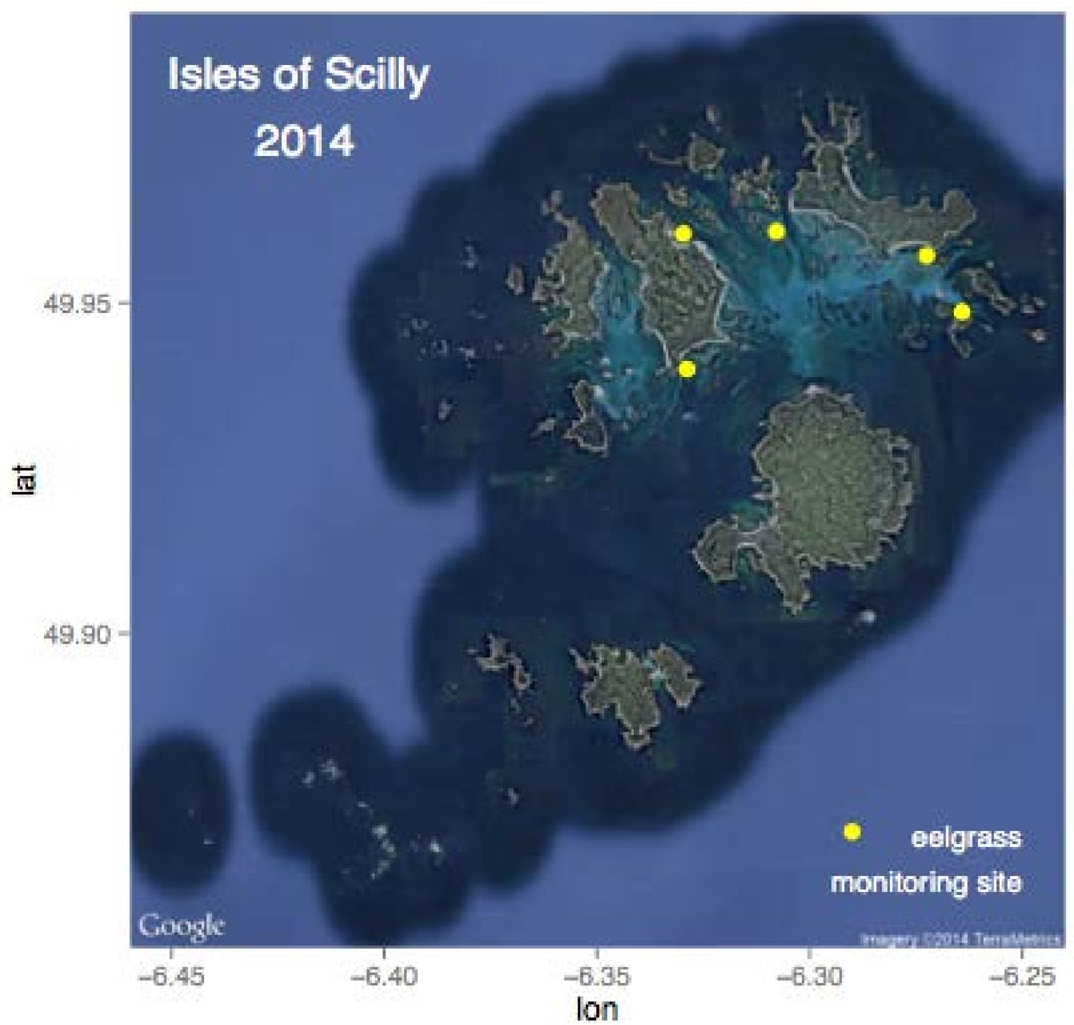

Figure 2 - Locations of the five survey sites around the Isles of Scilly in 2014. Solid yellow circles indicate sites. Clockwise from bottom-left: Broad Ledges Tresco (blt), Old Grimsby Harbour (ogh), West Broad Ledges (wbl), Higher Town Bay (htb) and Little Arthur (la).

3. METHODS

3.1 Survey methods

Survey team

The team for the 2014 Isles of Scilly eelgrass survey comprised Olle Åkesson (Sussex Wildlife Trust), Chiara Bertelli (Swansea University), James Bull (Swansea University), Kevan Cook (Natural England), Emma Kenyon (Sussex University), Cyril Nicholas (formerly Natural England and long-time Islander) and Max Robinson (Swansea University). 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 Kevan's RIB, Eva, which has been the platform for the Isles of Scilly eelgrass survey for at least the last ten years.

Survey location

As far as possible, surveys were carried out at the same five locations as in previous years (figure 2). 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, 2014.

Site	Latitude	Longitude	Depth (chart datum)	Date surveyed
blt	49°56.4′N	06°19.6′W	0.2m	27 / 07 / 2014
htb	49°57.2′N	06°16.6′W	+0.5m	28 / 07 / 2014
la	49°56.9′N	06°15.9′W	1.0m	29 / 07 / 2014
ogh	49°57.6′N	06°19.8′W	0.6m	28 / 07 / 2014
wbl	49°57.5′N	06°18.4′W	0.6m	30 / 07 / 2014

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.

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).

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 seagrass 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.

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 2014, as well as on temporal trends through the whole period of the current Isles of Scilly eelgrass survey, 1996 - 2014. In all cases, we adopt the simple approach of:

1) identifying the quantitative question to be focussed on;
2) graphically presenting the observation that answers the question; and
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. Exploring and explaining these spatial patterns is the subject of a current PhD project at Warwick University, by Mike Irvine, who joined the 2013 IoS eelgrass survey. 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. These form unequal sized categories (‘a’, ‘b’, ‘c’, ‘d’ and ‘e’, as above) that form a logical order and should, therefore, be treated as ‘ordinal data’. This type of multinomial analysis is not trivial and beyond the scope of the current report. While far from an optimal solution to modelling these data, here we converted percentage bracket scores (0-5) to ‘proportion data’ (0-1), first by averaging raw infection scores across quadrats, then dividing through by five. We are currently developing ordinal regression methods to treat these data properly, which we intend to present in the next Isles of Scilly eelgrass survey annual report (2015 - marking 20 years of the survey). Here, we modelled ‘proportion data’ by logit-transforming (where, $logit[p] = ln[p / (1-p)]$) the proportions and modelling with Gaussian (Normal) GLMs.

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

4. RESULTS

4.1 2014 Survey findings

Shoot counts

We ask the question whether there is a significant difference in mean shoot density between survey sites. This is assessed as a two part mixture model, combining a binomial model of presence / absence in quadrats with a negative binomial count model. We find that the first null hypothesis of equal proportions of occupied quadrats <u>is</u> rejected (χ^2 = 20.5, df = 4, p < 0.001). However, we find that the second null hypothesis of equal shoot densities across survey sites is <u>not</u> rejected (χ^2 = 6.11, df = 4, p = 0.19).

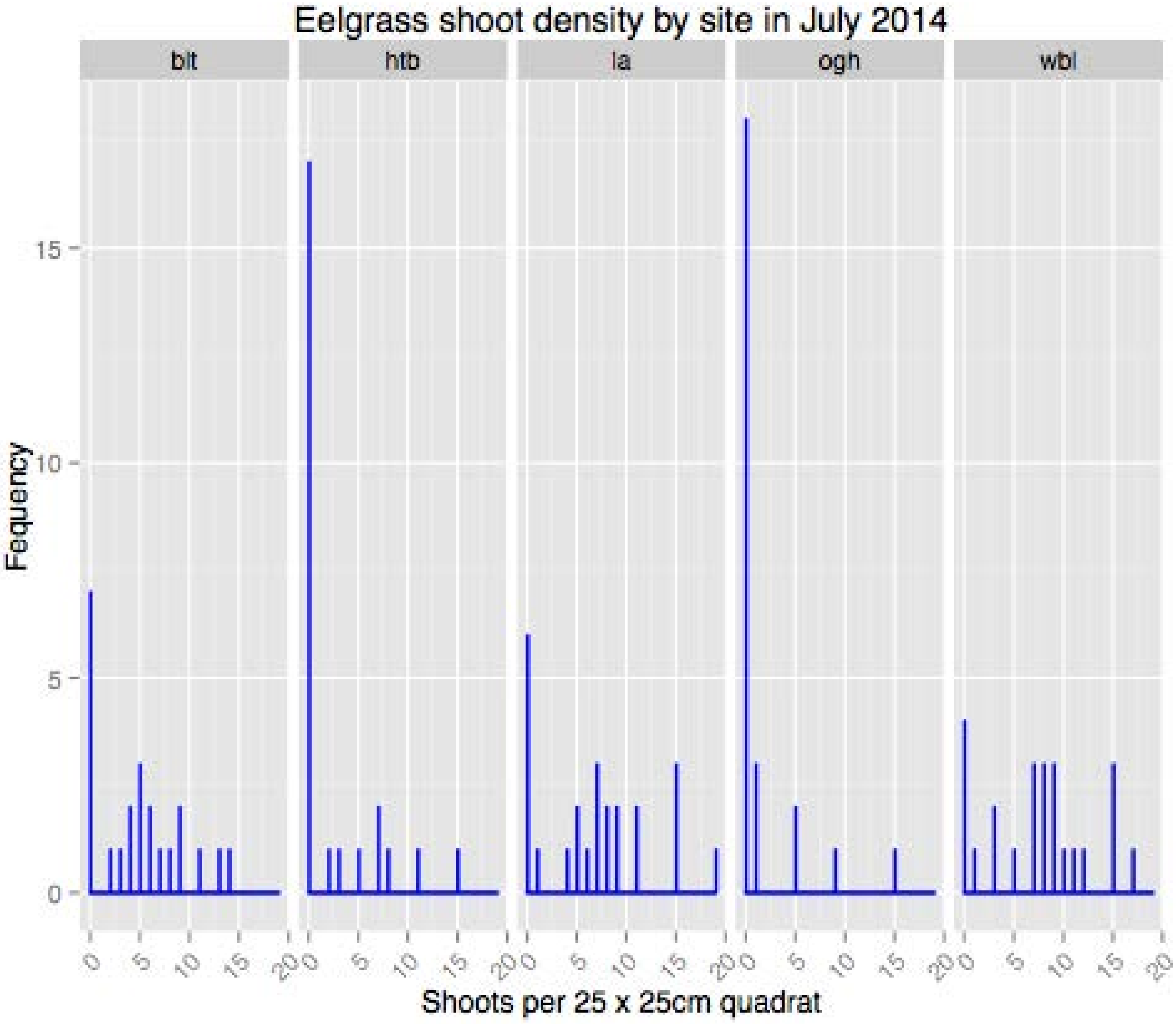

Figure 3 - Frequency histogram of the number of eelgrass shoots recorded per 25 x 25cm quadrat at each of the five survey locations.

We conclude that, within the limits of our survey, spatial heterogeneity is evident between sites at the level of eelgrass 'patchiness' but, where eelgrass is present shoot densities do not vary significantly.

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. We ask the question whether there is a significant difference in mean (non-zero quadrat) canopy heights between survey sites. This is assessed using a generalised linear model with gamma errors. We find that the null hypothesis of equal canopy heights across survey sites <u>is</u> rejected (F = 3.09, df = 4, p = 0.022). In particular, we find that mean canopy height at West Broad Ledges is significantly larger than the other sites (t = 2.85, p = 0.006).

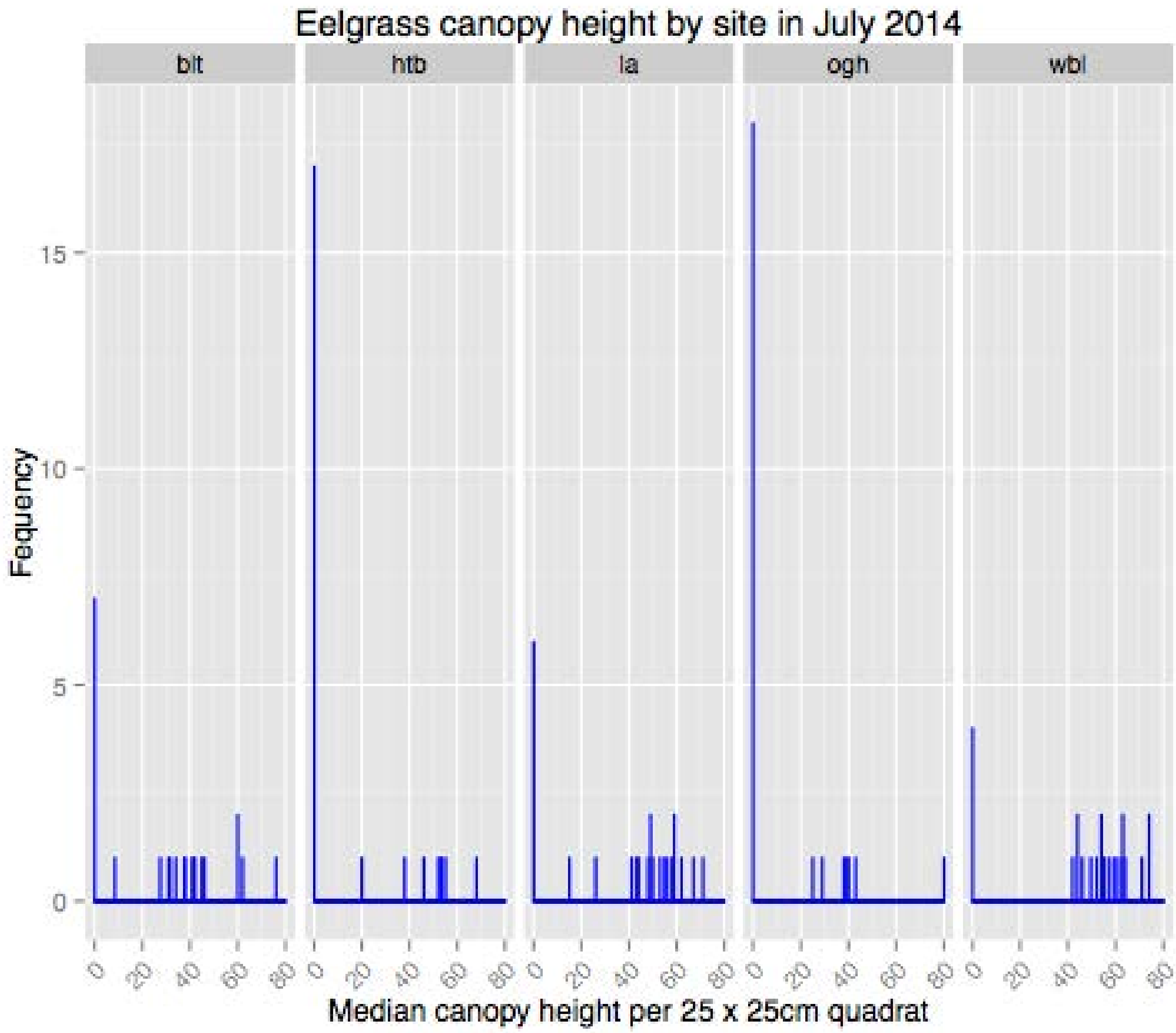

Figure 4 - Frequency histogram of the ‘canopy height’ (cm) of eelgrass shoots recorded per 25 x 25cm quadrat at each of the five survey locations.

This finding is in contrast to previous years (see time series results), in which eelgrass at Little Arthur has consistently produced the greatest canopy height.

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. We ask the question whether there is a significant difference in mean (non-zero quadrat) LAI between survey sites. 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 ($F = 2.51$, $df = 4$, $p = 0.051$).

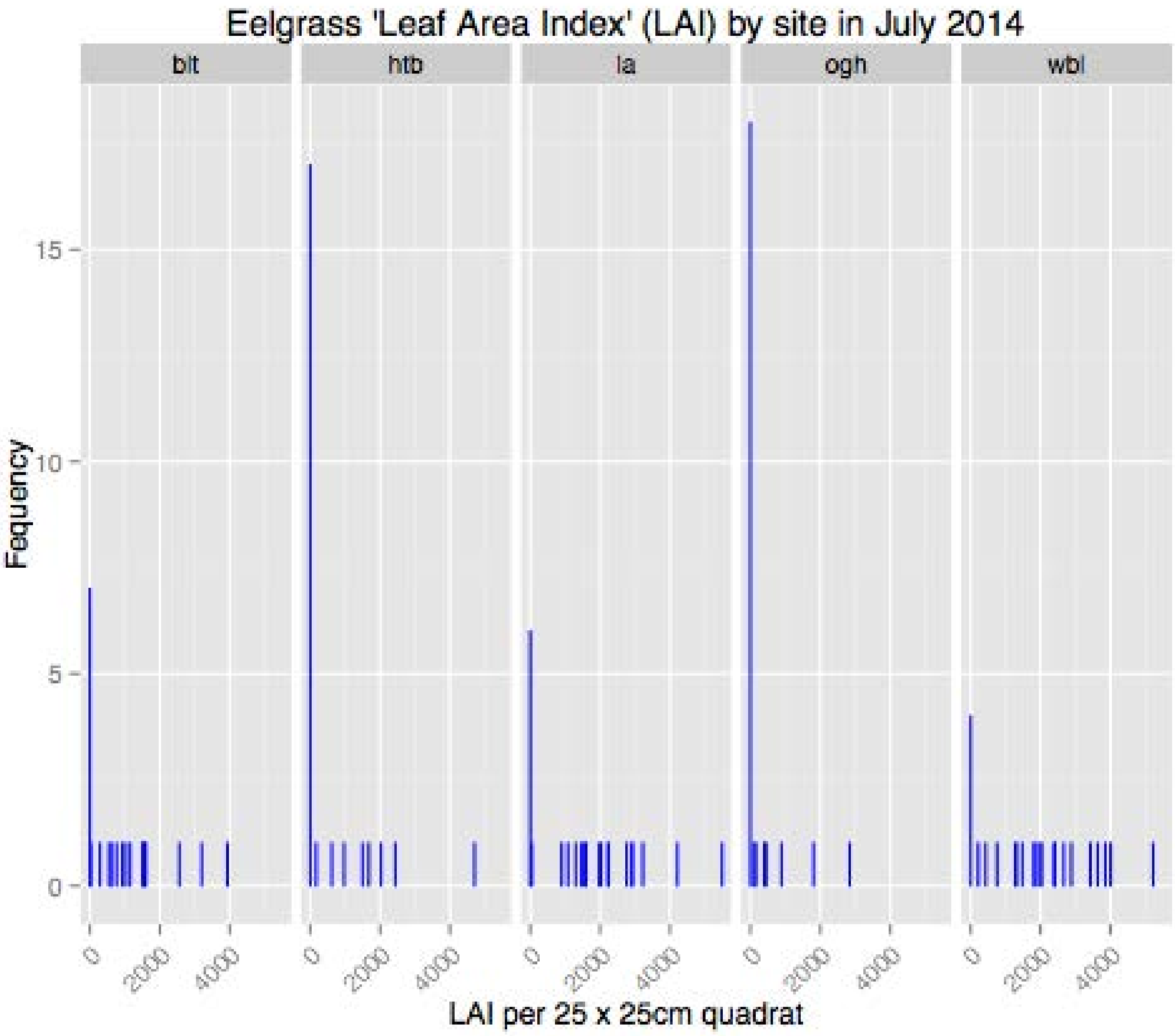

Figure 5 - Frequency histogram of the 'Leaf Area Index' (LAI) of eelgrass recorded per 25 x 25cm quadrat at each of the five survey locations.

Within the limits of our study, spatial heterogeneity in mean leaf area index is not evident between sites. Despite the fact that LAI is a secondary measure, derived from canopy height and shoot density, the differences in canopy height evident at West Broad Ledges do not translate to differences in LAI.

4.2 Time series analysis, 1996 - 2014

Shoot counts

We ask the question whether mean (non-zero quadrat) shoot density changes through time. 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 Broad Ledges Tresco (t = 2.33, p = 0.020), Higher Town Bay (t = 2.91, p = 0.004) and Little Arthur (t = 2.30, p = 0.022). In all three cases, there is a significant decline in mean shoot density through time.

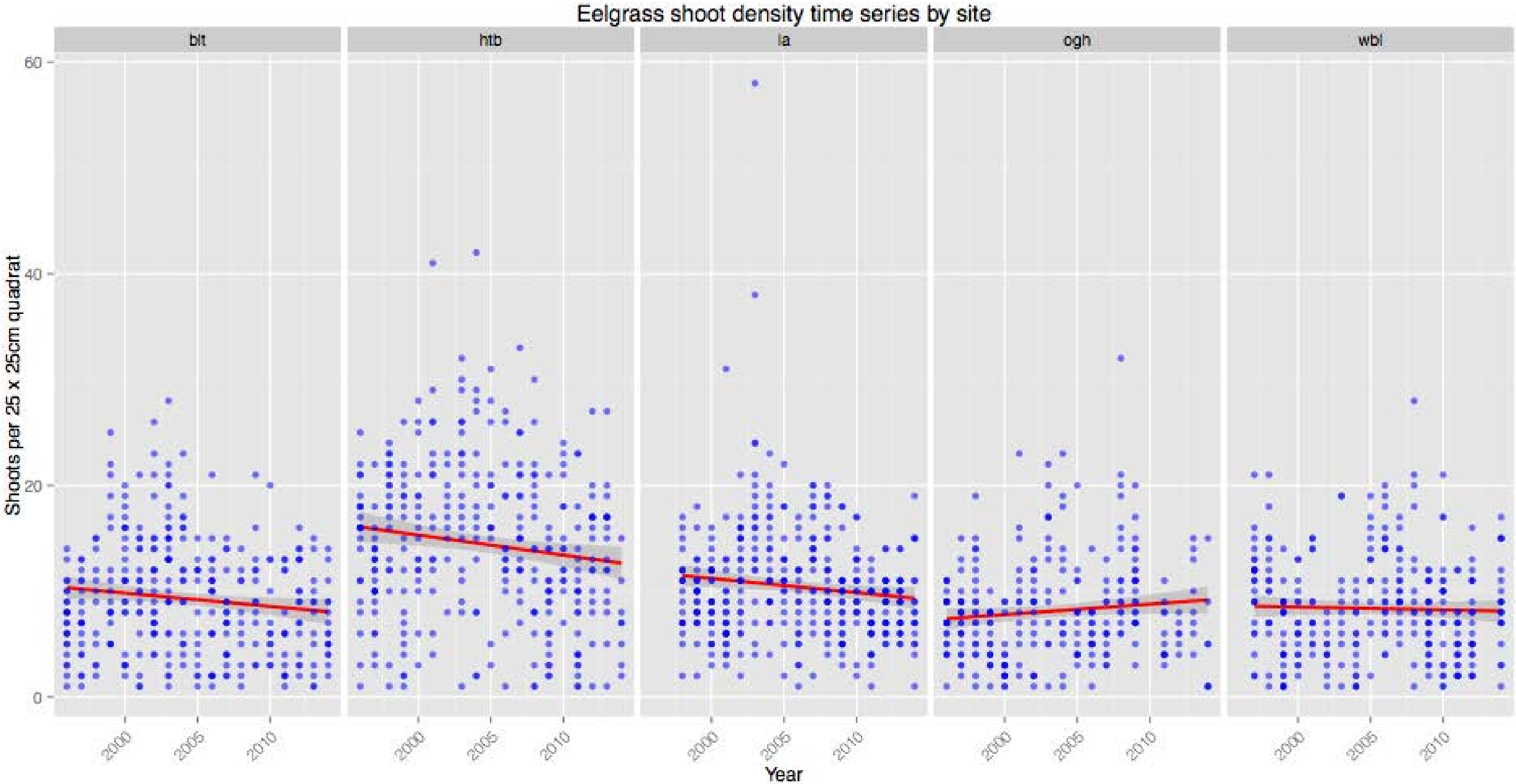

Figure 6 - Time series of eelgrass shoot densities for all quadrats at each of the five survey sites, from 1996 to 2014. Solid blue circles indicate individual quadrat shoot counts. Circles have a degree of opacity in order to show where multiple quadrats had identical counts in a given survey site (i.e. data points that sit on top of each other). 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.

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. We ask the question whether mean (non-zero quadrat) canopy height changes through time. 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 Broad Ledges Tresco ($t = 2.40$, $p = 0.017$), Higher Town Bay ($t = 3.65$, $p < 0.001$) and Little Arthur ($t = 2.35$, $p = 0.019$). In the cases of htb and la, there was a significant decline in mean canopy height through time. In contrast, blt was found to have increasing canopy height through time. Little Arthur is typically found to have to largest canopy height. However, this was not found to be the case in the 2014 survey (see canopy height histogram).

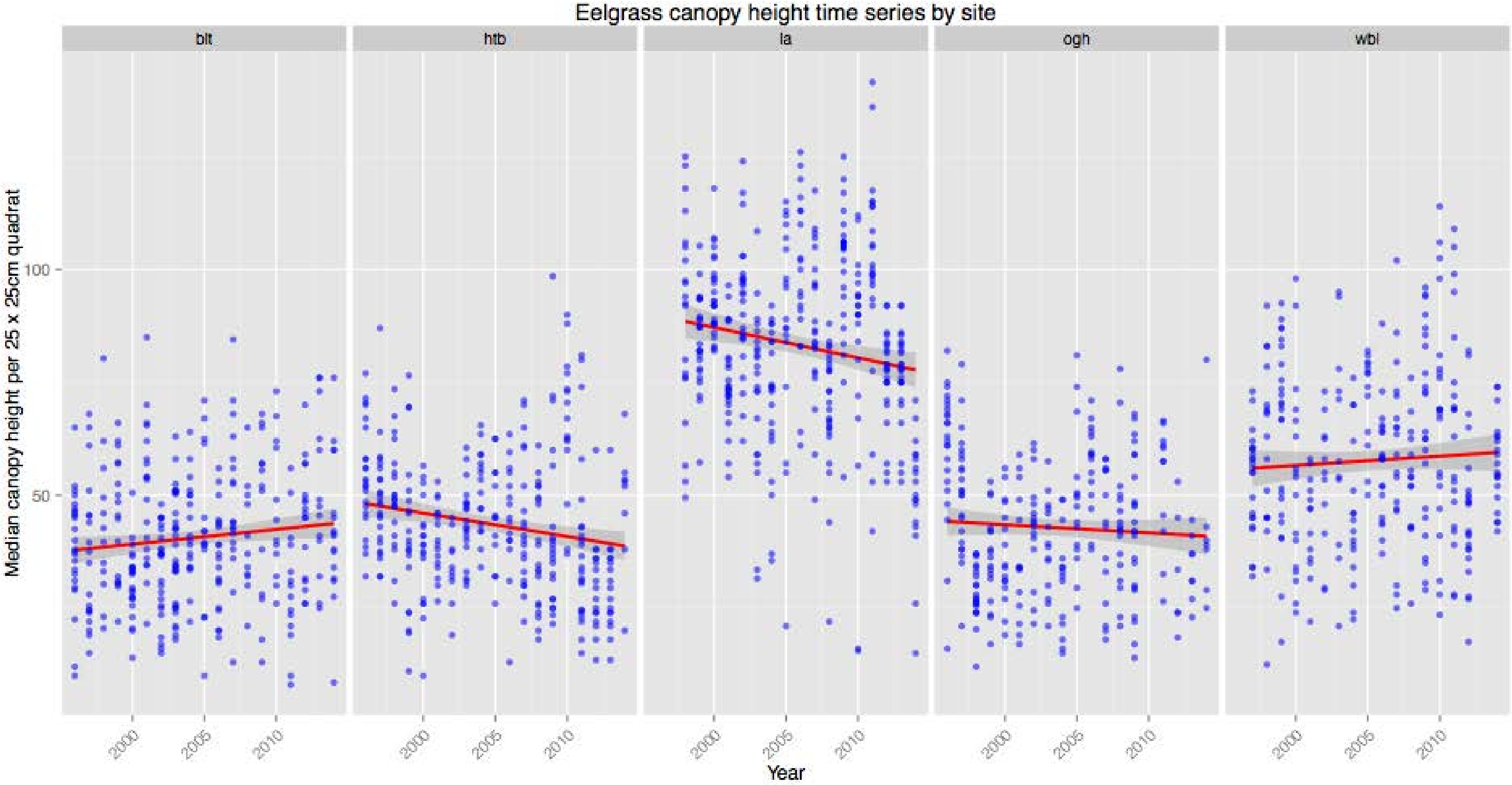

Figure 7 - Time series of eelgrass 'canopy heights' for all quadrats at each of the five survey sites, from 1996 to 2014. Solid blue circles indicate individual quadrat canopy heights. Circles have a degree of opacity in order to show where multiple quadrats had identical counts in a given survey site (i.e. data points that sit on top of each other). 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.

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. We ask the question whether mean (non-zero quadrat) leaf area index changes through time. 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 Higher Town Bay ($t = 3.90$, $p < 0.001$) and Little Arthur ($t = 2.50$, $p = 0.013$). In both cases, there is a significant decline in mean LAI through time. Interestingly, we see no such trend at Broad Ledges Tresco. There, a decline in shoot density is balanced by an increase in canopy height, resulting in no overall trend in LAI.

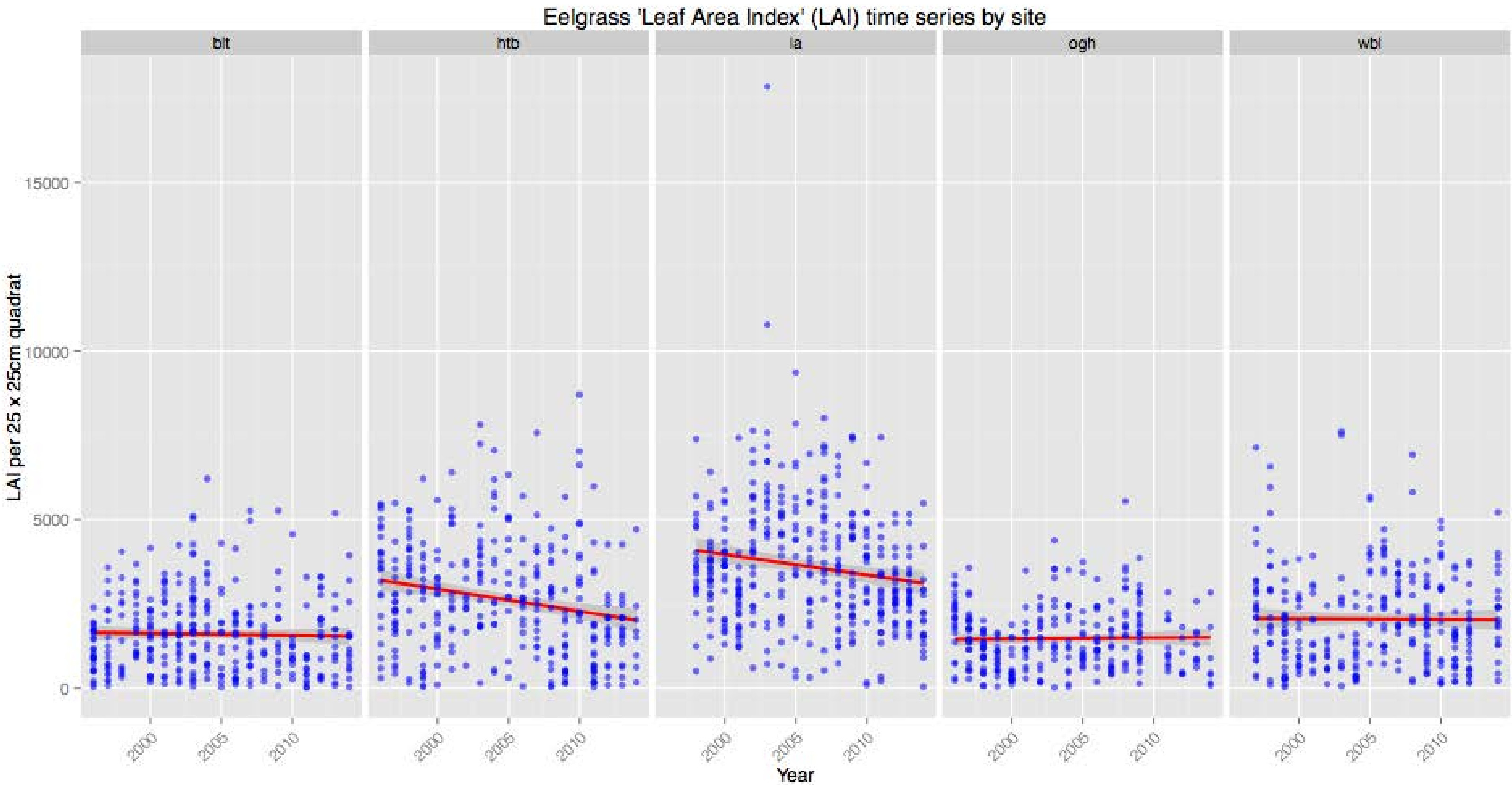

Figure 8 - Time series of the 'Leaf Area Index' (LAI) of eelgrass for all quadrats at each of the five survey sites, from 1996 to 2014. Solid blue circles indicate individual quadrat shoot counts. Circles have a degree of opacity in order to show where multiple quadrats had identical counts in a given survey site (i.e. data points that sit on top of each other). 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'
We ask the question whether the proportion of occupied (non-zero shoot density) quadrats changes through time. 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 ($t = 3.65$, $p < 0.001$). Here, there has been a significant decline in the proportion of quadrats with eelgrass present.

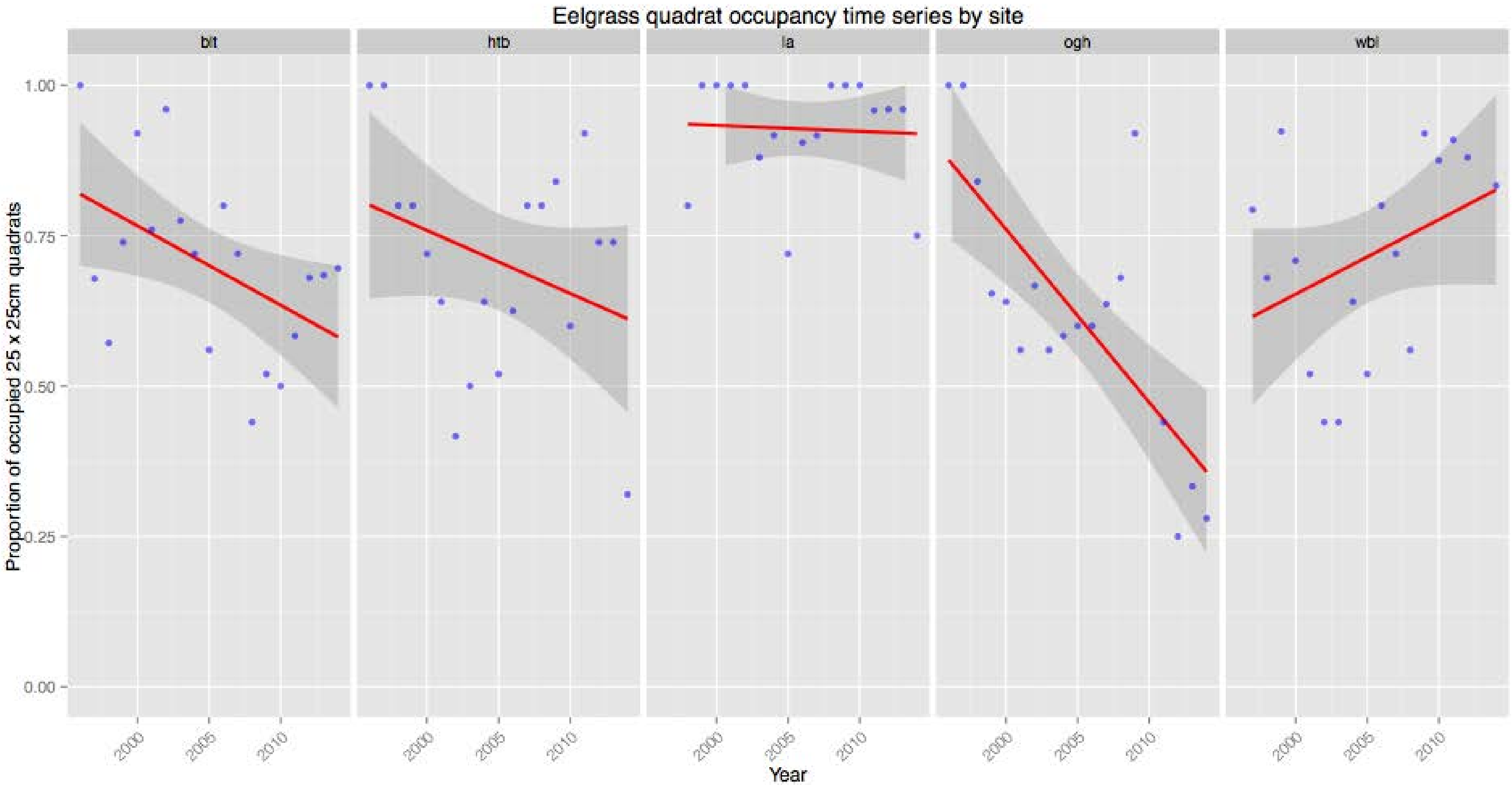

Figure 9 - Time series of the proportion of occupied quadrats at each of the five survey sites, from 1996 to 2014. Solid blue circles indicate individual quadrat shoot counts. Red lines show overall temporal trends (Generalised Additive Model smooth, using cubic splines). Trend lines are surrounded by 95% confidence envelopes in grey.

Wasting disease

We ask the question whether there is a significant difference in mean infection scores between survey sites. 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 = 29.7, df = 4, p < 0.001). In particular, Broad Ledges Tresco and Old Grimsby Harbour have lower than average infection scores, while Higher Town Bay and West Broad Ledges have higher than average infection scores.

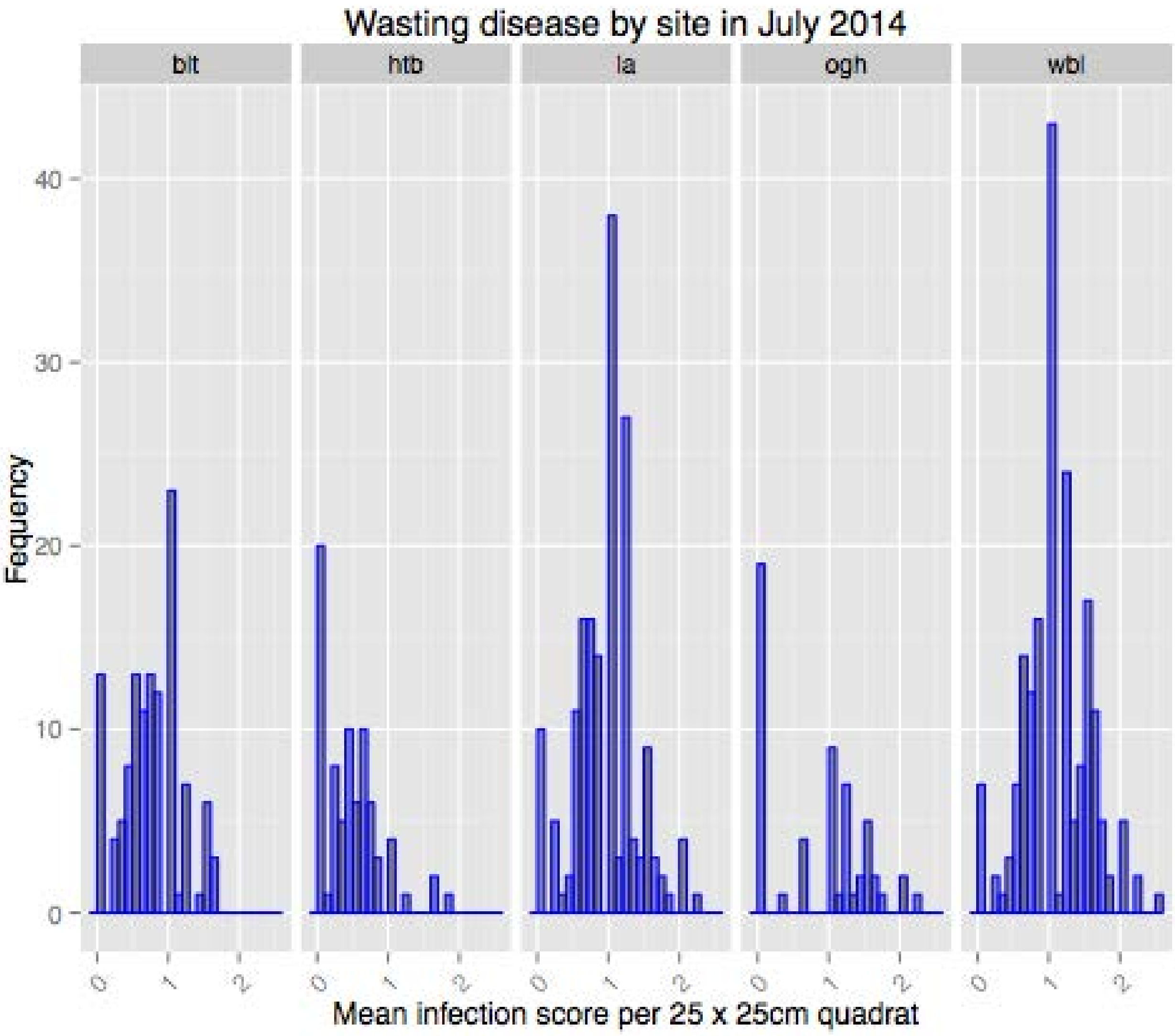

Figure 10 - Signs of wasting disease in each of the five survey sites in 2014. Here, we present average infection scores (0-5) per quadrat.

Due to the sub-optimal statistical modelling used here, as described in our analytical methods section, we do not go on to investigate long-term trends in wasting disease in this report. However a fuller investigation of the role of wasting disease in the population dynamics of eelgrass over the life of this survey (1996 - 2010) has recently been published by some of the authors of this report (Bull et al., 2012).

Epiphytes
We ask the question whether there is a significant difference in mean epiphyte scores between survey sites. 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 = 24.4, df = 4, p < 0.001). In particular, Broad Ledges Tresco had lower than average epiphyte scores, while Higher Town Bay had higher than average epiphyte scores.

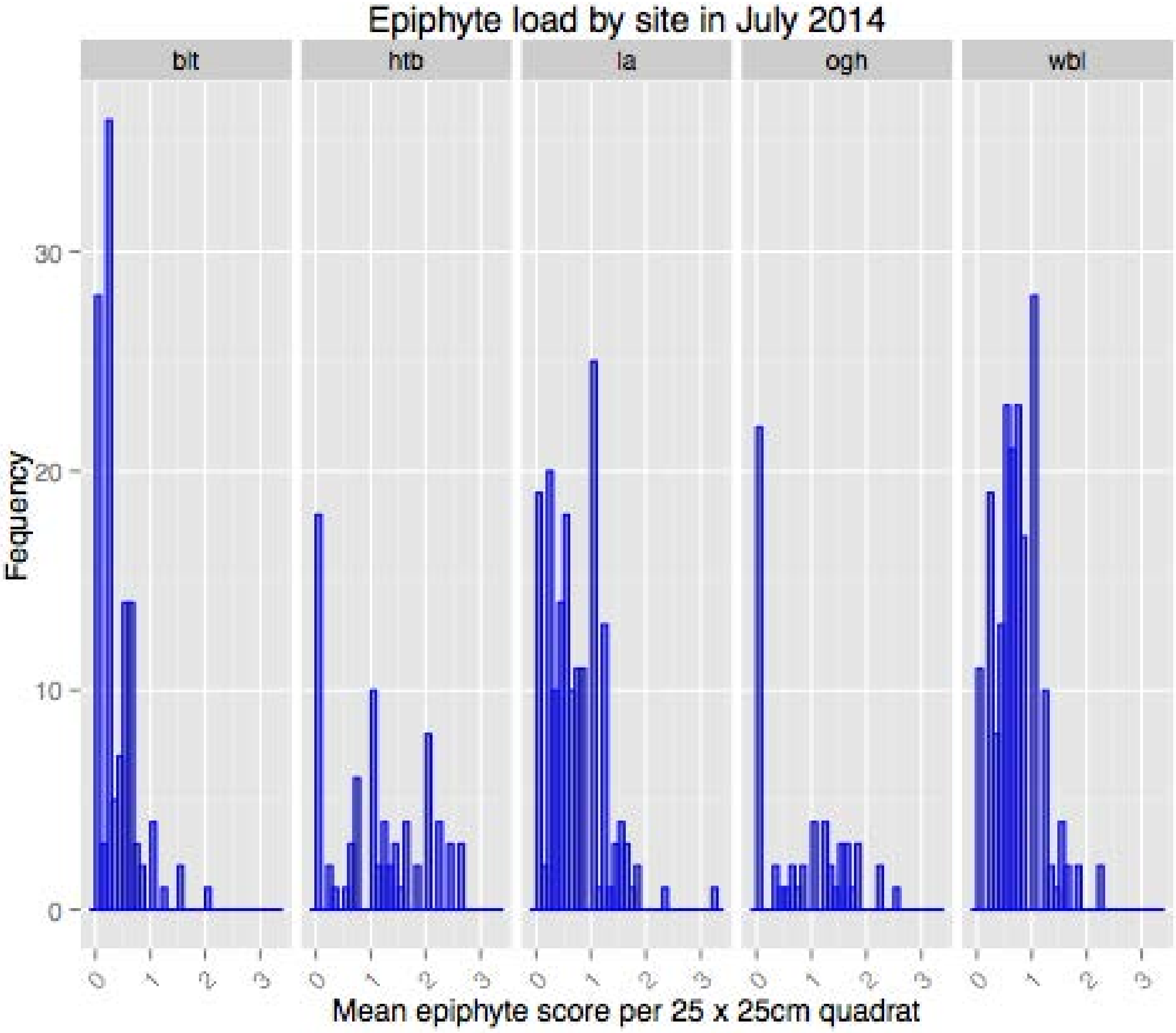

Figure 11 - Eelgrass epiphyte scores in each of the five survey sites in 2014. Here, we present average epiphyte scores (0-5) per quadrat.

Due to the sub-optimal statistical modelling used here, as described in our analytical methods section, we do not go on to investigate long-term trends in epiphytes in this report. However a fuller investigation of the role of epiphytes in the community dynamics of eelgrass over the life of this survey (1996 - 2011) has recently been published by some of the authors of this report (Lobelle et al., 2013).

5. CONCLUSIONS

5.1 Key findings

Broad Ledges Tresco

2014 might be described as a relatively 'typical' year for eelgrass at blt. All shoot metrics, as well as 'patchiness' were intermediate, compared to the other survey sites. Interestingly, blt is the only bed in which some decline in shoot density over the years, is balanced by increases in maximum leaf lengths, resulting in no overall change in our proxy measure for Leaf Area Index. We have no way to judge whether this in an indication of a high level of resilience at this site, or a transient coincidence. In either case, a long-term decline in shoot density cannot be off-set by greater shoot size forever. However, we also note that blt had lower than average levels of wasting disease and epiphytes, compared to other sites, this year.

Higher Town Bay

htb showed higher than average levels of both wasting disease and epiphytes this year. In addition, the long-term trends in eelgrass metrics are not positive, with declines in both the shoot density and shoot size. Again, we cannot demonstrate that disease and epiphyte cover are causative in the these declines.

Little Arthur

In 2014, la was intermediate in all measures recorded, compared to other survey sites this year. This is in itself remarkable and might give cause for concern, since in previous years la has supported some of the highest levels of shoot density and size. The biggest contrast here, compared to previous years was in maximum leaf length. One possible explanation for this is the winter storms of 2013 / 4, which may well have held up shoot growth through direct disturbance at the start of the growing season and / or lingering turbidity later on.

Old Grimsby Harbour

In 2014, ogh was found to exhibit lower than average levels of infection, relative to other sites. In other respects, the 2014 results do not stand out. However, the finding that is particularly striking at this site is the significant decline in 'patchiness' (the proportion of occupied quadrats) throughout the period 1996 - 2014. This site is clearly the most impacted by local boat traffic but, based solely on our findings, we resist speculating that this is causative. Interestingly, it is thought that the primary transmission route for the pathogen that causes wasting disease is by leaf-to-leaf direct transmission. It is possible that eelgrass patchiness actually inhibits infection by acting as 'fire breaks' in the vegetation. This is one of the aspects of seagrass spatial dynamics currently being investigated by Mike Irvine, a PhD student at Warwick University.

West Broad Ledges

In 2014, wbl had the highest average 'canopy height' (median longest leaf) and also relatively high infection scores. The leaf length finding is more the result of eelgrass at Little Arthur producing much shorter leaves that usual, than wbl producing unusually large shoots this year.

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.

5.2 Future directions

The overriding message is that a range of long-term trends in eelgrass status around the Isles of Scilly have only become evident through this type of extended annual study. We clearly hope that these findings are seen as justification to continue this study into future years. A compelling reason to support this is that monitoring that does not generate understanding is of very limited use.

Population dynamic modelling is the key approach for identifying the processes and mechanisms that underpin observed fluctuations and distributions. These types of analysis are only robust once annual studies progress through their second decade and beyond. Such analysis is also extremely sensitive to gaps in time series. Evidence that the Isles of Scilly eelgrass survey has reached the point where continued monitoring can generate understanding is a series of papers published in the peer-reviewed academic literature (Bull et al. 2012, Lobelle et al. 2013, Potouroglou et al. 2014).

In addition to continuation of the current study, a PhD student at Warwick University, Mike Irvine, mentioned a number of times in this report, came out to Scilly on the 2013 survey in order to develop modelling methods to bridge between studies of eelgrass density, and studies of eelgrass spatial distribution on a broader scale (patterns of ‘extent’). His research is beginning to bring together data from the annual Isles of Scilly eelgrass surveys and high resolution mapping of eelgrass around the archipelago, based on aerial photography. These combined approaches, mathematically linked by fractal geometry, stand to deliver both new fundamental understanding of eelgrass dynamics and have the potential to be developed into novel analytical tools to assess likely responses to environmental change.

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 (and this year our dive kit since we no longer have the use of the Wellcross Workshop). As usual, Island Carriers went the extra mile in helping us move kit and launch (and recover!) Eva. 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.

This year, the annual survey was organised in association with Project Seagrass (http://www.projectseagrass.org) and we look forward to mutually supporting each other's international seagrass research in future.

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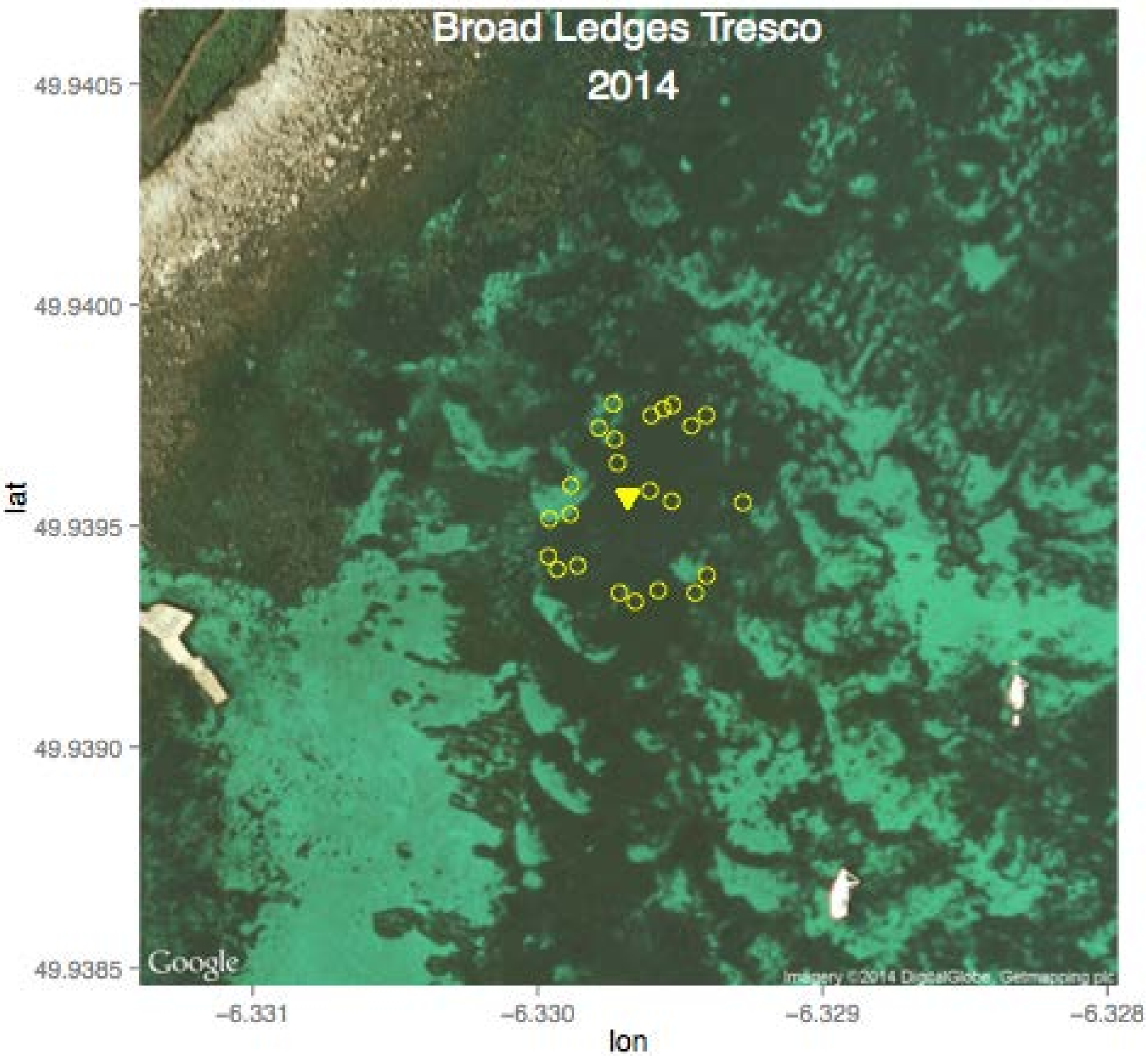
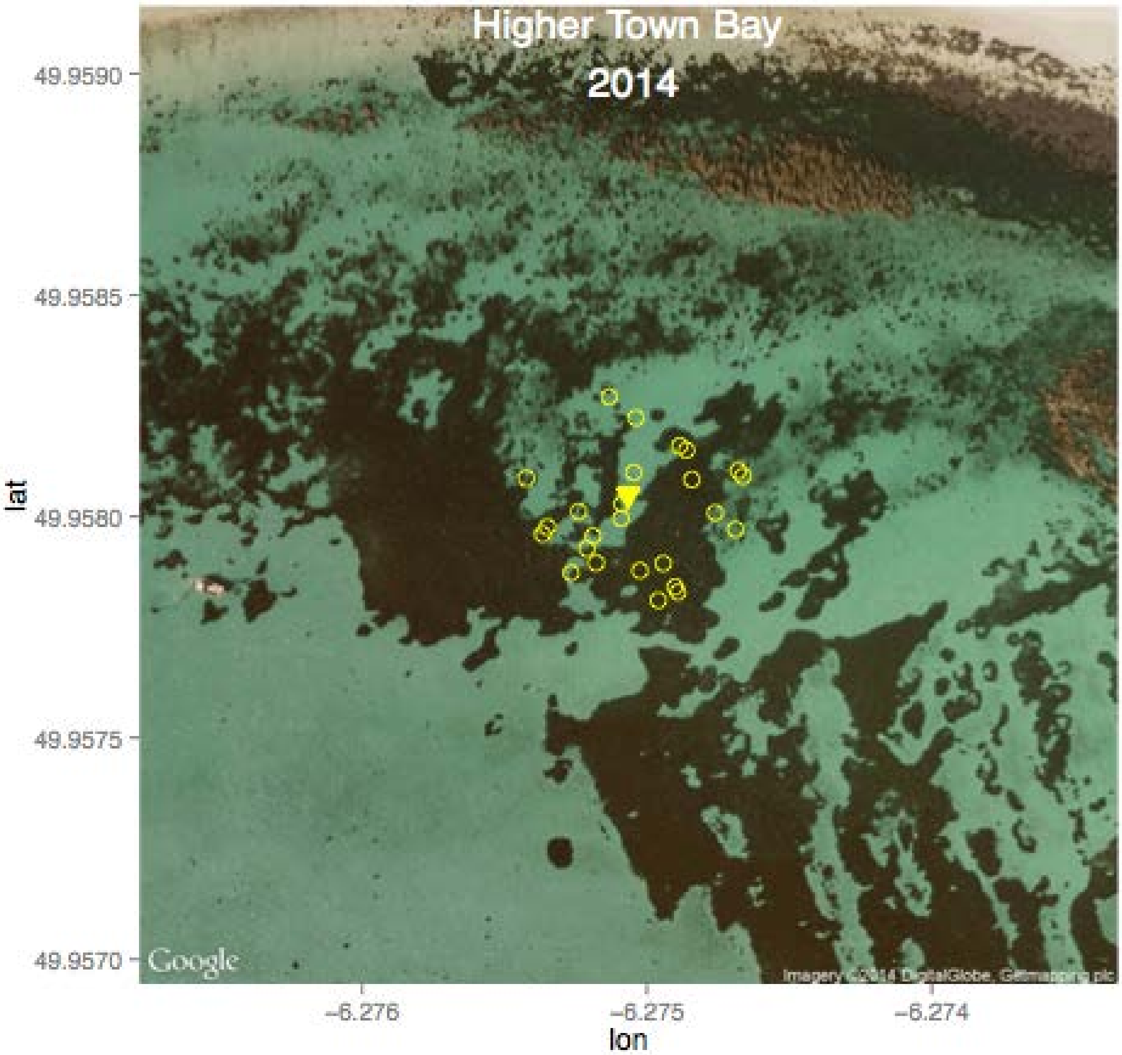
Appendix 1 Locations of quadrats used in the 2014 survey

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. In particular, note the survey of West Broad Ledges (wbl) in which 2014 quadrats lie on 2005 bare sand. This gives some indication of the fluidity of the seagrass colonisation over time. 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.





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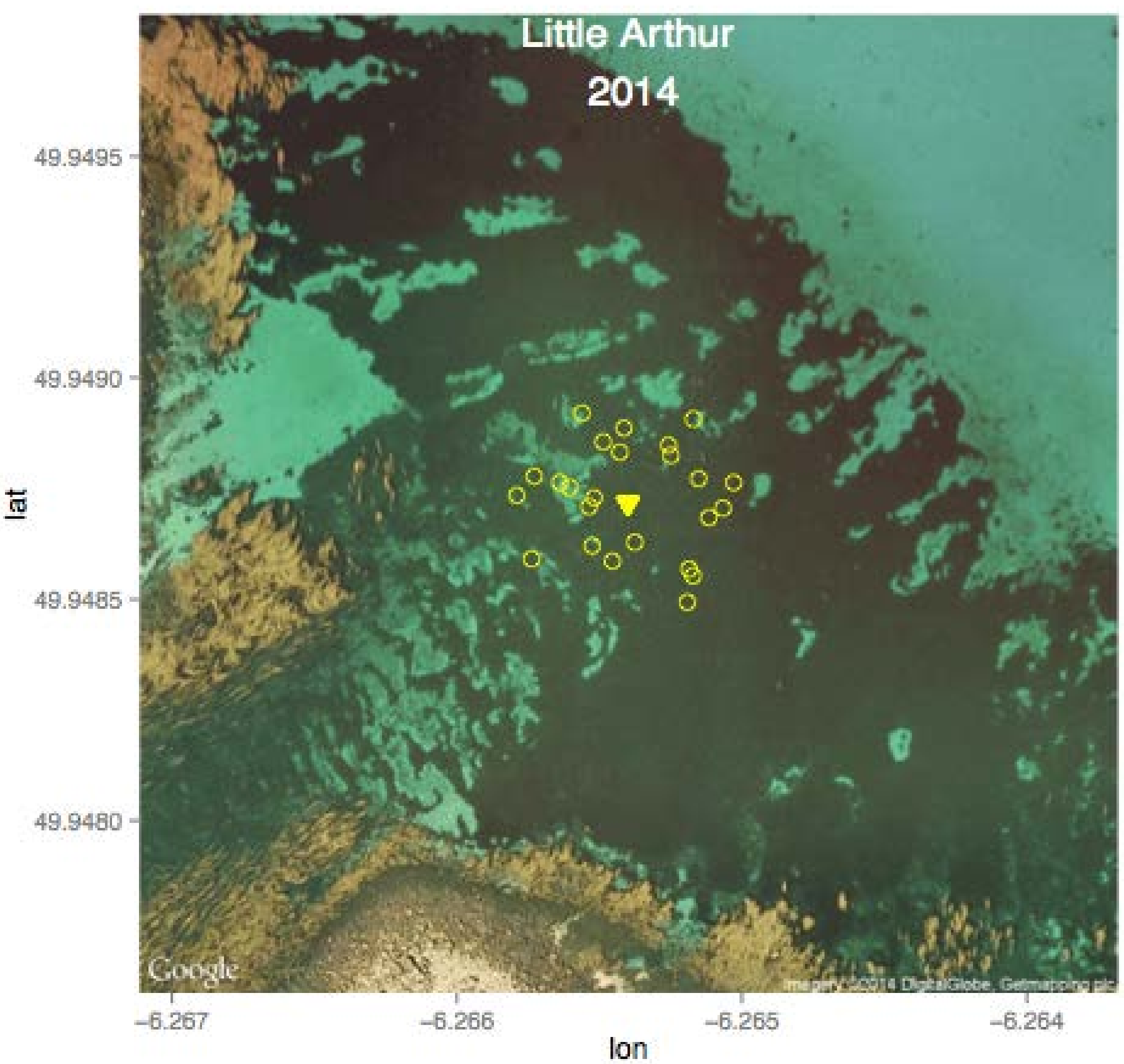
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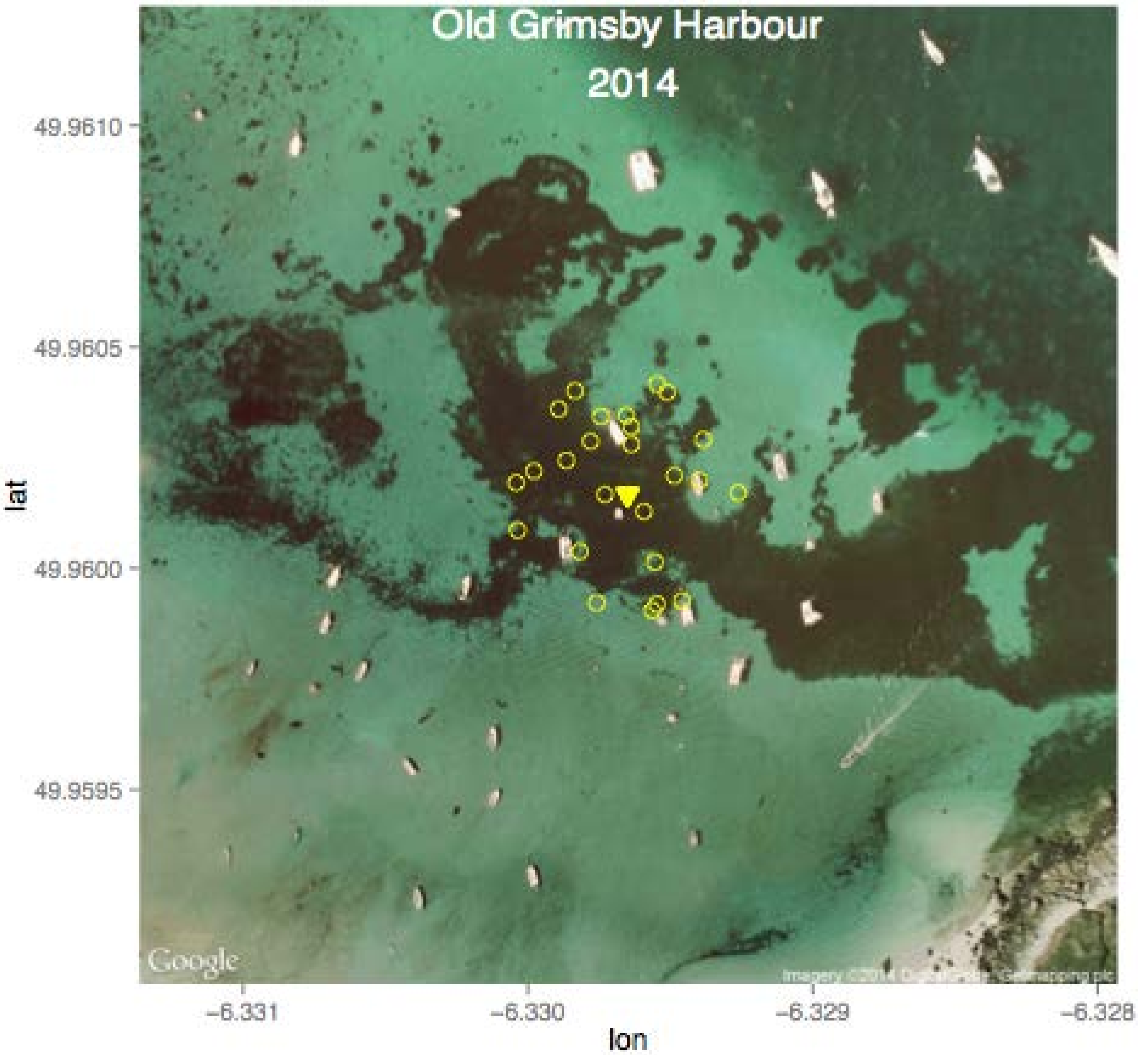

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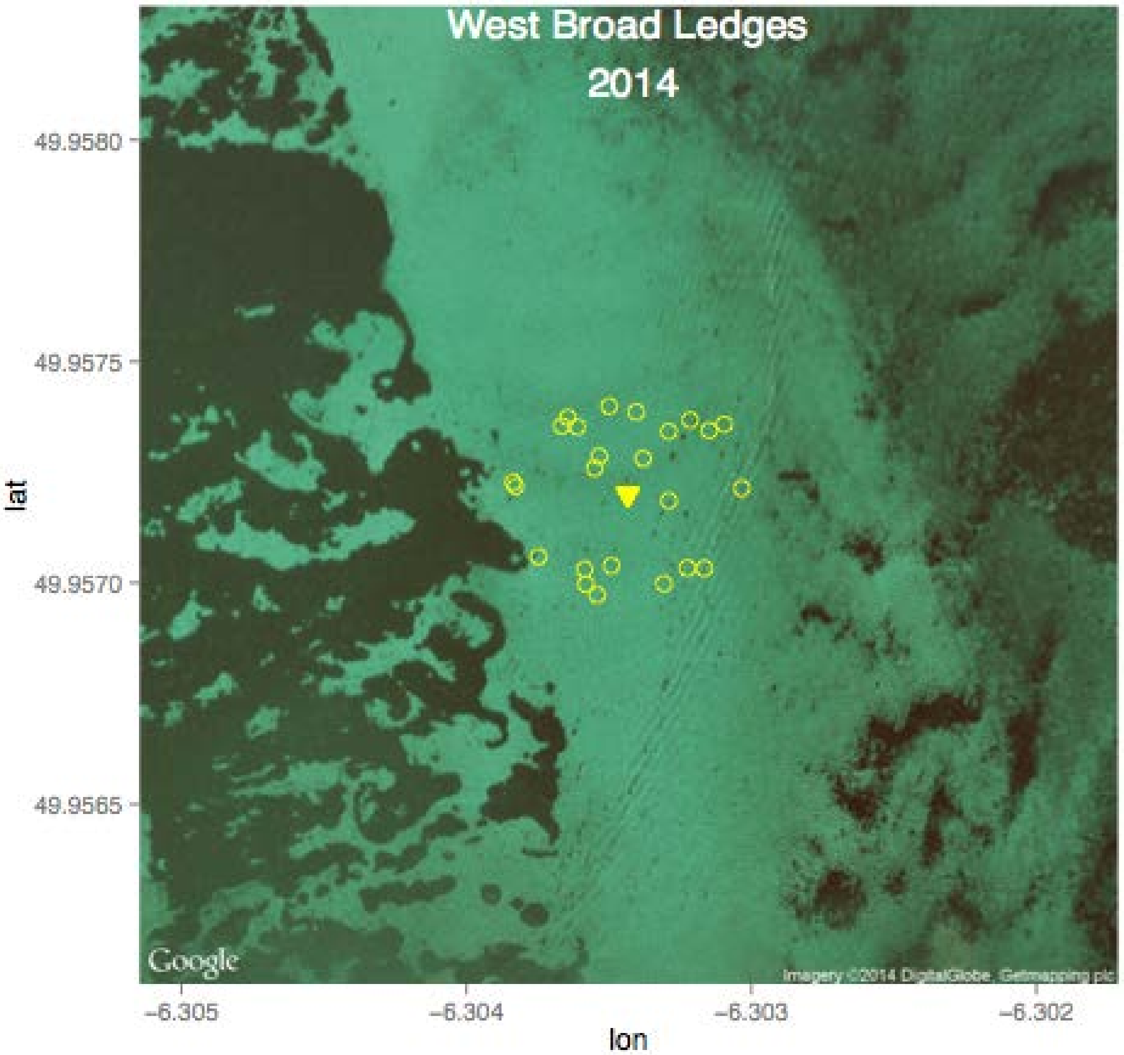
West Broad Ledges
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Imagery ©2014 DigitalGlobe, Getmapping plc
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−6.303
−6.302
lon

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	11.1	96	0	NA	NA	NA	NA	NA	NA	NA	NA
2	28.4	44	0	NA	NA	NA	NA	NA	NA	NA	NA
3	23.9	42	0	NA	NA	NA	NA	NA	NA	NA	NA
4	25.5	224	0	NA	NA	NA	NA	NA	NA	NA	NA
5	24.3	185	0	NA	NA	NA	NA	NA	NA	NA	NA
6	20.5	254	0	NA	NA	NA	NA	NA	NA	NA	NA
7	14.6	281	0	NA	NA	NA	NA	NA	NA	NA	NA
8	28.1	135	8	4.25	0.89	43.38	10.62	1.04	0.32	0.49	0.21
9	25	233	14	3.93	0.47	58.29	10.00	1.11	0.29	0.33	0.18
10	18.7	337	14	6.14	6.96	64.07	23.81	0.80	0.29	0.32	0.25
11	29.6	145	9	4.67	1.41	34.78	13.29	0.79	0.42	0.48	0.36
12	5.7	75	7	4.00	1.63	53.86	16.43	0.82	0.26	0.32	0.38
13	25.6	26	5	3.80	1.79	31.00	13.04	0.65	0.56	0.34	0.42
14	21.2	16	6	5.83	3.19	42.17	23.83	0.57	0.43	0.30	0.27
15	23.7	22	5	5.60	1.52	53.00	19.07	0.75	0.49	0.37	0.33
16	29	93	9	4.33	1.32	38.22	10.87	0.61	0.21	0.44	0.45
17	21.5	216	6	4.67	0.82	35.83	9.11	0.30	0.18	0.34	0.15
18	23.6	351	4	4.25	0.96	41.75	18.01	0.48	0.34	0.16	0.11
19	8.8	343	3	3.00	2.00	30.67	11.37	0.40	0.53	0.40	0.53
20	26.5	176	2	2.00	0.00	8.50	2.12	0.50	0.00	1.75	0.35
21	15.2	253	6	4.33	0.52	44.00	13.80	0.86	0.36	0.38	0.36
22	14.8	347	11	4.55	1.13	49.27	18.12	0.78	0.29	0.27	0.26
23	24.8	162	4	4.75	1.26	26.75	11.59	0.83	0.58	0.41	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	25.9	279	0	NA	NA	NA	NA	NA	NA	NA	NA
2	17.8	47	0	NA	NA	NA	NA	NA	NA	NA	NA
3	18.4	53	0	NA	NA	NA	NA	NA	NA	NA	NA
4	16.5	77	0	NA	NA	NA	NA	NA	NA	NA	NA
5	13.7	220	0	NA	NA	NA	NA	NA	NA	NA	NA
6	22.4	102	0	NA	NA	NA	NA	NA	NA	NA	NA
7	5.7	15	0	NA	NA	NA	NA	NA	NA	NA	NA
8	19.3	6	0	NA	NA	NA	NA	NA	NA	NA	NA
9	24.9	349	0	NA	NA	NA	NA	NA	NA	NA	NA
10	19	205	0	NA	NA	NA	NA	NA	NA	NA	NA
11	21.9	248	0	NA	NA	NA	NA	NA	NA	NA	NA
12	6.3	196	0	NA	NA	NA	NA	NA	NA	NA	NA
13	23.7	245	0	NA	NA	NA	NA	NA	NA	NA	NA
14	27.6	153	0	NA	NA	NA	NA	NA	NA	NA	NA
15	24.4	216	0	NA	NA	NA	NA	NA	NA	NA	NA
16	17.1	217	0	NA	NA	NA	NA	NA	NA	NA	NA
17	2.9	212	0	NA	NA	NA	NA	NA	NA	NA	NA
18	29.3	81	4	9.00	10.00	52.50	2.65	0.54	0.25	0.64	0.33
19	19.4	171	7	5.43	0.53	53.14	6.47	0.70	0.22	1.37	0.36
20	27.7	164	15	4.67	0.82	66.00	9.44	0.62	0.37	1.75	0.45
21	19.5	108	8	4.13	1.13	49.00	12.13	0.41	0.17	1.19	0.62
22	28.4	251	12	5.42	4.01	52.08	13.11	0.45	0.35	0.78	0.37
23	13.2	78	2	4.00	1.41	20.00	11.31	0.20	0.28	0.94	0.37
24	28.3	NA	5	4.60	0.55	42.00	7.11	0.47	0.25	1.43	0.49
25	26.1	279	7	4.43	0.79	47.29	10.77	0.91	0.55	2.42	0.16

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	18.9	357	0	NA	NA	NA	NA	NA	NA	NA	NA
2	28	240	0	NA	NA	NA	NA	NA	NA	NA	NA
3	14	220	0	NA	NA	NA	NA	NA	NA	NA	NA
4	28	274	0	NA	NA	NA	NA	NA	NA	NA	NA
5	16.6	338	0	NA	NA	NA	NA	NA	NA	NA	NA
6	17.8	35	0	NA	NA	NA	NA	NA	NA	NA	NA
7	16.1	42	1	3	NA	15	NA	0.67	NA	2.33	NA
8	13	351	7	4.71	0.49	32.86	13.33	0.81	0.55	1.14	0.50
9	15.1	195	15	4.07	0.80	46.87	8.49	1.25	0.36	0.36	0.22
10	8.6	279	9	4.00	0.00	43.78	8.03	1.11	0.25	0.86	0.31
11	9.8	265	20	5.20	3.55	65.25	9.63	0.59	0.27	1.28	0.59
12	23.9	93	8	4.13	1.55	41.38	19.99	0.76	0.56	0.28	0.20
13	27.1	79	11	4.27	0.79	57.00	19.62	0.91	0.38	0.54	0.46
14	17.9	287	8	4.75	1.04	52.25	11.15	1.03	0.39	0.77	0.23
15	18.8	71	10	6.30	6.29	52.30	15.29	1.16	0.42	0.73	0.34
16	24.5	286	11	4.55	0.69	57.45	9.09	1.02	0.21	1.16	0.26
17	29	149	15	4.73	0.70	58.33	10.32	0.71	0.28	0.52	0.27
18	22.6	137	5	5.00	0.71	58.00	7.58	0.85	0.25	0.39	0.25
19	10	170	5	5.60	1.52	56.20	8.17	0.59	0.16	0.22	0.23
20	15.2	285	6	5.17	0.75	71.83	9.11	0.86	0.17	1.15	0.32
21	24.5	138	7	5.00	0.58	63.71	12.01	1.14	0.15	0.43	0.27
22	26.8	38	7	4.14	0.69	44.00	14.47	1.31	0.41	0.21	0.15
23	20.7	100	4	4.50	0.58	48.75	18.37	1.31	0.45	0.20	0.28
24	25.4	333	15	4.00	0.85	50.93	18.44	1.29	0.39	0.63	0.24

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	20.7	341	0	NA	NA	NA	NA	NA	NA	NA	NA
2	28.2	276	0	NA	NA	NA	NA	NA	NA	NA	NA
3	29.2	333	0	NA	NA	NA	NA	NA	NA	NA	NA
4	27.5	21	0	NA	NA	NA	NA	NA	NA	NA	NA
5	27.8	89	0	NA	NA	NA	NA	NA	NA	NA	NA
6	5.7	270	0	NA	NA	NA	NA	NA	NA	NA	NA
7	28.7	15	0	NA	NA	NA	NA	NA	NA	NA	NA
8	17.6	299	0	NA	NA	NA	NA	NA	NA	NA	NA
9	19.8	359	0	NA	NA	NA	NA	NA	NA	NA	NA
10	16.3	325	0	NA	NA	NA	NA	NA	NA	NA	NA
11	18.4	79	0	NA	NA	NA	NA	NA	NA	NA	NA
12	18.8	220	0	NA	NA	NA	NA	NA	NA	NA	NA
13	30	153	0	NA	NA	NA	NA	NA	NA	NA	NA
14	28.5	165	0	NA	NA	NA	NA	NA	NA	NA	NA
15	28.3	196	0	NA	NA	NA	NA	NA	NA	NA	NA
16	29.8	168	0	NA	NA	NA	NA	NA	NA	NA	NA
17	12.6	4	0	NA	NA	NA	NA	NA	NA	NA	NA
18	29.1	252	0	NA	NA	NA	NA	NA	NA	NA	NA
19	17.1	3	5	3.20	1.10	27.60	10.55	0.60	0.44	0.15	0.20
20	12.7	68	1	4.00	NA	39.00	NA	1.50	NA	0.00	NA
21	27.6	321	5	4.40	0.89	38.60	13.67	1.09	0.28	1.30	0.43
22	5.9	136	1	3.00	NA	29.00	NA	0.67	NA	0.33	NA
23	24.3	284	1	5.00	NA	80.00	NA	1.20	NA	0.60	NA
24	18.3	158	9	4.33	0.87	45.22	9.88	1.41	0.45	1.19	0.33
25	23.5	54	15	4.53	1.19	40.00	11.42	1.33	0.33	1.52	0.55

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	26.4	197	0	NA	NA	NA	NA	NA	NA	NA	NA
2	28.7	87	0	NA	NA	NA	NA	NA	NA	NA	NA
3	20.8	6	0	NA	NA	NA	NA	NA	NA	NA	NA
4	24.2	158	0	NA	NA	NA	NA	NA	NA	NA	NA
5	24.5	322	10	4.30	1.06	58.20	20.32	1.00	0.51	1.46	0.50
6	29	276	9	4.33	1.00	60.67	14.34	1.37	0.49	0.74	0.25
7	28.3	274	8	6.13	4.91	68.50	21.56	1.33	0.58	0.68	0.20
8	12	323	7	4.29	1.11	39.86	14.31	1.10	0.53	0.71	0.40
9	9.8	23	3	3.67	1.53	36.00	14.00	1.50	0.50	0.88	0.56
10	10.4	99	1	4.00	NA	55.00	NA	2.00	NA	1.00	NA
11	10.6	308	5	4.60	0.55	56.00	13.34	1.34	0.24	1.52	0.22
12	30	54	9	4.33	1.00	50.00	12.21	1.32	0.41	0.57	0.24
13	18.4	193	15	4.27	0.46	56.67	10.08	1.06	0.29	0.47	0.16
14	27.4	235	12	4.25	0.45	56.00	16.02	1.35	0.36	0.50	0.27
15	21.7	210	15	4.47	0.99	58.00	12.85	1.25	0.48	0.40	0.23
16	23.8	141	10	7.60	7.53	73.30	12.33	0.70	0.35	0.92	0.31
17	26.8	134	8	4.50	1.20	48.00	10.74	0.87	0.60	0.28	0.14
18	24.4	40	8	3.88	0.83	57.88	15.13	1.21	0.33	0.57	0.30
19	22.6	348	9	4.33	0.71	60.89	10.95	0.72	0.20	0.82	0.24
20	21.2	323	11	4.45	0.82	66.73	24.22	0.95	0.40	0.84	0.33
21	18.8	33	17	4.29	0.69	70.53	12.78	1.16	0.31	0.70	0.29
22	26	52	3	5.33	1.53	46.33	4.93	1.25	0.34	0.36	0.41
23	24.9	205	7	4.43	0.98	45.86	9.79	1.11	0.22	0.80	0.37
24	23.9	316	15	4.67	0.82	53.87	12.24	0.81	0.27	0.73	0.29