Aberthaw Power Station cooling water pH variation

RWE Generation UK plc

Ecological monitoring report 2017

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Executive summary

Aberthaw Power Station (operated by RWE Generation UK plc) is a 1500 MW coal-fired plant located on the South Wales coast, abstracting cooling water (CW) from, and returning it to the Bristol Channel via two outfalls positioned at low water in Limpert Bay near Breaksea Point. Owing to possible changes in the coal feed to the station, it was anticipated that increased sulphur levels in the coal would result in a lowering of the pH of the discharge. In advance of this, RWE sought a variation of their Environmental Permit to accommodate the lowering of the pH of the discharge from a current instantaneous pH of 5.8 to a proposed pH of 5.6.

Through consultation, Natural Resources Wales (NRW) agreed to a trial of a different coal feed for a limited period (end of January to end of July 2016), subject to an agreed ecological monitoring programme being in place to inform any application for a permanent permit variation. Reports were submitted to NRW concluding there was no evidence of a reduced discharge pH affecting marine biota in the vicinity of the discharge (Jacobs, 2016a). In March 2017, a permanent Environmental Permit variation was issued with the lower discharge pH Emissions Limit Value and a requirement to carry out repeat ecological condition surveys.

This report presents the results of the first annual ecological condition survey. Here, the distribution and condition of the benthic communities assessed in July and August 2017 that characterise Limpert Bay are presented. Any ecologically significant variations reported from the baseline established in 2015 have been assessed to determine if they could be attributable to the increased pH conditions of the discharge.

Assessment of the distribution and health of these benthic communities were drawn from repeating the work conducted in 2015 and 2016. Quadrat assessments of the upper, mid and lower shore communities were undertaken across four transect lines: HO (Historic Outfall), LE (Limpert East), EO (East Outfall) and LW (Limpert West). The transect line at the reference site at Nash Point was also revisited (NP). Gastropods were abundant across both Limpert Bay and Nash Point, and specimens of the limpet (*Patella vulgata*) and the common periwinkle (*Littorina littorea*) were again collected from all five transects to assess the health of these populations, as determined by a Condition Index (CI). At all sites the beds of the honeycomb worm *Sabellaria alveolata* that had been mapped previously were re-assessed to determine any change in their extent and quality. Physico-chemical data of the tidal waters was collected from 13 sampling sites between March and August 2016, and again in July and August 2017 pH values were again recorded across the same sites.

During the period between the completion of the revised pH trial in summer 2016, to the issuing of the Environmental Permit variation in March 2017, the station had been in operation but with cooling water pH values > 5.8 (recorded from the Seal Pit). Following the issue of the Environmental Permit variation and through to the completion of the survey on 23rd August 2017, the station had not been generating and thus there has been no significant cooling water discharge in the months prior to the survey period or pH values < 5.8.

In July and August 2017, the pH in the vicinity of outfall ranged between 8.09 and 8.16, much higher than values recorded during the trial period in 2016 (6.5 to 7) and within the ambient range recorded at the remote sampling sites.

The spatial distribution of intertidal benthic communities of Limpert Bay and Nash Point in 2017 reflect those reported during the trial period. The greatest differences overall were between the study area and the more exposed reference site at Nash Point where natural physical and biological factors were determined to be the primary influencing factor on the community. The 2017 mid and upper shore community data complemented the 2015-2016 assessments which also showed this spatial pattern. A higher proportion of barnacles, the carnivorous dogwhelk (*Nucella lapillus*) and lower shore macroalgal cover characterised Nash Point, whereas across Limpert Bay communities were abundant in fucoid algae and gastropod grazers.

Spatial and temporal variations across the shore were also driven by variations in substrate, where a mosaic of sediments and boulders were found at the upper shore of EO and HO, but bedrock plateaus characterised LW and NP. Spatial differences across the lower shore were influenced by the proportion of *S. alveolata* cover, which was greater across LW and NP, as a result of greater landward extent of these colonies across the western areas, compared to the east of Limpert Bay.

The *S. alveolata* mapping assessments conducted in 2017 have corroborated the previous results of assessments in 2015-2016. The beds remain prominent across the western areas of Limpert Bay, but this habitat also persists to the east of the bay, albeit in narrower bands. To the east, previously unrecorded colonies between the present outfall structures and the historic ones were exposed lower on the shore.

In 2017, additional *S. alveolata* data were collected to look at the spatial variation in the formation, health and associated communities of these ecologically important biogenic features. The data collected reflected historic surveys in the Bristol Channel that describe some intertidal reefs as poorly developed or eroded under algal canopies, and those across Limpert Bay as colonised crusts over rock. An abundance scale was applied and colonies characterised; the distribution of these colonies described as ranging between 'Common' and 'Abundant' with the tubes a mosaic of mainly crisp or worn apertures. As with the 2015-2016 surveys, there were no elevated reef formations present across either Limpert Bay or Nash Point (e.g. 'Super-Abundant'), with ball (e.g. hummock) and large encrusting sheet formations featuring as the dominant type. The communities associated with these formations showed statistical overlap in assemblage features, but with lower fucoid cover (*Fucus serratus*) and high abundances of *N. lapillus* at Nash Point.

Spatial differences were observed in the health of the dominant gastropod populations (*L. littorea* and *P. vulgata*). Comparing only those populations sampled in August 2016 and August 2017, a general pattern of higher CI values was reported for those populations at the sites proximal to the outfall, and not from the reference site. Those populations close to the outfall may be benefitting from the thermal plume, as it may provide a buffering effect against the seasonal decline in sea temperature and potential cessation in growth over winter.

Overall, it is considered that there is no ecologically significant variation between the distribution, abundance and overall condition of the intertidal benthic communities as monitored in 2015-2016 to those recorded in the summer of 2017. It is concluded that the biota have been unaffected by the period of reduced pH discharge.

1. Introduction

1.1 Overview

Aberthaw Power Station, operated by RWE Generation UK plc (RWE) is a 1500 MW coal-fired plant located on the South Wales coast, 9 km west of Barry. It abstracts cooling water (CW) from, and returns it to, the Bristol Channel via two outfalls positioned at low water near Breaksea Point. The pH of the discharge complies with the discharge requirements established through an Environmental Permit issued by the Environment Agency (now National Resources Wales – NRW).

Owing to possible changes in the coal supply to the station, it was anticipated that increased sulphur levels in the coal will result in a lowering of the pH of the discharge. In advance of this, RWE sought a variation of their discharge conditions to accommodate the possible lowering of the pH of the discharge. Through consultation, the NRWagreed to a trial of a different coal feed and hence a lowered discharge pH for a limited period (January to July 2016), subject to an agreed benthic ecological monitoring programme being in place to inform any application for a permanent permit variation. During 2015 and 2016 a trial was undertaken to assess impacts on biota from a lowered discharge pH. Reports were submitted to NRW concluding there was no evidence of a reduced discharge pH affecting the benthic biota (Jacobs, 2016a). In March 2017, an Environmental Permit variation was issued by NRW with the lower discharge pH Emissions Limit Values and a requirement to carry out repeat condition surveys.

This report presents the results of the first annual post trial monitoring of the intertidal communities in the vicinity of Aberthaw, building on the existing data collected during the 2015-2016 preliminary assessments.

1.2 Intertidal ecology and conservation interests

Aberthaw Power Station is located in the upper Bristol Channel at Limpert Bay, just downstream of what is considered as the mouth of the Severn Estuary, i.e. the line between Lavernock Point to the north and Brean Down to the south. Although not located within any designated conservation area, Aberthaw is close to a number of sites of conservation importance.

The intertidal zone in the vicinity of Aberthaw is predominantly formed of rock pavements, ledges, and outcrops, but also contains a range of other habitats, including sandflats, shingle ridges, sand dunes, saltmarshes and a saline lagoon. The rocky shore intertidal communities are characteristic of the bay with macroalgae such as the toothed wrack (*Fucus serratus*), *Fucus vesiculosus, Corallina* sp. and sea lettuce (*Ulva lactuca*); fauna such as the limpet (*Patella vulgata*), periwinkle (*Littorina littorea*), top shells (*Gibbula* spp.), dogwhelk (*Nucella lapillus*) and barnacle (*Semibalanus balanoides*) (Bamber, 1997).

In addition to the fauna outlined above, the honeycomb worm (*Sabellaria alveolata*) is also present in the intertidal habitats at Limpert Bay. Aggregations of this tube dwelling species can result in reefs of considerable size which in turn support diverse communities. Although not a species of specific conservation importance, *S. alveolata* reef habitat is included on the Section 7 list of habitats of principal importance for conservation of biodiversity in Wales under the Environment (Wales) Act, 2016. Countryside Council for Wales (CCW) biotope maps indicated the presence of the biotope LS.LBR.Sab.salv ('*Sabellaria alveolata* reefs on sand-abraded eulittoral rock') to the west of the discharges, reflecting work reported by Innogy (2003) which indicated a similar distribution. The recent surveys in 2015-2016 which had mapped the extent of these biogenic features at Limpert Bay as part of the pH variation study (Jacobs, 2016a) was comparable with the historic CCW biotope maps. However, a landward extension of the beds in the west and the presence of beds now existing to the east of the outfall structures was recorded (see Appendix A). Extensive areas of *S. alveolata* reefs are also known from subtidal habitats in the Bristol Channel with reefs present 3 km south of Aberthaw (Innogy, 2003; Mettam, *et al.,* 1994).

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1.3 Power Station operation

The initial pH variation trial ran over six months, between the end of January and end of July 2016 and Table 1.1 summarises the station activity (load factor) over this time and up to the latest sampling month of August 2017. The load factor is the ratio between the actual energy generated by the station and the maximum energy that can be generated if the station is operating at its rated power output.

The highest operational activity was recorded in January 2017; however, from April 2017 onwards no operation took place up to and during the recent summer 2017 assessments. In addition to this, the pH values of the power station's main seal pit chamber ('T1') had an average pH value 6.44 (from 4,367 recordings) between the period of October 2016 and March 2017. Monthly pH values of the seal pit during this period are listed in Table 1.1 below. The absence of station activity between April 2017 and the summer 2017 assessments, and the high average pH values in the preceding autumn and winter 2016/2017 period must, therefore, be taken into consideration in interpretation of the ecological data collected in the recent assessments.

Table 1.1 : Station operation pre-, trial, and post-trial (supplied by RWE, August 2016 and September 2017). Indicated are the sampling months for the pre-trial, trial and post-trial period.*Month of Environmental Permit variation issue by NRW.

Period	Month	Trial pH discharge conditions	Survey completed	Load factor (%)	Mean monthly pH Seal Pit Main T1
Pre-Trial	November 2015		×	46	----
	December 2015			42	----
Trial	January 2016			68	----
	February 2016	×		81	----
	March 2016	×	×	70	----
	April 2016	×	×	74	----
	May 2016	×	×	19	----
	June 2016	×		51	----
	July 2016	×		6	----
Post-Trial	August 2016		×	5	----
	September 2016			12	----
	October 2016			50	6.69
	November 2016			85	6.35
	December 2016			83	6.35
	January 2017			90	6.35
	February 2017			87	6.24
	March 2017*			56	6.65
	April 2017			0	n/a
	June 2017			0	n/a
	July 2017		×	0	n/a
	August 2017		×	0	n/a

1.4 Monitoring purposes

By combining the output of the predictive modelling and the trends identified during the annual metal evaluation studies in biota (e.g. Jacobs, 2017), it was concluded that of the key receptors identified in Jacobs, 2016a, an *in* *situ* assessment of the intertidal rocky shore communities would provide a suitable tool to enable identification of any potential effects as a result of the reduced pH conditions. The likely impingement of the plume on, proximity to the outfall, and limited mobility in comparison to other organisms (birds, fish and marine mammals) of intertidal benthic communities made them an ideal study group.

Rocky shore communities can be useful indicators of changes in water quality and local environmental conditions, and can be monitored in the context of expected natural variations. Epibenthic algal and invertebrate communities can be rapidly and easily assessed *in situ*, at pre-determined locations from the source input, and with repeated sampling can provide suitable temporal data sets.

During consultation with NRW, concerns were raised that a reduction in the pH of the discharge may affect *S. alveolata* that currently inhabit areas influenced by the cooling water plume. Significant areas of the intertidal zone are colonised with the worm tubes forming biogenic reef structures, therefore it was considered important to monitor these features in terms of their extent and characteristics in order to determine any potential effects.

Owing to the exposed nature of the study area and strong tidal currents, a relatively sparse fauna was found to reside across much of the shore, although abundant populations of gastropod molluscs were present across the site. Sub-lethal responses of molluscs to chemical or environmental stressors can influence physiological processes such as tissue and/ or shell growth. Such changes can be detectable by examining biometric ratios such as shell height: tissue weight, which has been employed as a Condition Index (CI). A rapid assessment of the 'health' of a population can therefore be undertaken with the calculation of this index that is based on simple biometric information. *Littorina littorea* and *Patella vulgata* were selected as suitable target species for such an assessment, as both species are considered to be present in sufficient numbers across the study *site. P. vulgata* has also been targeted for the annual FGD metals in biota study at Aberthaw since 2007 (Jacobs, 2017).

The shore at Nash Point has been included in the present study as a reference site. Nash Point is located 10km away from Aberthaw, but is geographically linked, allowing natural spatial and temporal patterns in recruitment, as well as any seasonal growth/declines of intertidal communities (independent of power station operational activities) to be taken into account.

The 2017 annual survey is a continuation of the recent pH variation study where November 2015 represented the pre-trial monitoring period, March to May 2016 the trial monitoring period, and August 2016 the post-trial monitoring period. The aims of this work are summarised below-

a) To assess the intertidal rocky shore benthic communities of Limpert Bay and at Nash Point (reference point) and identify any ecologically significant spatial or temporal variations.

b) To assess the extent and features of the intertidal *S. alveolata* beds (and their associated communities) of Limpert Bay and at Nash Point and identify any ecologically significant spatial or temporal variations.

c) To assess the health of the target gastropod populations (*P. vulgata* and *L. littorea*) of Limpert Bay and at Nash Point and to identify any ecologically significant spatial or temporal variations in their condition of these populations.

d) If significantly important ecologically spatial or temporal differences are detected, to assess the patterns of these variations and to ascertain if they are attributable to the reduced pH conditions, proximity to the outfall or an artefact of natural environmental influences and biotic interactions.

2. Methods

2.1 Site selection

The intertidal transect lines at Limpert Bay were selected based on those sampled annually as part of the long-term Aberthaw Flue Gas Desulphurisation (FGD) monitoring work (2007 to present, see Jacobs, 2017) and the recent pH variation study undertaken between 2015-2016 (Jacobs, 2016a). The transects comprised upper, mid and low shore sites, as shown in Figure 2.1 (grid reference positions given are listed in Appendix B). The transects were denoted as follows:

- HO (Historic Outfall)
- LE (Limpert Bay East)
- EO (East outfall)
- LW (Limpert Bay West)

The Nash Point (NP) reference site (SS 91440 68371) lies approximately 10 km west of the Aberthaw power station, and is also shown in Figure 2.1.

Any *S. alveolata* beds present between Transect HO in the east, to just beyond Transect LW in the west, were re-assessed in 2017. At Nash Point a sub-sampled area of the beds was mapped and assessed, which included the area west of the transect line (NP), and as far east as the freshwater inflow over the shore. The broad shoreline in this area supports extensive beds, and mapping the whole area would not have provided additional reference information (see Figure 2.2 for extent of beds mapped between 2015 and 2016).

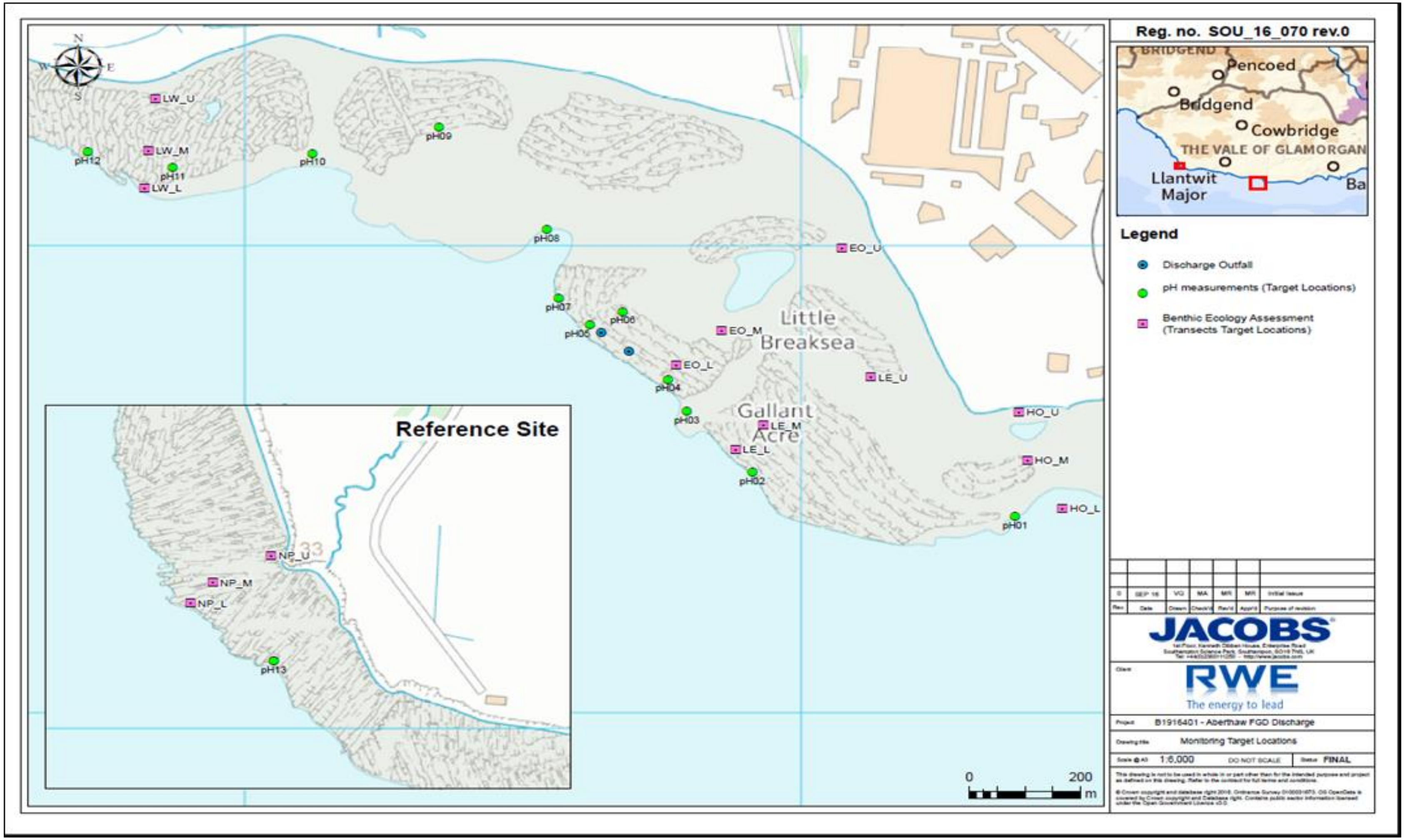

Figure 2.1 : Transect site positions and target pH measurements sites at Limpert Bay (easternmost survey area on region map) and Nash Point (Reference site (inset); westernmost survey area on region map), sampled between July and August 2017 (U = upper, M = mid, and L = low shore positions).

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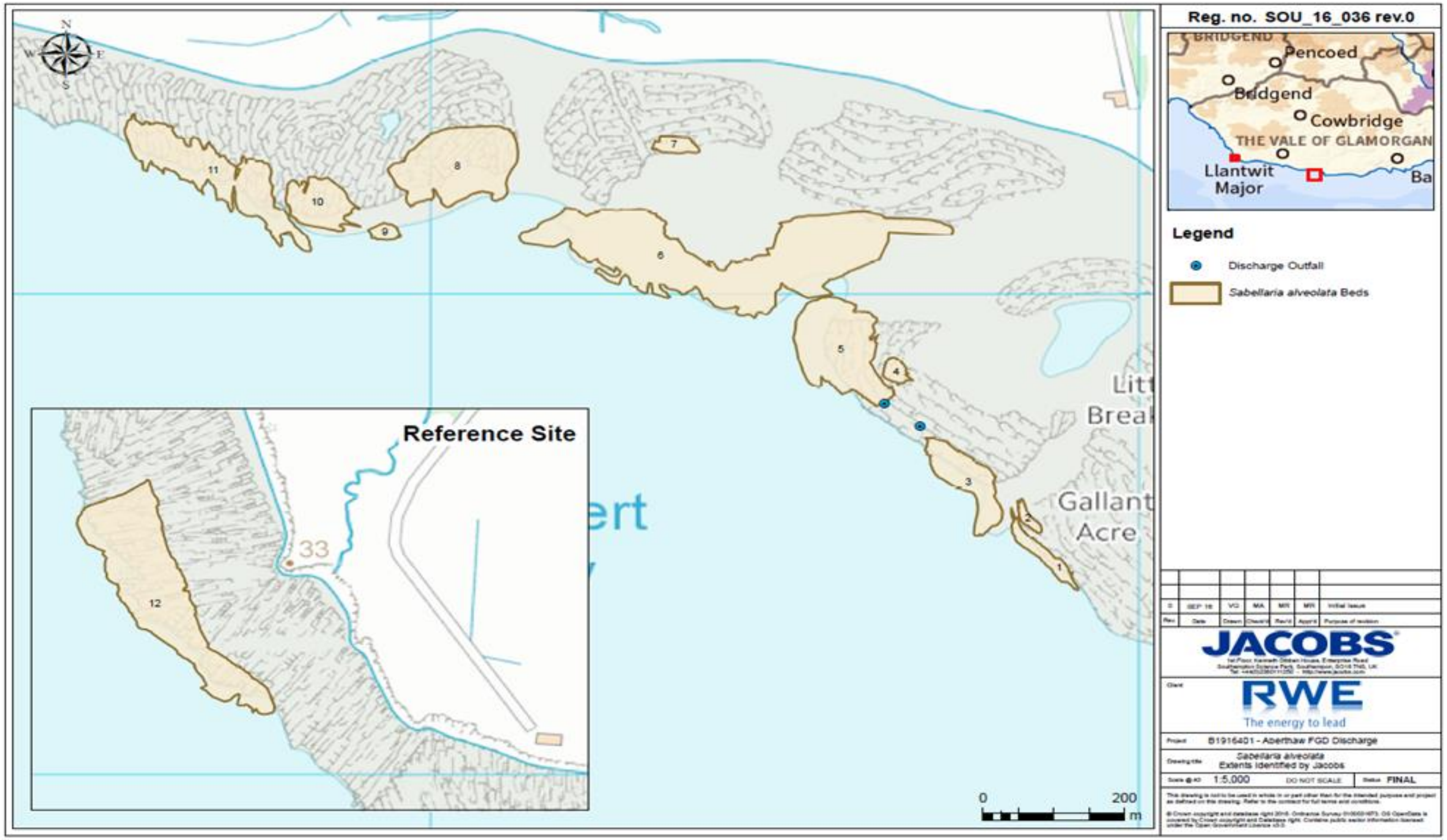

Figure 2.2 : ***Sabellaria alveolata*** **beds across Limpert Bay and Nash Point (Reference site, inset), surveyed between November 2015 and August 2016.**

2.2 Sampling and laboratory processing

2.2.1 Benthic community assessments

Species assemblage surveys were carried out at all upper, mid and low shore positions along each of the four transect lines at Limpert Bay (HO, LE, EO and LW) and at Nash Point (NP). Within each shore level, five replicate 0.25 m^2 gridded quadrats were placed together within close proximity to the target position. The quadrats were positioned to be representative of the shore level under study and where possible avoiding large rock pools. At Aberthaw there are extensive shallow pools providing refuge for other fauna (e.g. *Corallina* sp.).

The abundance of flora and fauna from each quadrat was assessed and recorded (by counts or percentage cover). Other conspicuous taxa on the shore not present within the quadrats were also recorded. Identification of organisms was done *in situ*, although for species in which differentiation in the field was difficult, such as certain algal epiphytes (e.g. *Ceramium*) or epifauna (e.g. sponges and hydroids), then these were identified to the most suitable taxonomic level for both accuracy and consistency. Very small species and/or those with high mobility (e.g. crabs) were included in the data capture, but were considered separately on interpretation of the data.

2.2.2 *Sabellaria alveolata* bed assessments

In July 2017, during low tide, the perimeters of the *S. alveolata* beds (numbered 1 to 12) were tracked on foot using a Trimble® Yuma 2 tablet to a +/- 3 m accuracy. The tablet was equipped with a differential Global Positioning System (GPS) and the navigational software HYDROpro®, with a local Ordnance Survey map preloaded and the recent 2015-2016 bed survey data overlaid (Figure 2.2).

Where possible, the lowest spring tide was always selected, but unavoidable temporal variation in tidal conditions resulted in some restriction in mapping the extreme tidal fringes of the beds on some occasions. In July 2017 access to the lowest intertidal limits of beds 3 and 11 were restricted and only the length of bed 1 could be mapped. In August, bed 1 was re-mapped at low water to capture as much spatial data as possible as this represents a narrow bed.

The critical distances used to differentiate between individual *S. alveolata* patches varies depending on the size of the area and features of the patches themselves (e.g. degree of coverage) (Allen *et al.,* 2002). The high-level approach utilised in this study precluded use of the smaller scale features such as narrow sandy gullies and rows of boulders that would further separate discrete sub-areas of a given bed.

Photographs and target notes on the broad bed features were recorded. General observations were also recorded, including the height of the structures, and any associated biota. These data, in conjunction with their extent/coverage, were used to classify colonies as a particular broad ‘formation’ type (Table 2.1). A semi-quantitative SACFOR scale score for application to *S. alveolata* was assigned to each bed (Appendix D) and this scale is a modification of the original scale. This scale can be compared to other *S. alveolata* abundance scales (e.g. ‘type’); these other scoring systems are also outlined in Appendix D.

In 2017, rapid quadrat assessments (1 m^2) were also undertaken to capture spatial variation in colony characteristics within each of the mapped beds. In each quadrat the percentage cover of *S. alveolata,* percentage of each formation type, and health categories were recorded (Table 2.1). In addition, rapid assessments of associated biota present (by counts or by percentage cover) were also undertaken. Each quadrat was photographed and its position referenced with a hand held GPS. A total of 37 quadrat assessments were undertaken across the 11 beds of Limpert Bay, and six across the single bed mapped at Nash Point. The number of quadrats assessed within each bed varied according to the size of the beds and where possible assessments were undertaken to capture information within both the upper and lower areas of the bed where tidal influence and exposure will naturally vary.

Table 2.1 : Descriptions of different formation types and health categories used to categorise *Sabellaria alveolata* colonies (Egerton, 2014 after Gruet, 1986).

a) Formation	Description
Patchy	Small crusts or mounds which are less than 30 cm^2
Hummock	Raised mounds which are greater than 30 cm^2
Sheet	Flat crusts which are greater than 30 cm^2
Reef	Large mounds which are greater than 1 m^2
b) Health	**Description**
Dead	Tubes have merged into a block of sediment. A piece of reef is detached from the substratum.
Worn apertures	There has been no clear new growth/tube building. The apertures can still be seen. The tubes are still attached to the substratum.
Crisp apertures	New growth of tubes can be seen, the apertures are crisp and will have a fine wall. Generally, a more lighter sand colour than worn reef.
Newly settled	Very small apertures between 1 mm and 4 mm. Usually found around the larger, older apertures.

2.2.3 Gastropod health assessments

Fifty individuals of the target species *Patella vulgata* and *Littorina littorea* were collected from each of the five intertidal transects from the mid to lower shore zone in August 2017. Samples were returned to the Jacobs laboratory for processing.

On return to the laboratory, the live gastropods were processed for biometric information. The maximum shell height, shell basal width and blotted tissue wet weight of each individual *L. littorea* were measured and recorded. The same was completed for *P. vulgata*, although shell weight was also recorded. All shell size measurements and wet weights were recorded to the nearest mm and 0.001 g, respectively.

2.2.4 Physico-chemical water quality

Single point readings of physico-chemical water quality parameters were recorded across the 12 target locations of Limpert Bay and at a single point at Nash Point (Figure 4.1) each survey month using either a hand held YSI® 556 or YSI® Pro sonde.

The following parameters were measured *in situ*:

- pH
- Temperature (°C)
- Salinity
- Dissolved oxygen (% and mg)
- Conductivity (mS.cm)

Both sondes were checked and laboratory calibrated prior to mobilising to site. The sondes were also calibrated in the field for atmospheric pressure and dissolved oxygen on arrival at site. Pre- and post-survey quality control (QC) checks were performed and recorded for salinity, DO and pH to quantify any instrument drift.

2.3 Data analysis

2.3.1 Benthic communities

Prior to analysis, the rocky shore taxa recorded during the quadrat transect surveys were checked for the most up to date nomenclature information using the World Register of Marine Species online database (WoRMS Editorial Board, 2017).

As the recorded assemblages were expected to naturally differ across the three different shore levels of low, mid and upper, statistical analysis and interpretation were applied separately to each zone.

Multivariate analysis was used to analyse the quantitative data relating to taxa abundance and distribution using the PRIMER (Plymouth Routine in Marine Ecological Research) software programme. Although the raw data contained mixed data (counts and percentages), similarity analysis between samples of mixed data (Bray-Curtis) can be undertaken, providing the interpretation of the results accounts for potential differences in the contribution of certain variables owing to their scale (Boaventrura, 2000, after Anderson and Underwood, 1997) (see Appendix E.1 for full details).

For initial temporal comparison across the entire sampling period (November 2015 to August 2017), the replicate quadrats sampled at each site were averaged, and non-parametric multi-dimensional (MDS) ordination with a Bray-Curtis similarity measure and cluster analysis (with SIMPROF) performed on the 4th root transformed mean data to visualise patterns in community data over space and time. A fourth root transformation was applied so as to preserve information of relative abundances and/or percentage cover of taxa across quadrats, but also to minimise differences in scale (Boaventura *et al.,* 2002).

Using the replicate quadrat data for August 2016 and August 2016 only, this was then repeated. Here, the ANOSIM routine was also used to identify statistical differences between sites/groups of sites ($p < 0.05$) where groupings had been initially identified via the graphical representation in the MDS ordinations and cluster dendograms (SIMPROF, $p > 0.05$).

Where differences were detected, the taxa most important for characterising 'groups' or distinguishing between them were undertaken using the SIMPER routine, where a species contribution to ≥10% of dissimilarity/similarity were considered to be important.

Where a result is stated as significant within the results section, it will be of statistical significance at $p = < 0.05$ and, where appropriate, the magnitude of the associated test statistic will also be discussed. The variability stated alongside the mean in the text will be represent ± Standard Deviation.

See Appendix E.1 for full statistical glossary for multivariate analysis in PRIMER.

2.3.2 *Sabellaria alveolata* bed assessments

Prior to analysis, the *S. alveolata* community data recorded during the rapid quadrat surveys from each bed were checked for the most up to date nomenclature information using the World Register of Marine Species online database (WoRMS Editorial Board, 2017).

Multivariate analysis was used to analyse the quantitative data on taxa abundance and distribution using PRIMER. MDS ordination with a Bray-Curtis similarity measure was performed on the 4^{th} root transformed quadrat raw (counts and percentages, see 2.3.1) data to visualise patterns in *S. alveolata* communities across all sampled beds. *S. alveolata* percentage cover data were removed from the analysis so to examine patterns in associated taxa present on these formations.

See Appendix E.1 for full statistical glossary for multivariate analysis in PRIMER.

Univariate analysis (One-Way ANOVA) was undertaken to assess any statistical significant differences ($p < 0.05$) in mean species richness and percentage cover of *S. alveolata* between the beds.

See Appendix E.2 for statistical glossary for univariate analysis in SigmaPlot.

2.3.3 Gastropod health assessments

The CI was calculated for each sample and used a relationship between tissue weight and shell size. High values indicate a better condition or health. The calculation of CI is given as:

$$\text{CI} = \frac{\text{tissue dry weight (g)} \times 1000}{(\text{shell size (cm)})^3}$$

(Lundebye *et al.,* 1997)

As wet weight had been recorded for each specimen, the values were converted to dry weight. For *Littorina littor*ea, wet weight:dry weight ratios were derived from data reported by Langston *et al*., 2012, and for *Patella vulgata*, values were converted using the average ratios for all gastropods detailed by Rumohr *et al*., 1987. The shell size parameter used for *L. littorea* was height and for *P. vulgata* it was maximum basal shell length.

Univariate analysis (Two-Way ANOVA) was undertaken to assess any statistical significant differences ($p < 0.05$) in mean CI and sizes between the August 2016 and 2017 sampled populations of the two species across all sites.

See Appendix E.2 for statistical glossary for univariate analysis in SigmaPlot.

3. Results

3.1 Benthic community assessments

The results of the transect community assessments across Limpert Bay (HO, LE, EO and LW) and at the reference site (NP) during the entire sampling period (2015-2017) are summarised below, but with additional focus on the two sets of data collected in August 2016 and 2017. The variation in benthic communities characterising the upper, mid and lower shore is reported separately below and reference made to key characterising taxa where appropriate.

3.1.1 Upper shore communities

Across many of the upper shore sites at Limpert Bay the substrata are a mosaic of bedrock, boulders, sand and mud, whereas at LW and at the reference site NP large expanses of exposed bedrock predominate (Figure 3.1- 2017, Figure 3.2- 2016). This is reflected in the range of 45 taxa recorded across all these sites (Appendix G), where sediment dwelling infauna were recorded (sand mason worm (*Lanice conchilega*) and lugworm (*Arenicola marina*)) as well as epifaunal calcareous tube worms (e.g. Serpulidae). Gastropods were commonly observed across all upper shores, and algae where present comprised the fucoids *Fucus spiralis* and *Fucus vesiculosus,* and opportunistic green macroalgae.

Figure 3.1 : Upper shore August 2017 (a) EO, (b) NP, (c) HO and d) LW.

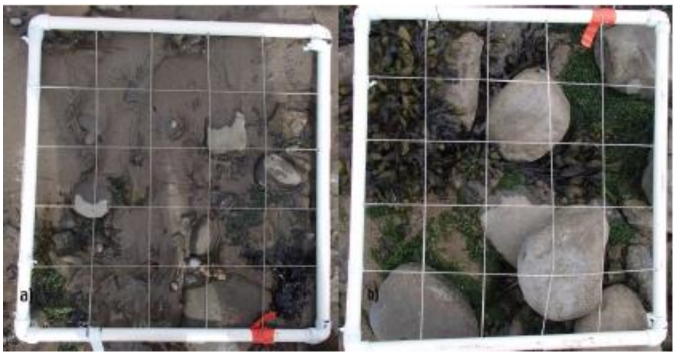

Figure 3.2 : Upper shore August 2016 (a) EO and (b) HO

The assemblages supported across the upper shore zones were also found to be variable and on interpretation of all mean species abundance data collected between November 2015 and August 2017, the upper shore communities sampled exhibited a low calculated similarity of 20.48% overall. There is generally evidence of a clear demarcation of communities spatially, but with some overlap between sites LE and LW (Appendix G). The upper shore communities assessed during the entire sampling period at HO were found to be not significantly different from one another (SIMPROF $\pi = 2.32$, $p = 0.32$, Appendix G) and for all communities at NP sampled between March 2016 and August 2017 also (SIMPROF $\pi = 1.34$, $p = 0.84$, Appendix G). For the communities sampled closest to the outfall (transect EO), there was no significant difference detected in the assemblages sampled between March and May 2016 and August 2017 (SIMPROF $\pi = 2.68$, $p = 0.11$, Appendix G). With the exception of March 2016 data for LE, there was no significant temporal differences in mean community abundances during the entire sampling period at LE and at LW at Limpert Bay, and with these two spatially distinct communities were found to not be significantly different from one another (SIMPROF $\pi = 1.09$, $p = 0.26$).

Further analysis of the replicate quadrat data of only the August sampling events of 2016 and 2017, has further confirmed this spatial separation in communities, but also with some temporal variation evident between the two years. The cluster dendogram and MDS plot of the August 2016 and 2017 data is represented in Figure 3.3, which presents six cluster groups identified from the SIMPROF analysis (groups I to VI).

There was a significant difference between all six clusters (One-way ANOSIM R = 0.92, $p = 0.001$), and at HO (group I and II) and EO (group III and IV) a significant difference between August 2016 and 2017 was evident. At EO in both years the community was characterised by *L. conchilega* and *Gibbula* sp, but it was the increased abundances of these taxa and *Littorina littorea* in 2017 that resulted in temporal changes in community structure. Although in both years at HO *F. spiralis* and *Ulva intestinalis* characterised this western site, it was the increased abundances of the Gammaridae amphipods and the flat topped periwinkle (*Littorina fabalis*) in 2017 that had contributed to overall temporal dissimilarity.

Cluster group IV comprised all quadrat data for the reference site NP in 2016 and 2017, and four from 2017 at LW, and was characterised by *Patella vulgata*, barnacles and juvenile littorinids that were often observed within the dead carapace of barnacles. The remaining quadrat data for LW 2016 and LE 2017 (except a single 2017 quadrat) and a single EO 2016 quadrat, comprised group VI and these upper shore communities were abundant in the gastropods *Gibbula* sp., *L. littorea* and *P. vulgata*. A common pattern of higher abundances of *P. vulgata* at the NP (group IV) compared to other sites was reported (SIMPER, calculated dissimilarity ≥ 10%).

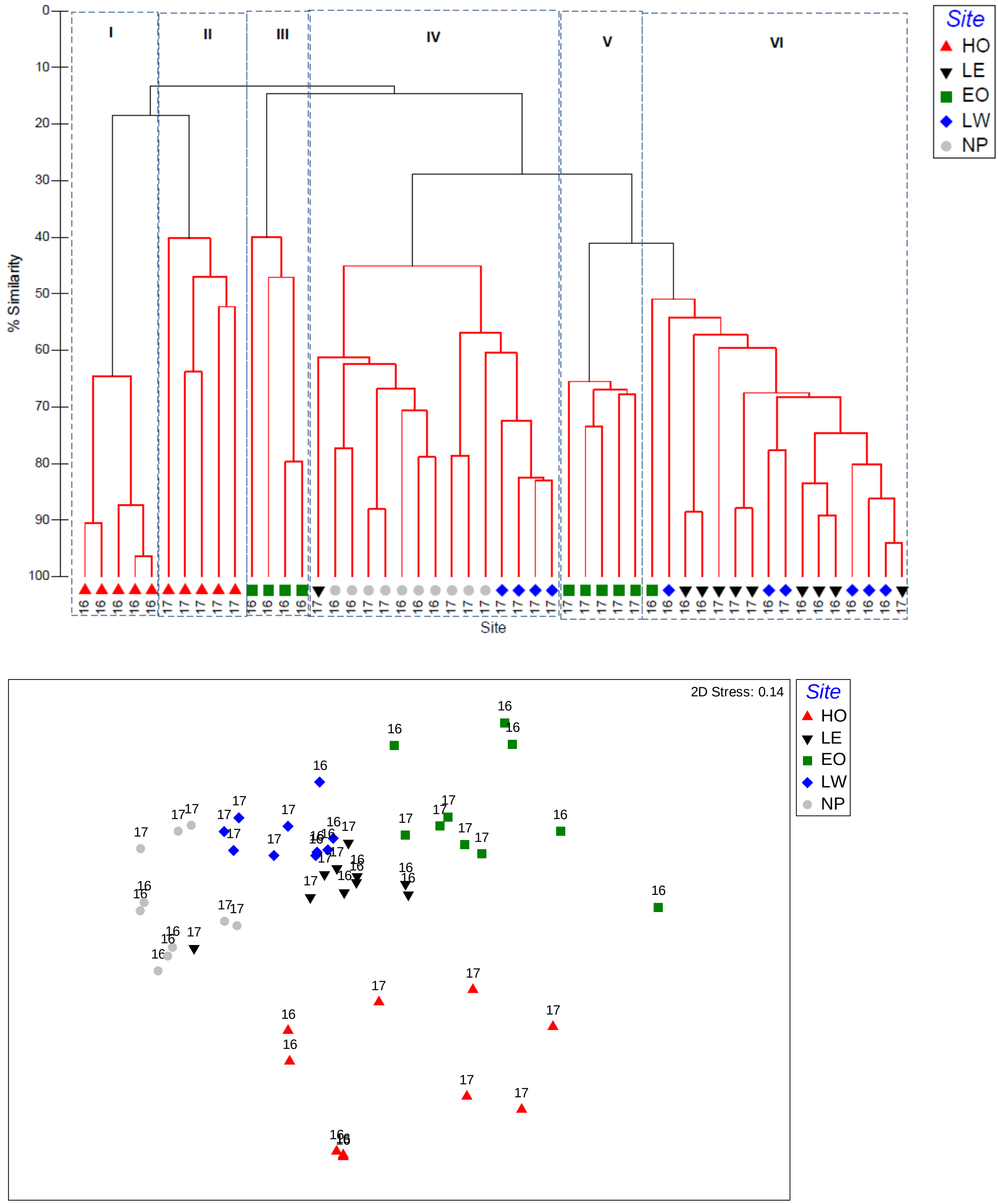

Figure 3.3 : Above: multivariate analysis of communities sampled across the upper shore sites in August 2016 and 2017 (16 and 17, respectively)(4th root transformed replicate quadrat abundance data with Bray-Curtis similarities), with dashed boxes on the dendogram encompassing those communities not significantly different from one another (SIMPROF, *p* = >0.05). Below: a two-dimensional MDS plot (stress = 0.14).

3.1.2 Mid shore communities

Across the mid shore, 48 taxa were recorded overall (Appendix H). The assemblages across all transect sites in Limpert Bay were characterised by gastropods and intermittent swathes of the fucoid *F. vesiculosus,* whereas across the reference site NP, such fucoid cover was not as predominant (Figure 3.4 and Figure 3.5).

Figure 3.4 : Mid shore August 2017 (a) EO, (b) LE, (c) HO and (d) NP

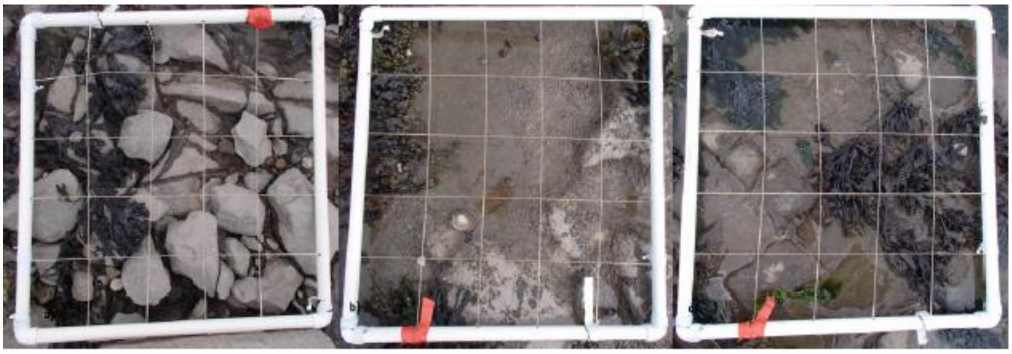

Figure 3.5 : Mid shore August 2016 (a) EO, (b) LE and (c) HO

Unlike the upper shore, across all transect sites and sampling dates, the average community data were found to be overall more spatially and temporally similar at 41.35%, but with a clear demarcation between the Limpert Bay and NP communities (Appendix I). All Limpert Bay average community data (except LE March 2016) were found to be not significantly different from one another ($\pi = 0.67$, $p = 0.22$). The November 2015 to August 2017 average community abundances at NP were also not significantly different from one another ($\pi = 1.34$, $p = 0.57$).

Further detailed analysis exploring temporal differences between the August 2016 and 2017 data re-affirmed this spatial pattern with two main clusters identified across all replicate data, comprising Limpert Bay (group III) and NP (group II), and with only a single replicate outlier for EO (quadrat no. 2) in 2016 (group I) (Figure 3.6). There was an overall significant difference detected (One-way ANOSIM $R = 0.83$, $p = 0.001$), but with no significant pairwise difference detected between group I and II (pairwise test $R = 0.1$, $p = 0.10$).

Limpert Bay (Group III) mid shore communities were characterised by the gastropods *P. vulgata*, *L. littorea* and *Gibbula* sp., barnacles and the fucoid *F. vesiculosus.* Nash Point (Group II) was characterised by *Nucella lapillus*, *Gibbula* sp., Actiniaria, barnacles and juvenile Littorinds. The higher relative abundances of *N. lapillus* and juvenile Littorinids at Nash Point (II) compared to Limpert Bay (III) was important in driving the community differences (SIMPER, calculated dissimilariity >10%). The lower relative abundances of *P. vulgata* at Limpert Bay compared to Nash Point was also ranked as important following SIMPER analysis.

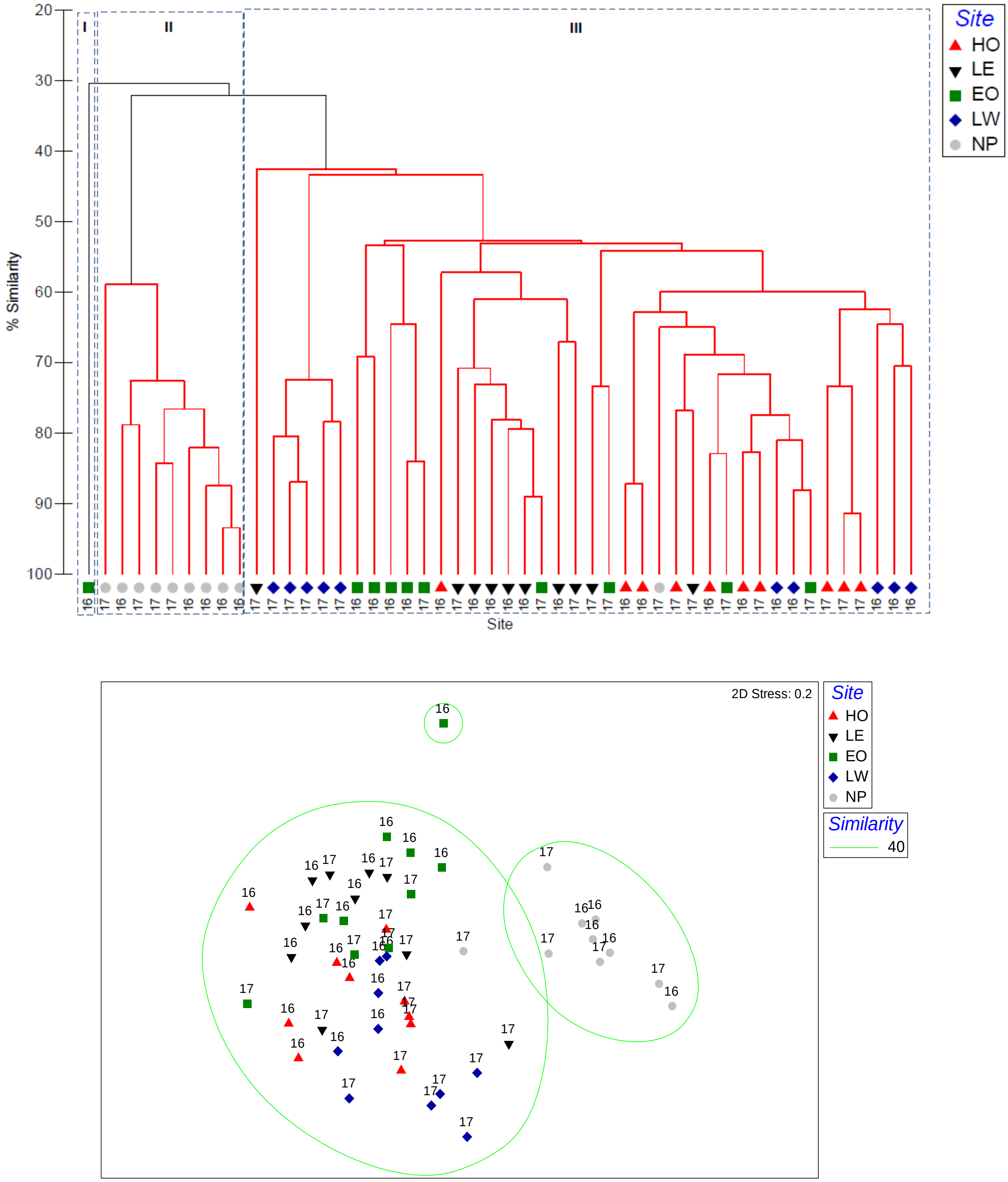

Figure 3.6 : Above: multivariate analysis of communities sampled across the mid shore sites in August 2016 and 2017 (4th root transformed replicate quadrat abundance data with Bray-Curtis similarities), with dashed lines on the dendogram indicating those communities not significantly different from one another (SIMPROF, *p* = >0.05). Below: a two-dimensional MDS plot (stress = 0.2).

3.1.3 Low shore communities

The low shore communities were characterised by *Fucus serratus* and colonies of *Sabellaria alveolata*, with a total of 56 taxa recorded across the sites (Appendix J). Some of the low shore transect sites fell within the upper limits of *S. alveolata* beds (e.g. at NP and HO), whereas LE and EO were positioned just above the upper limit of the narrower beds 1 and 3, respectively (Figure 3.7 and Figure 3.8). For assessments of communities associated with the *S. alveolata* beds see section 3.2.2 (e.g. the 1 m^2 quadrat assessments).

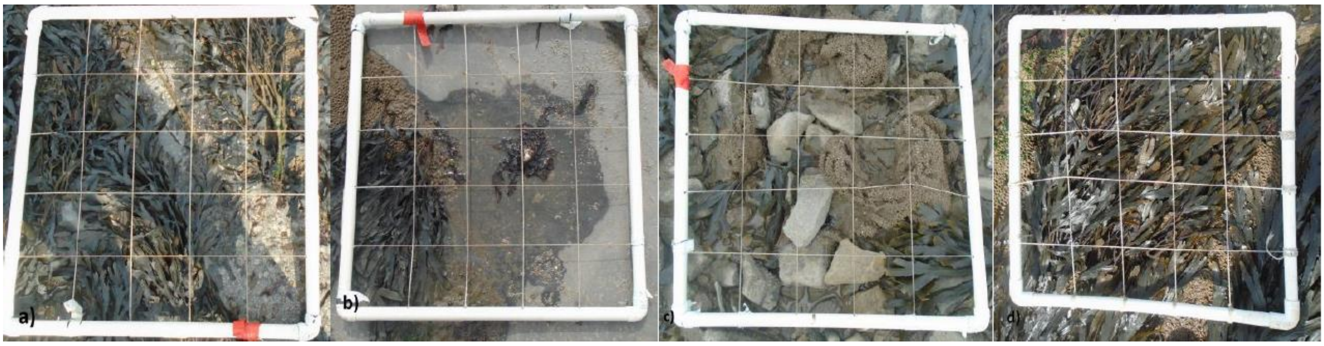

Figure 3.7 : Low shore August 2017 (a) EO, (b) LE, (c) HO and (d) LW

Figure 3.8 : Low shore August 2016 (a) EO, (b) LE and (c) HO

As with the upper shore communities, the lower shore mean community abundances also exhibited a general spatial pattern (Appendix K). All community data sampled at EO between November 2015 and August 2017, and at the neighbouring LE up to August 2016, was found to not be significantly different from one another (SIMPROF π = 2.21, p = 0.07). Mean community abundances at HO sampled during the entire sampling period was also reported to not be significantly different from one another (SIMPROF π = 1.88, p = 0.30). The most western low shore site at Limpert Bay (LW) and the reference site NP indicated similarities in community structure with most communities sampled shown to be temporally not significantly different from one another (SIMPROF π = 1.25, p = 0.37).

Analysis of the August 2016 and August 2017 replicate quadrat data further confirm disparity between these communities mainly at a spatial scale than across a temporal one. Six cluster groups were identified across the data set with only a temporal split between the two years for LW (group III and VI), and notably for LE (group I and V) (Figure 3.9). Quadrat data collected from the outfall site EO from both years were found to not be significantly differently from one another (group II: SIMPROF π= 1.34, p = 0.42) as was for HO (group IV: SIMPROF p = >0.05). The lower shore replicate community data from the western transect LW and at NP indicated some overlap in communities and comprised the largest cluster group VI (Figure 3.9).

The summer EO communities (group II) were characterised by the fucoid *F. serratus* and *F. vesiculosus. S. alveolata* was also an important characterising taxon, but contributed only 3.84% overall (SIMPER). The summer HO low shore communities (group IV) were also characterised by *Gibbula* sp. and *S. alveolata*, but with *F. serratus* and *N. lapillus* also ranked highly. Group VI that comprised most of the quadrat assessment for LW and NP in both sampling years was characterised by *S. alveolata,* and the algae *Ulva lactuca, Corralina* sp. and *Cladostephus spongiosus.*

There was a significant difference between all community clusters (One-way ANOSIM R = 0.86, *p* =< 0.001), but a notable temporal difference was detected at LE between 2016 (group I) and 2017 (group V). SIMPER identified the lower relative abundances of *L. littorea* and *Patella* sp.*,* and higher cover of *S. alveolata* in August 2017 compared to 2016 as important differences between these two assemblages.

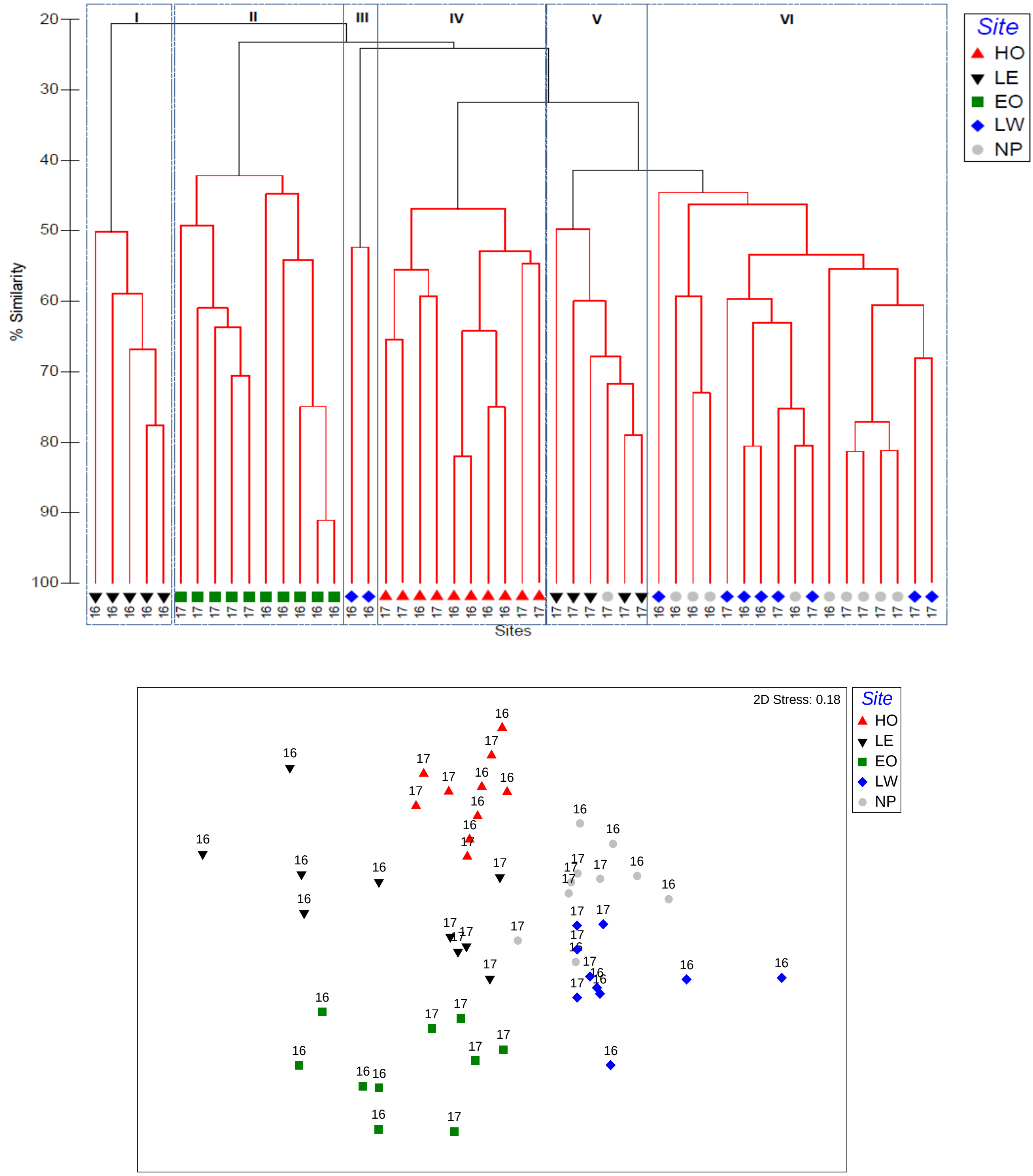

Figure 3.9 : Above: Multivariate analysis of communities sampled across the low shore sites in August 2016 and 2017 (4th root transformed replicate quadrat abundance data with Bray-Curtis similarities), with dashed lines on the dendogram indicating those communities not significantly different from one another (SIMPROF, *p* = >0.05). Below: two-dimensional MDS plot (stress = 0.18).

3.2 *Sabellaria alveolata* bed assessments

3.2.1 *Sabellaria alveolata* bed extent

The beds of Limpert Bay and at the reference site Nash Point as mapped in July and August 2017 are shown in Figure 3.10, and overlay the ‘total bed’ areas mapped between November 2015 and August 2016. This provides an overview of the extent of the beds within these two study areas and a temporal comparison between the initial pH variation assessment and the first annual assessment post the 2016 trial. The extent of the beds is summarised below, with details and photographs of each bed described in Appendix L and Appendix M. Bed formations and their associated benthic communities are detailed in section 3.2.2

There continued to be a spatial distinction between the east and west of Limpert Bay, with a greater landward extent of colonies along the western side of the outfall structures (e.g. beds 5 and 6) compared to the fewer, narrower beds which were present on the eastern side, up to HO (Beds 1-3). There was no indication of any reduction in the spatial extent of the colonies across both sites since the initial assessments in 2015-2016. The beds as indicated from the previous surveys encompassed all surveys (six in total), and any variation at the seaward edge was likely to be a natural artefact of differences in tidal conditions between survey events (see Appendix C for low water conditions). Beds 9 and 10 were mapped on a lower state of tide in July 2017 and bed 9 is now determined to be an eastern extension of bed 10 reflecting the extent of the biotope historically determined by NRW (Appendix A).

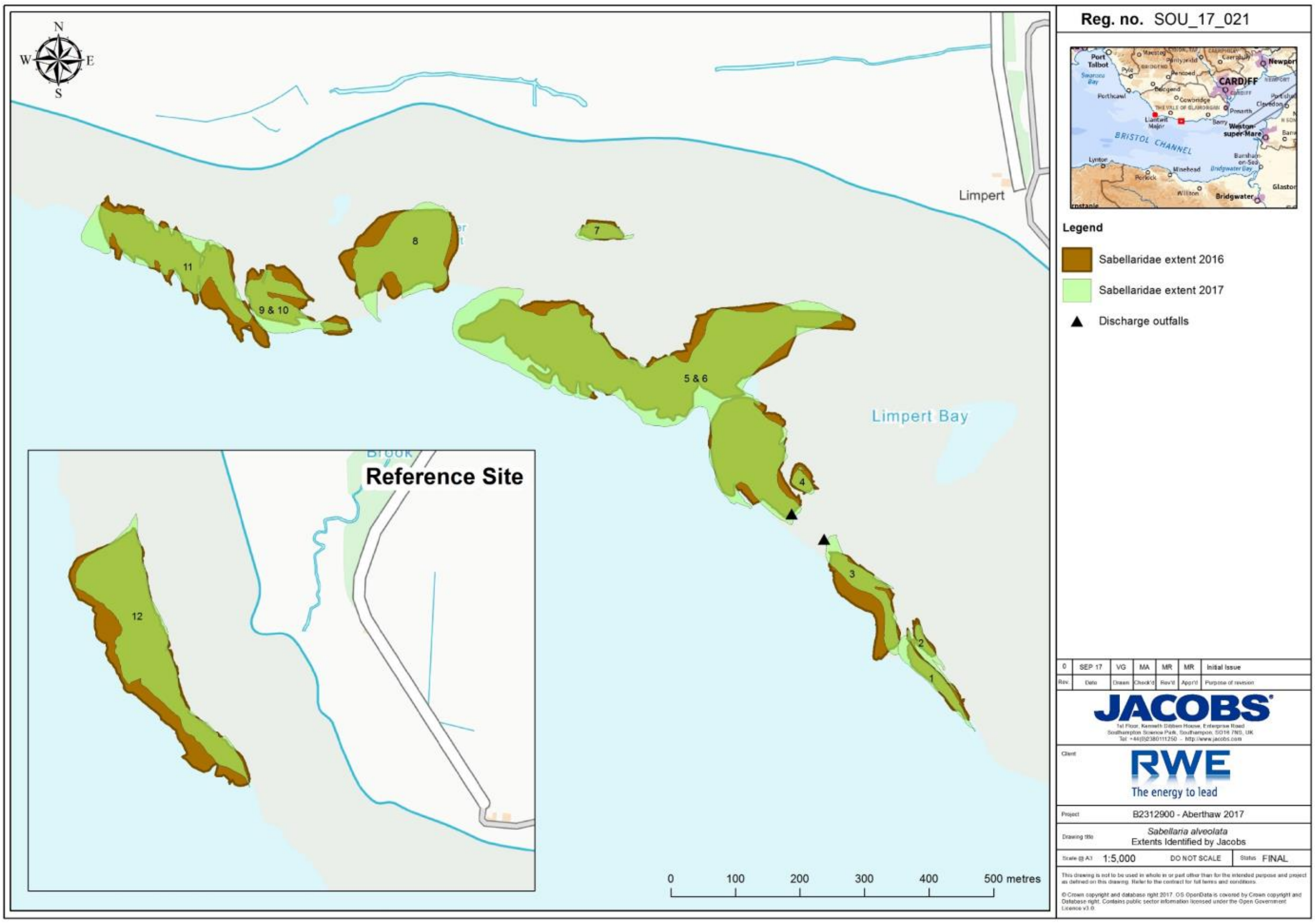

Figure 3.10 : *Sabellaria alveolata* extent mapped at Limpert Bay and the reference site Nash Point, 2015-2016 (brown) and in 2017 (green).

In 2017, *S. alveolata* beds were still present up to the edges of the western and eastern outfall structures (beds 3, 4 and 5) although there continued to be no colonies observed between the two structures, only dense swathes of fucoid algae. However, crusts and mounds of *S. alveolata* remained present within the structures themselves and colonies were found to persist at the historic (redundant) outfall structures that lie just west of transect line HO (Figure 3.11).

Figure 3.11 : Fucoid cover across the low shore area between the western and eastern current outfall structures (LEFT), colonies of *S. alveolata* present within the structures themselves (CENTRE), and within the old outfall structures (RIGHT), July 2017.

To the east of the old eastern outfall structure, an extensive area of hummock formations were present (SACFOR: 'Abundant'/'Type 3'), and as with the 2015-2017 surveys, these were also not mapped in 2017 as they lie to the west of transect line HO.

Figure 3.12 : Looking eastwards from HO, Limpert Bay, August 2017.

On the western side of Limpert Bay, several large areas of sandy deposits interrupted the beds (e.g. between beds 5 and 6, and 6 and 8) and in 2017 there was evidence of tubes developing between the beds and along the edges. This potential encroachment of colonies would have influenced the widening of some beds (e.g. 5 and 6) from the mapping surveys (Figure 3.10). The historic NRW biotope maps show a greater eastern extension of bed 5 and a retraction of 6 across these sandy areas, in comparison to the beds mapped in 2015-2016 (Appendix A) indicating potential long term temporal shifts in these boundaries.

Figure 3.13 : Developing *S. alveolata* between bed 5 and 6 at Limpert Bay, July 2017 (N51 23.128 W3 25.272).

During the mapping surveys of 2015-2016, discrete thin crusts and patches of *S. alveolata* were observed to the west of bed 1 and transect LE, towards the historic outfall structures, but these did not appear to have the attributes of a bed and as such were not mapped. In July 2017, these colonies appeared more extensive (Figure 3.14) and in August 2017 at low tide more elevated structures were observed towards the seaward edge (Figure 3.15).

Figure 3.14 : Thin veneer crusts of *S. alveolata* colonies across rocky platforms between western historic outfall structure and bed 1 at Limpert Bay looking south-east (LEFT) and close-up (RIGHT), (N51 22.757 W3 24.560, July 2017).

Figure 3.15 : Exposed at low tide *S. alveolata* bed between western historic outfall structure and bed 1 at Limpert Bay, looking south (LEFT) and west (RIGHT) (August 2017).

A summary description of each of the 11 beds mapped to the east and west of the outfall structures at Limpert Bay and at Nash Point is provided in Appendix L and Appendix M, respectively. The beds overall were a mosaic of sheet and hummock formations, and with low elevated reefs in places where continuous colonies were present. Within the beds, abundance cover ranged from 'Common' to 'Abundant' which according to the corresponding classification scales listed in Appendix D are also equivalent to a 'Type 6' to 'Type 3' formation and are all determined to be 'reef forming' structures.

3.2.2 *Sabellaria alveolata* bed features and associated benthic communities

The additional quadrat assessment undertaken this year within the beds has provided greater spatial coverage of the *S. alveolata* bed features and their communities across the low shore of Limpert Bay than previously described in the 2015-2016 surveys and in addition, captures community data between the transect lines LW in the west of the bay and EO by the outfall structures. The location of quadrats across the two study sites are shown in Appendix N.

The percentage cover of *S. alveolata* was often very variable within each bed (Figure 3.16); however, there was no indication of a pattern of reduced coverage within those beds that lie in close proximity to the outfall (e.g. beds 3-5) compared to beds that were remote from this point (e.g. beds 11 and 12, the latter at Nash Point).

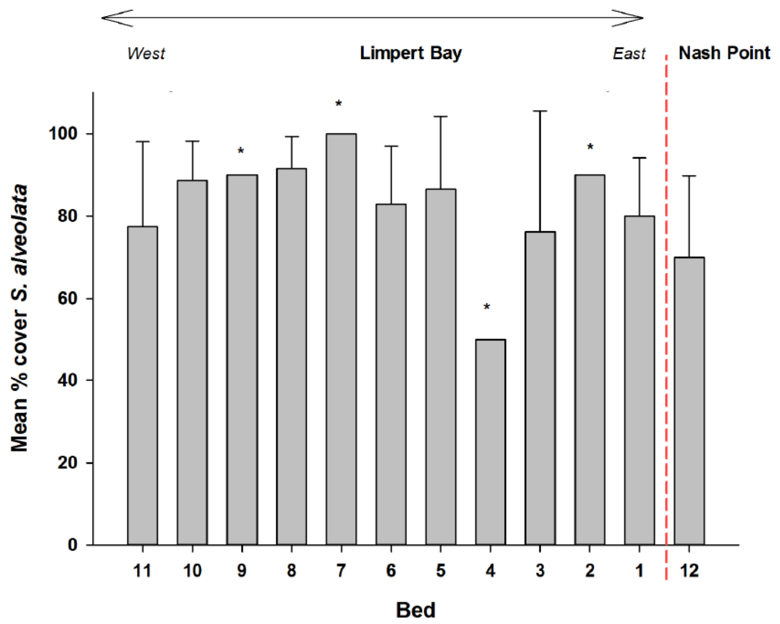

Figure 3.16 : Mean percentage cover of *S. alveolata* recorded across 1 m^2 quadrats assessed within each bed mapped at Limpert Bay and Nash Point, July 2017. Error bars = standard deviation. * = Single replicate quadrat assessed within a given bed. The outfall structures lie between beds 3 (east) and 4 and 5 (west).

The variation in percentage cover may also be indicative of the spatial variability in the formation types of *S. alveolata* colonies within each bed assessed, with a range of sheet and hummock forms often the dominant type recorded overall within the beds (Figure 3.18). Although coverage within a 1 m^2 quadrat may have been less than 100%, it could encompass elevated hummocks of significant tube structures. Reefs were only reported across the quadrats where the elevated colonies were continuous within the quadrat and extended uninterrupted beyond it, within the local vicinity. Although deemed a reef they were all of low elevation not exceeding the heights of the hummocks observed in this area. ‘Turret’ like structures were also observed, and if clustered together covering an area > 30 cm^2 these were recorded as hummocks and not as patchy formations. Examples of these features were commonly observed across Nash Point (Figure 3.17).

Figure 3.17 : Quadrat 12D from Nashpoint, July 2016. Showing erect 'turret' structures.

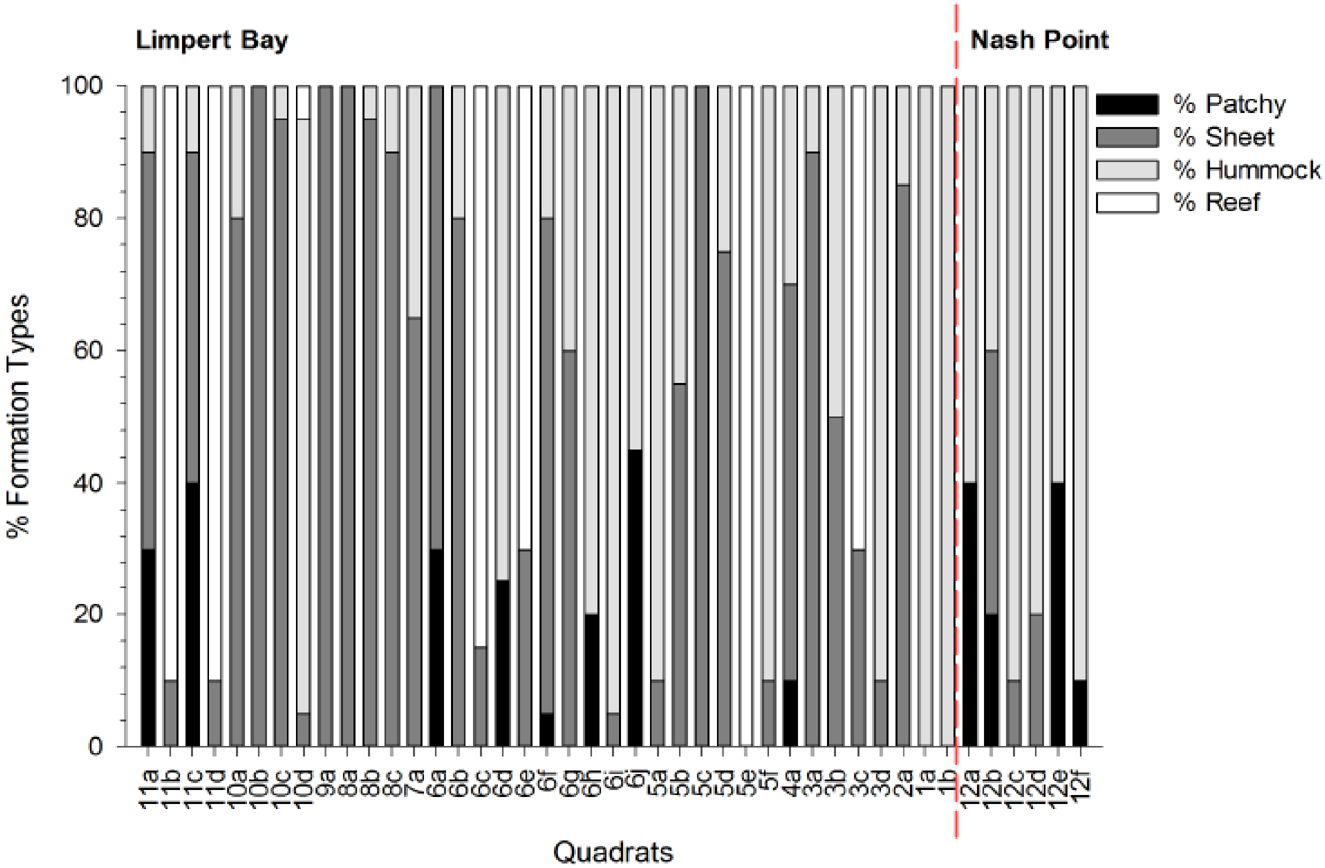

Figure 3.18 : Percentage of each formation type for *S. alveolata* colonies recorded within each quadrat ('a' – 'j') assessed across the beds of Limpert Bay (beds numbered 1-11) and Nash Point (bed 12), July 2017. The outfall structures lie between beds 4,5 and 3.

Health assessments across the beds produced results showing varying proportions of dead and worn apertures and crisp apertures within individual quadrats (Figure 3.19). The percentage proportion of newly settled worms are likely to be underreported here as an artefact of the rapid assessment employed. Within the beds to the east of the outfall (1 – 3) most assessments were dominated by colonies with crisp apertures and visible 'porches' to the entrance to their tubes. Bed 5 to the west had overall a higher proportion of 'dead' colonies observed (quadrats 5C and 5D) but with crisp apertures still visible within the quadrats. There is no indication that the beds by the outfall (beds 3, 4 and 5) were of lesser quality than those remote to the structures.

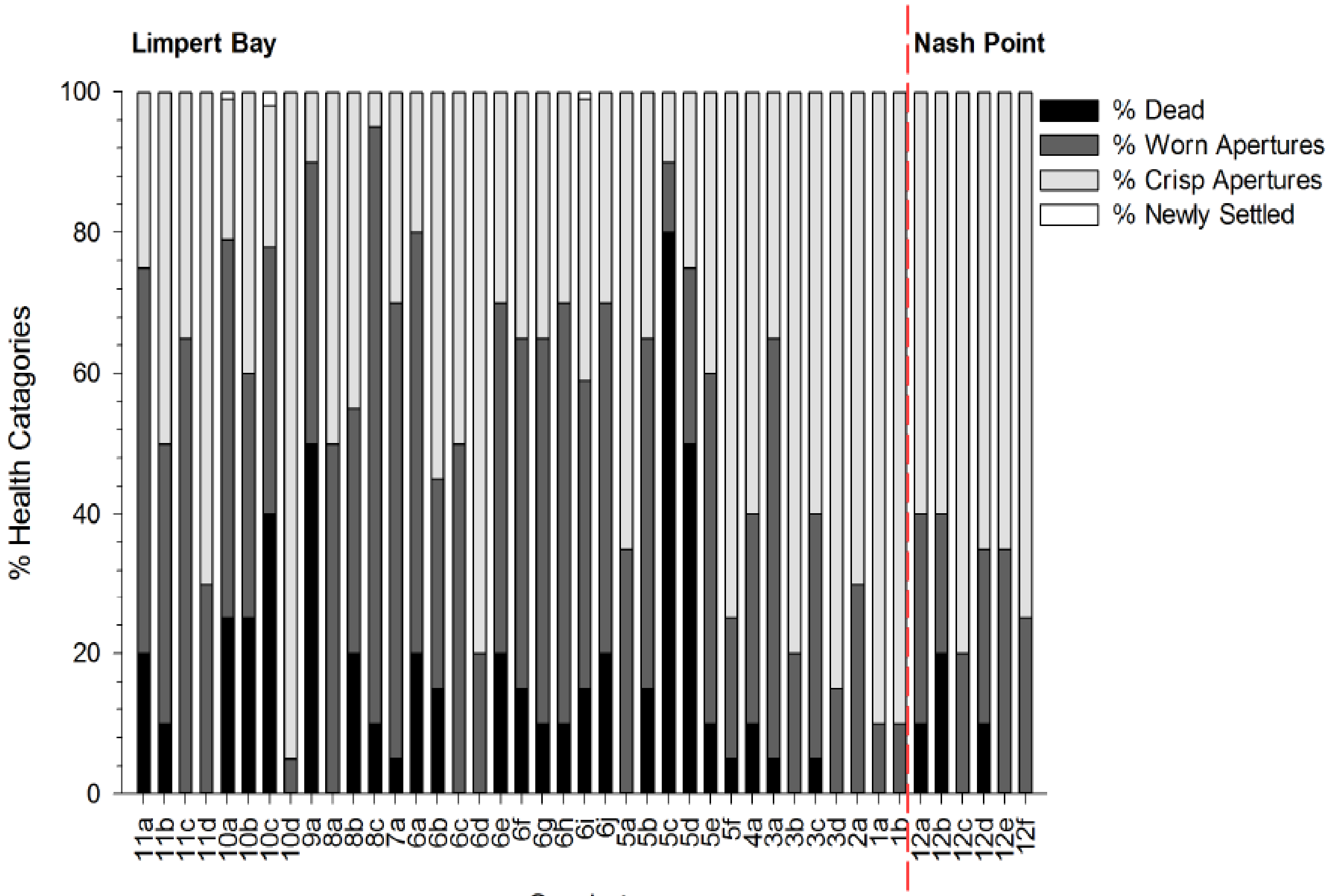

Figure 3.19 : Percentage proportions of each health category for *S. alveolata* colonies recorded within each quadrat ('a' – 'j') assessed across the beds of Limpert Bay (beds numbered 1-11) and Nash Point (bed 12), July 2017. The outfall structures lie between beds 4,5 and 3.

A total of 33 taxa were reported in total, including *S. alveolata*, during the rapid assessments across the beds of Limpert Bay and Nash Point, with the opportunistic macroalgae *Ulva lactuca* reported across all beds and in 40 of the 43 quadrats. *Fucus serratus* was recorded across all beds and within 30 out of the 43 assessments. Appendix N lists all taxa recorded in total for each of the 12 beds. The maximum number of taxa recorded was 22 across bed 6 (n = 10) and 21 across beds 5 and 12 (n = 6). The lowest species richness was recorded at bed 7 (4 taxa, n = 1) and bed 8 (5 taxa, n = 3). Statistical comparisons found significantly higher mean richness was reported only for bed 12 at Nash Point compared to bed 8 at Limpert Bay (One-way ANOVA F = 4.13, *p* = 0.03, Holm=Sidak multiple comparison test, *p* = < 0.05) (Figure 3.20).

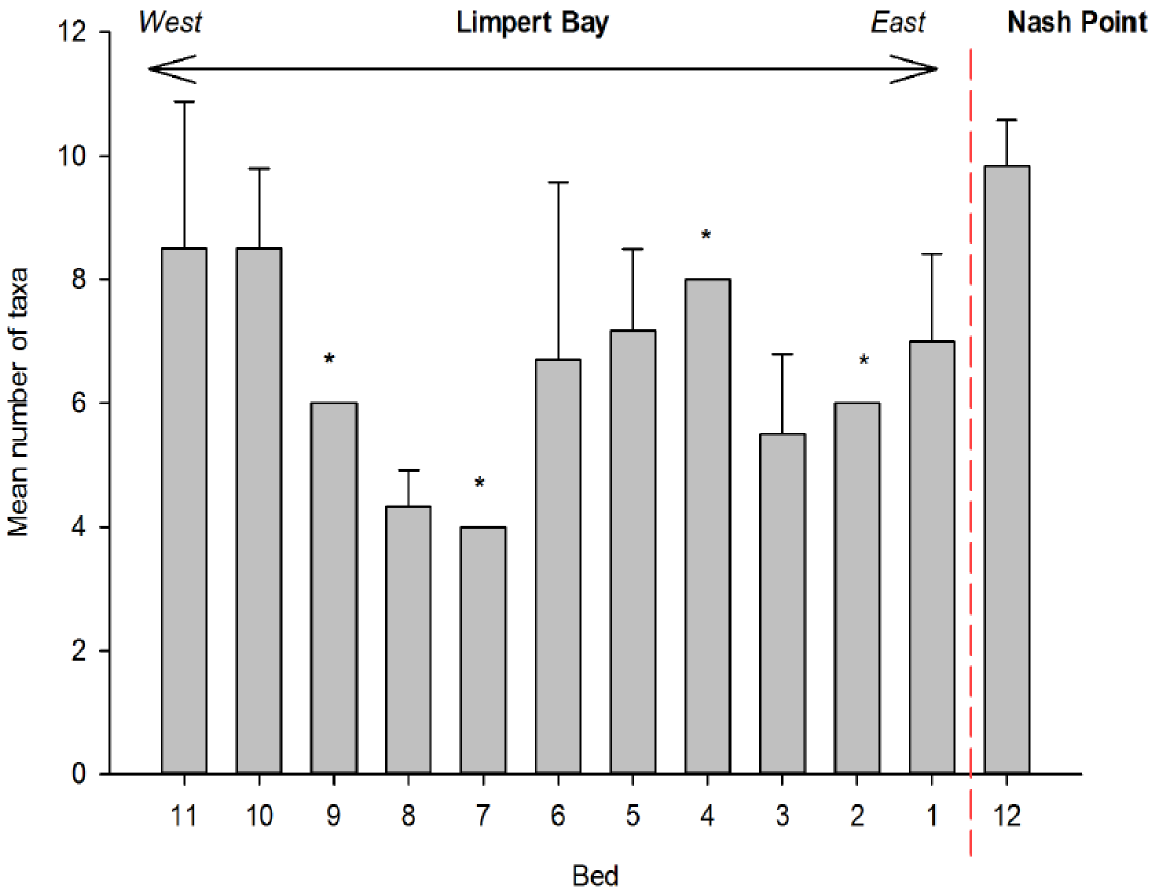

Figure 3.20 : Mean number of taxa recorded from each bed at Limpert Bay (1-11) and at Nash Point (12), July 2017. Error bars = standard deviation. * = Single replicate quadrat assessed within a given bed.

Community analysis (excluding the single replicate beds 2, 4, 7 and 9) overall revealed no significant spatial differences in community assemblages associated with *S. alveolata* beds (One-way ANOSIM, $R^2 = 0.09$, $p = 0.12$). However, examination of the individual *post-hoc* ANOSIM pairwise tests between the beds, did reveal significant differences between bed 12 at the reference site Nash Point and all beds analysed from Limpert Bay ($p = < 0.05$), except bed 11 and bed 1. Community distribution of all quadrat assessments are represented in Figure 3.21 and with no clear distinction between the assemblages that comprise each bed. SIMPER analysis revealed the ephemeral algal species *Ulva lactuca* as a characterising component of all bed communities. A general pattern of lower percentage coverage of *Fucus serratus* at Nash Point compared to the Limpert Bay beds was found, but with higher counts of *Nucella lapillus*.

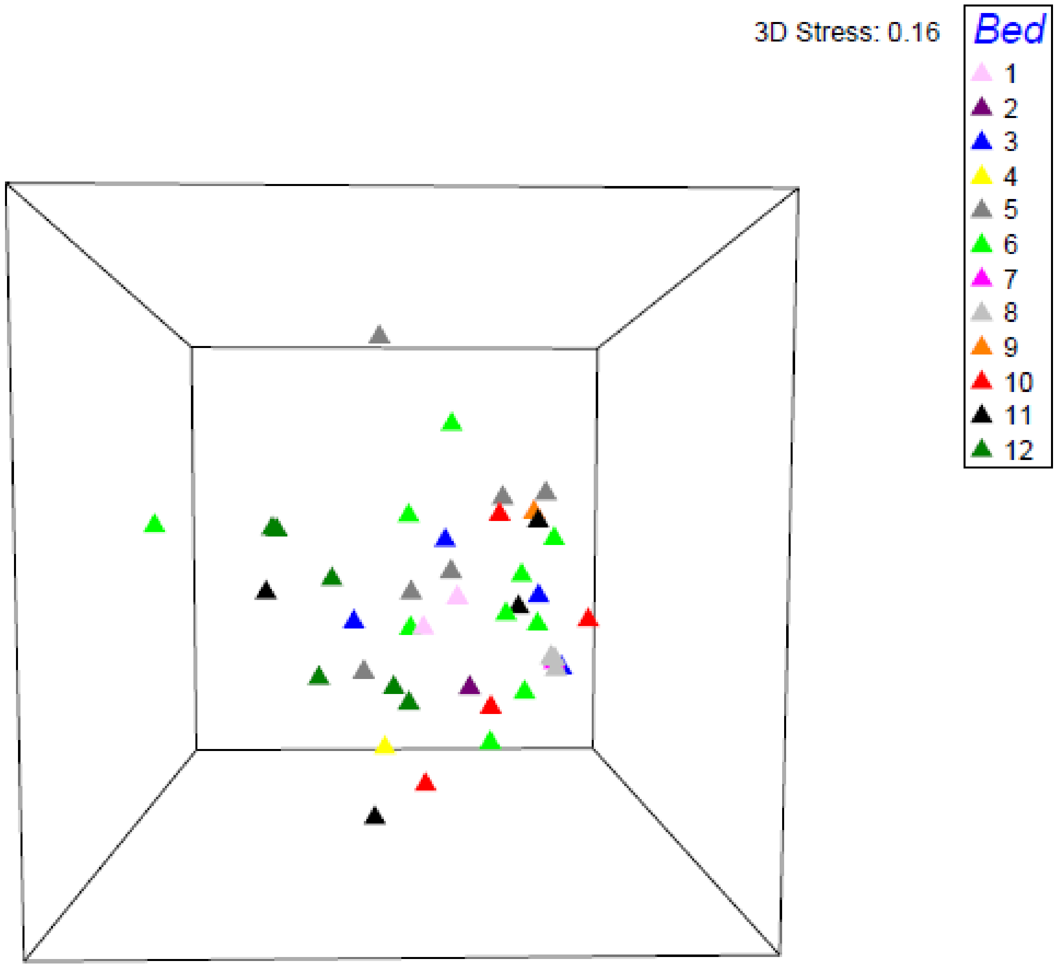

Figure 3.21 : Three-dimensional MDS plot of fourth root transformed *S. alveolata* community data sampled across the *S. alveolata* beds of Limpert Bay (Bbeds 1 – 11) and at Nash Point (bed 12) in July, 2017. Stress = 0.15 (*S. alveolata* abundance data removed).

3.3 Gastropod health assessments

3.3.1 *Littorina littorea*

Overall, a significant spatial variation in the mean CI values (F = 29.80, *p* = <0.001) of *Littorina littorea*, sampled across Limpert Bay and the reference site NP during August 2016 and 2017 was detected but there was no clear pattern evident (Figure 3.22). In 2017, the highest CI values were reported at the sites in closest proximity to the outfall, LE and EO (25.08 and 20.23 respectively), with LW exhibiting the lowest (14.57). However, in 2016 both LE and LW populations exhibited the highest values (20.96 and 19.83 respectively) and at the reference site, the lowest (14.65). LE and LW were the only sites to show significant temporal variation between years (Holm-Sidak pairwise test *p* < 0.001) with an increase at LE but a decrease at LW.

The mean sizes (shell height) of *L. littorea* significantly varied spatially and temporally (Two-Way ANOVA, *p* < 0.001), but with no consistent pattern in gradient of size across the sites and between the two sampling dates (Figure 3.23).

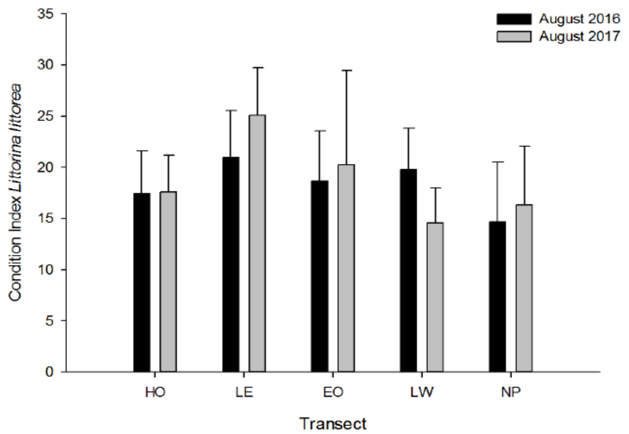

Figure 3.22 : Mean condition index (CI) for *Littorina littorea* (± St.Dev, n = 50) sampled across Limpert Bay (HO, LE, EO and LW) and at Nash Point (NP) in August 2016 and August 2017.

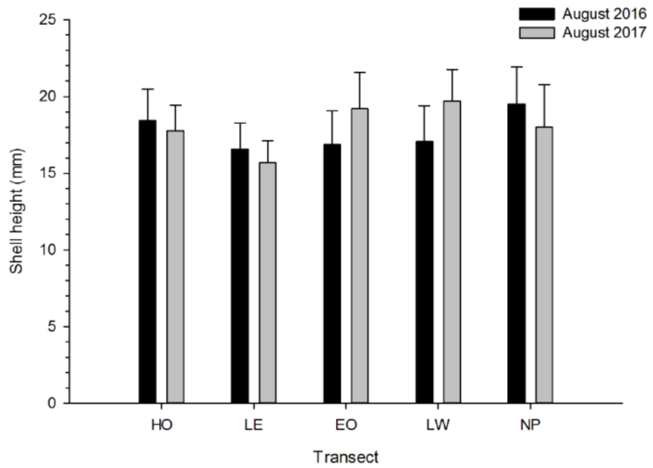

Figure 3.23 : Mean shell height (mm) for *Littorina littorea* (± St.Dev, n = 50) sampled across Limpert Bay (HO, LE, EO and LW) and at Nash Point (NP) in August 2016 and August 2017.

3.3.2 *Patella vulgata*

Figure 3.24 shows the calculated mean CI values for *Patella vulgata* sampled across Limpert Bay and the reference site NP during August of 2016 and 2017. Only at the reference site NP was there a significant temporal variation detected, with an increase between 2016 and 2017 (Holm-Sidak, $p < 0.001$). However, a significant spatial effect was detected between the populations (F = 32.99, p = < 0.001), with highest CI values observed at LE and EO in 2016 (14.48 and 15.28 respectively) and 2017 (14.61 and 14.30, respectively) and these were significantly higher than most other sites including NP (Holm-Sidak, p <0.001).

In both years, significantly smaller specimens were recorded from NP (28.4 to 29.36 mm), compared to the transect sites at Limpert Bay (38.04 to 42.08 mm) based on mean shell length, (Two-Way ANOVA F = 130.57, p <0.001, Figure 3.25).

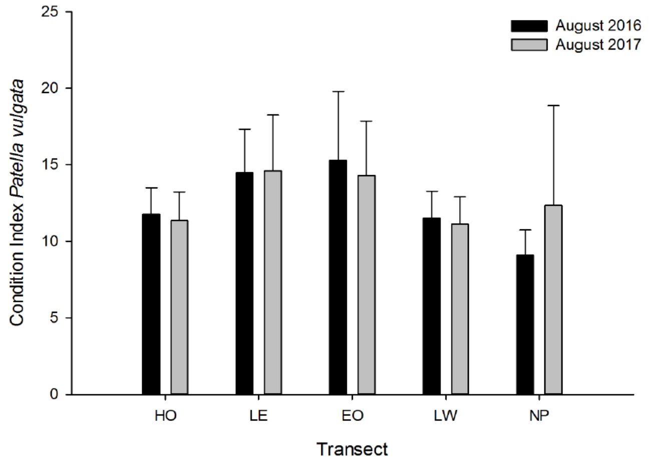

Figure 3.24 : Mean condition index (CI) for *Patella vulgata* (± St.Dev, n = 50) sampled across Limpert Bay (HO, LE, EO and LW) and at Nash Point (NP) in August 2016 and August 2017.

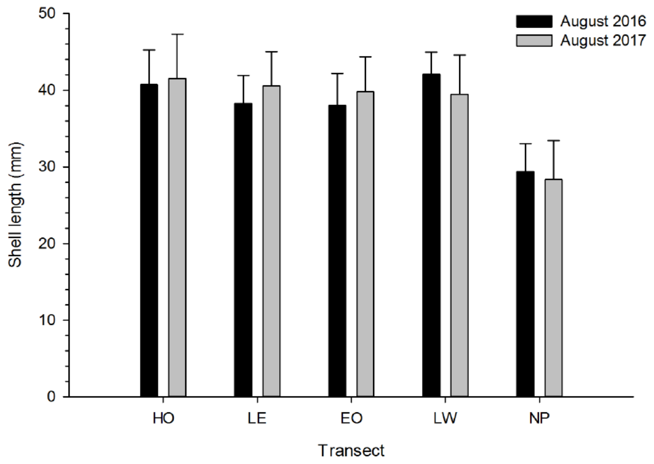

Figure 3.25 : Mean shell basal length (mm) for *Patella vulgata* (± St.Dev, n = 50) sampled across Limpert Bay (HO, LE, EO and LW) and at Nash Point (NP) in August 2016 and August 2017.

3.4 Physico-chemical water quality

Physico-chemical data were collected across the 13 target sampling sites in July and August 2017 (see Figure 2.1 for location of sampling sites). The raw data collected in 2016 and 2017 are listed in Appendix P and Appendix Q, respectively.

At each site in July and in August 2017 a single reading was taken, and the mean of the two pH measurements for each site are shown in Figure 3.26 below. The minimum recorded mean value overall in 2017 was 8.07 at the reference site Nash Point (pH_13) and the highest of 8.75 at the eastern site pH_02 at Limpert Bay. The sampling site in closest proximity to the outfall (pH_06) fell within this range with values between 8.09 to 8.16. This is in contrast to the physico-chemical data collected during the trial in 2016, where pH values of between approximately 6.5 and 7 were recorded.

Overall, there was no indication of reduced pH of the tidal waters in close proximity to the outfall in comparison to those from locations out with of the potential influence of the discharge during 2017 monitoring. The temperatures recorded at pH_06 ranged between 18.3 and 19.1°C and overlapped with those at the reference site Nash Point (18.7 – 18.9°C).

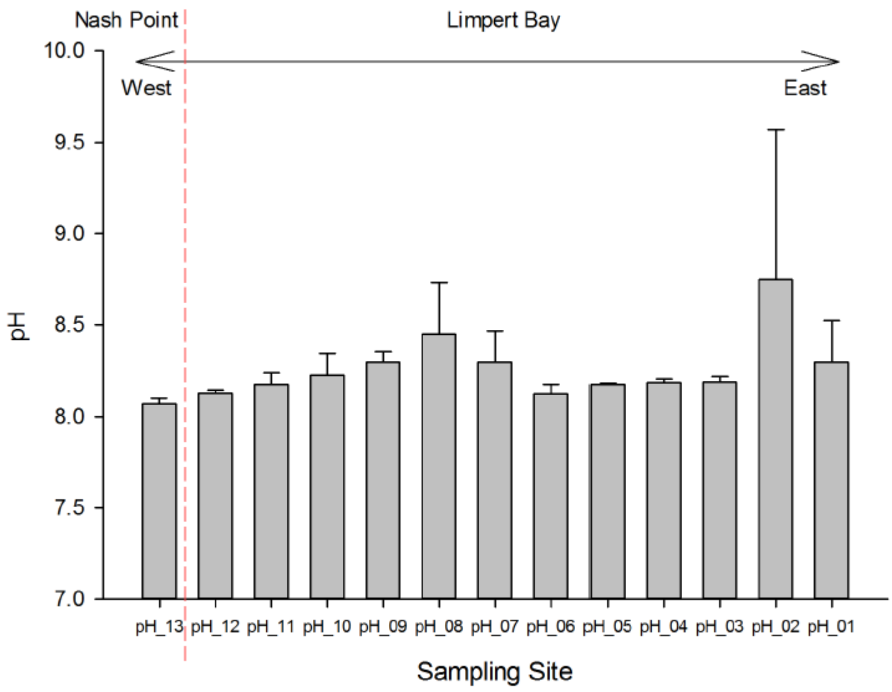

Figure 3.26 : Mean pH readings across Limpert Bay and at Nash Point (n = 2, ± St.Dev) sampled in July and August 2017. The outfall structures lie between sampling sites pH_05 and pH_06, and pH_04.

3.5 Additional field observations

The following observations were also recorded during the 2017 monitoring campaign:

- High numbers of starfish (*Asterias rubens*) were observed across the beds during low tide at Nash Point in July and August 2017.
- The opportunistic macroalgae species *Ulva lactuca* was abundant across much of Limpert Bay and Nash Point in 2017.
- Low numbers of *Mytilus edulis* were observed across the bed at Nash Point, but none were recorded during the *S. alveolata* bed assessment surveys at Limpert Bay.
- Calcareous algae *Corallina* sp. was recorded across both sites, and had a high coverage within large shallow pools. This species was under-represented in the data as such microhabitats were avoided when situating quadrats. Similarly, these pools provide refuge for other species of macroalgae and gastropods as well as gobies and carideans (shrimps and prawns).
- The invasive and non-native species (INNS) *Sargassum muticum* was observed (as in the previous year) along the rock pools within the ledges, towards the eastern side of the outfall structures (Figure 3.27).

Figure 3.27 : *Sargassum muticum* in pools connected to the eastern outfall structure, August 2016.

4. Discussion

The aim of the 2017 monitoring campaign was to assess the distribution and condition of the benthic communities that characterise Limpert Bay, and to determine if any spatial and temporal variations identified were attributable to the changing pH conditions of the discharge at Aberthaw Power Station.

4.1 Station operation and potential effects

Discharges containing acids and alkalis can affect the pH of seawater; however, the natural buffering capacity of seawater ensures that levels can return relatively quickly and such variations are likely to be local to the point of release. The potential effects of a change in pH in the marine environment may include: the potential for the release of CO_2, influence on the speciation and toxicity of substances and direct and indirect lethal and sub-lethal effects on marine organisms (review in Jacobs, 2016a).

The pH of the Bristol Channel/Severn Estuary remains fairly constant, ranging between 8 and 8.2 (Ellis, 2003). From the modelling data it was concluded that there would be little difference in the predicted surface pH of a lower discharge pH limit of 5.6, and that it would be limited to the immediate vicinity of the outfall, with values ≤7 within 350 m (Jacobs, 2016a). The physico-chemical data collected in July and August 2017 when the station was not generating showed no differences in the pH of the tidal waters between the sampling sites by the outfall and from the remote locations in the bay, and at Nash Point, with averages ranging between 8.07 and 8.75 overall. This was in contrast to data collected during the trial period in 2016 where values proximal to the outfall were lower and between 6.5 to 7 where the station was working up to 74% load factor.

Station operation in the last 12 months has been variable with higher generating activity during the winter months, and no activity during the summer months (Table 1.1). The reduced generating activity during the summer months translated into no significant spatial variation in the pH values recorded during July and August 2017, with the tidal waters sampled at the outfall reflecting ambient conditions of sites further afield. As such, the current assessment of the condition of the benthic communities across Limpert Bay has taken into consideration the reduced potential impact of the discharge since the termination of the trial period in July 2016.

4.2 Benthic communities

The distribution of intertidal benthic fauna and macroalgae of the two study sites are shown to be representative of those assemblages expected to naturally inhabit the sun and wave exposed northern shores of the Bristol Channel. The intertidal assemblages as determined from the transect assessments exhibited clear spatial distribution patterns. Distinctions between the upper, mid and lower shore communities are mainly attributable to natural zonation patterns driven by scales of exposure, insolation, desiccation and biological competition (see Jacobs, 2016a for statistical analysis between shore heights). The assessments at Limpert Bay have largely corroborated Bamber’s (1997) historic description where fucoids, coralline algae, *Ulva lactuca* and gastropod and barnacle fauna characterise the shore and with localised changes in structure, with distance from the outfall and as a result of natural influences. They are also in alignment with historic transects across the Bristol Channel and Severn Estuary, undertaken by Mettam (1994) where biota were characteristic of communities inhabiting a coastline that has a gradient of shifting salinities and exposure.

It was evident that within each tidal band there was spatial variation in the species complement across Limpert Bay and notably in comparison to Nash Point; however, this degree of spatial variability differed between shore levels. Across the mid shore at Limpert Bay communities overlapped, all characterised by an abundance of fucoid algae cover and gastropod grazers, whereas at the reference site of Nash Point, algal cover was reduced and barnacles and *Nucella lapillus* were dominant. The 2017 data complemented the 2015-2016 assessments that also showed this spatial distinction between the two study sites across the mid tide level.

This community level distinction between Limpert Bay and Nash Point was also evident in part for the upper and lower shore assessments, but with some similarities with the western communities at LW at Limpert Bay. The upper shores at Nash Point and at LW were abundant in barnacles and had little or no algal cover, compared to the upper shore sites towards the east that supported patches of *Fucus spiralis*. Both Limpert Bay and the reference site Nash Point are located along the exposed region of the Bristol Channel, and although both are south-facing, Limpert as a bay affords some protection compared to Nash Point (Mettam, 1994). As such it may be expected that within the more exposed upper and mid shore platforms at Nash Point, large brown fucoid species would give way to encrusting lower profile species; a typical distribution pattern of wave-exposed shores in the North-East Atlantic (Burrows *et al.,* 2008).

Across the lower shore sites of Nash Point and LW, communities had a higher percentage cover of *S. alveolata* and the seaweed *Cladostephus spongiosus* compared to the sites by the outfall (e.g. EO and LE). In Jacobs (2016a), the notable absence of *C. spongiosus* and lower coverage of *S. alveolata* at the low shore transect sites by the outfall was discussed in relation to potential natural variables. The additional data collected from 1 m^2 quadrats across all beds mapped at Limpert Bay in 2017 (see Appendix O) has demonstrated that *C. spongiosus* was more widely distributed across Limpert Bay than previously recorded. This species was recorded from beds 3, 5, 6 and 9, in addition to beds 11 and 12 that correspond to the transect lines LW and NP. The higher percentage cover of *S. alveolata* (determined from 0.25 m^2 quadrats) at Nash Point was representative of the greater degree of landward extent of the beds at this site and in the western half of Limpert Bay, in comparison to the narrower beds that lie just below transect lines EO and LW. The extent, formation type and associated benthic communities of the *S. alveolata* colonies is discussed further in section 4.3 below.

Bamber (1997) reported that in the vicinity of the outfalls at Aberthaw, growth of fucoid algae and *Ulva lactuca* was poor and that they were replaced by encrusting coralline algae as the dominant algal species. In August 2016 and 2017 at EO *Fucus serratus* and *Fucus vesiculosus* were the characterising species and *U. lactuca* also observed as present. The calcareous algal species *Corallina* sp. was also observed across the rock pools at Limpert Bay and so their abundance will be under reported here, as rockpools were not sampled by the quadrats. If historically, and during this current assessment period, the reduced pH conditions were of ecological significance to communities under influence of the outfall, then calcareous algae such as *Corallina* sp. would be likely absent as calctic species have been shown to reduce their coverage along a decreasing pH gradient (Porzio *et al.,* 2011).

The introduction of the INNS brown algae *Sargassum muticum* has been shown to have a negative impact on the local indigenous fucoid algae, but with no impact on calcareous algae such as *Corallina* sp. (Stær *et al.,* 2000). This INNS was recorded as present immediately to the east of the outfall structures (Figure 3.27) and not recorded in the quadrats, because as with *Corallina* sp. this species also inhabits and dominates the rock pools along the rocky ledges. *S. muticum* had not been reported by Bamber in 1997, suggesting a relatively recent establishment in the area. Its range extends north of Limpert Bay and in the Irish Sea, with a large increase in its occurrence since its introduction in the 1970s (Yesson *et al.,* 2015; Bunker *et al.,* 2012). Under artificial conditions the congeneric species *Sargassum vulgare* can be abundant under lower acidities (Porzio *et al.,* 2011). If any lower pH conditions have occurred within close proximity to the outfalls, it may be expected that *S. muticum* would exhibit a similar degree of tolerance, and as its growth is positively correlated with summer temperatures it is unsurprising to observe it within the localised warmer waters of the outfall. *S. muticum* is also known to compete with *S. alveolata* (review by Gibb *et al.,* 2014). However, as this alga is restricted to the large rock pools, this will naturally limit its extent across the shore.

Temporal changes in the communities between August 2016 and 2017 were observed across the upper and lower shores. The upper shores across much of Limpert Bay are a mosaic of sandy and muddy deposits, cobbles, boulders and bedrock which will support a more diverse range of infaunal and epifaunal species. Communities at the upper reaches of EO in 2017 had shown an increase in *Littorina littorea* and the tube dwelling *Lanice conchilega*. *L. conchilega* has been commonly recorded at this site in the 2015-2016 surveys (Jacobs, 2016a) and a reported increase may be related to its patchy distribution within the finer sediments that are common across this upper shore area (see Figure 3.1). *L. littorea* is a highly mobile species, and movement of a population may occur in warmer months (MarLin, 2016). Burrows *et al.* (2008) observed that if algal detritus collects in between boulders and cobbles, these crevices can support high densities of periwinkles which utilise the detrital material. The health of the sampled *L. littorea* populations (as determined from CI values) across the two study sites is discussed in Section 4.4

Across the lower shore, there had been no temporal differences between the 2016 and 2017 communities, at any of the sites, except at LE where in 2017 lower numbers of gastropods, but higher cover of *S. alveolata*, was reported. This variation may be in part owing to sampling across the upper fringes of bed 1 that lies below transect LE, but also the western extension of bed 2 that may have encroached the transect area (see Figure

3.10). *P. vulgata* will be expected to be absent or reduced where *S. alveolata* colonies dominate, due to the local reduction in suitable substrata for settlement and establishment.

4.3 *Sabellaria alveolata* colonies

Successful recruitment and development of *S. alveolata* across an intertidal environment is heavily dependent upon local geomorphological and hydrological conditions. A hard substratum and strong water movements coupled with an adequate supply of sand promote tube construction (Allen *et al.,* 2002); these environmental conditions characterise the tide-swept shores of both Limpert Bay and neighbouring Nash Point.

The *S. alveolata* mapping assessments in 2017 have corroborated the previous assessments of 2015-2016 where extensive beds remain prominent across the western areas of Limpert Bay, and with this habitat still persisting to the east of the bay, albeit in narrower bands (beds 1 to 3). The historic NRW biotope surveys (2003), had shown a narrower extent on the western side and an absence of this feature to the east of the outfall structures. This temporal difference indicates a substantial increase in abundance and distribution of *S. alveolata* over a decadal period and so precludes the consideration that successful establishment of this organism across Limpert Bay is restricted by the discharge. To the west of bed 1, further colonies were exposed lower down the shore (see Figure 3.14 and Figure 3.15). These were not mapped due to tidal conditions at time of the observations, but it is recommended that in any future surveys, these areas be mapped on the lowest possible tide to determine the western extent of these narrower beds.

Changes in reef morphology can occur over a period of 10 years with the structure of the reef itself evolving in cycles of settlement, growth, destruction and new growth (Allen *et al.,* 2002). In 2017, additional data were collected to look at variation in the formation and health of these colonies. The data collected reflect historic surveys in the Bristol Channel that describes some intertidal reefs as poorly developed or eroded under algal canopies, and across Limpert Bay as colonised crusts over rock (Mettam, 1994). More recent assessments had observed them to be of reasonable quality, with a mixture of low crusts, 'ball' formations and small reefs (Innogy, 2003). An abundance scale, as described by Bush (2015), was applied in 2017, and characterised the distribution of these colonies in 2017 as ranging between 'Common' and 'Abundant' (see Appendix D), with the tubes a mosaic of mainly crisp or worn apertures. As with the 2015-2016 surveys, there was no elevated reef formations present across either Limpert Bay or Nash Point (e.g. 'Super-Abundant'), with ball (hummock) and large encrusting sheet formations featuring as the dominant type.

Biogenic reefs are regarded as important in locally increasing habitat complexity and thus the potential ecological niches that can be exploited by other organisms. Results of the 1 m^2 quadrat assessments in 2017 found that the biotic communities associated with each bed mapped across Limpert Bay was biologically indistinct from one another, and there was only disparity from the reference site reported. This departure was due to reduced cover of *F. serratus* and higher abundances of *N. lapillus* at Nash Point, and this result overlaps with the transect assessments where lower algal cover was apparent due to wave exposure (as discussed in section 4.2) and greater populations of *N. lapillus* supported by greater resource availability (discussed further in section 4.3).

S. alveolata is sensitive to a suite of anthropogenic stressors. These may include smothering by or starvation from sediment via changes in sedimentary regimes or from mussel cultivation and direct physical disturbance (e.g. trampling) (Plicanti *et al.,* 2016; review by Noernberg *et al.,* 2010). However, recovery rates of *S. alveolata* following physical disturbance have been shown to be rapid, indicating a possible high resilience to such pressures (review by Gibb *et al.,* 2014). However, there is still insufficient information available in the current scientific literature to determine with absolute certainty the sensitivity of *S. alveolata* to changes in pH. Studies conducted on its congener Ross worm (*Sabellaria spinulosa*) have indicated a tolerance to a wide range of conditions, providing suitable substratum is available (Jackson, 2008). For example, a dominance of *S. spinulosa* was reported by an outfall location, where the discharge reached levels as low as pH 4 (Hoare and Hiscock, 1974). As this subtidal species shares similar life strategies to *S. alveolata* it may be assumed that they will have comparable levels of tolerances. Despite the limited information available on the sensitivity of Sabellariidae worms to changing water chemistry Bamber and Irving (1997) reported higher growth of *S. alveolata* tubes by a cooling water discharge over winter where temperatures were raised by 8-10 °C, compared to at a control site.

These current data reported here have supported the conclusion that in the UK, *S. alveolata* has high persistence, and where populations have settled on suitable habitat these will generally persist through time and with broad-scale stability in SACFOR abundance and form (Bush, 2015). However, anthropogenic impacts and wider effects of extreme weather events (e.g. harsh winters) remain of concern. It is important that for any future monitoring work, the appropriate level of assessment is undertaken to assess if any changes to the colonies are linked to wider ecological trends, or if they are a result of power station activity.

4.4 Gastropod mollusc populations

Shelled molluscs are susceptive to reduced pH conditions; however, the effect of acidification is highly variable among species and even within the same species (see Gazeau *et al.,* 2013 for review). Behaviour, metabolism, recruitment, calcification and immune response are all biological processes that are impacted by reductions in pH and as such variation in pH may potentially lead to increased mortality. Alterations in behaviour and physiological responses are mechanisms that individuals can use to acclimate and compensate to shifting conditions (Davies, 1966; Bibby et al., 2007, Langer et al., 2014). However, an organism's ability to acclimate to shifting conditions are limited and once certain thresholds of tolerance are reached detrimental impacts on the population may be observed.

Gastropod molluscs are widely distributed across Limpert Bay, with an abundance of grazing limpets, periwinkles and trochids across all shore levels and carnivorous dogwhelks towards the lower margins. *Patella vulgata* and *Littorina littorea* are important bioengineers on the shore; often considered keystone species as their grazing regulates algal growth on the hard substratum (Hawkins *et al*., 1983, Lubchenco, 1983). Additionally, *L. littorea* has been noted as a highly suitable bio-indicator species of the marine environment due to its higher tolerance to contaminants (Bauer *et al*., 1995 and Van den Broeck *et al*., 2009). The distribution and variation within gastropod populations across Limpert Bay will be influenced by a multitude of interacting biotic and abiotic factors, including any potential influences from the Power Station.

Community analysis reported higher abundances of *P. vulgata* at the mid and upper shore of the reference site Nash Point than across Limpert Bay in August 2016 and 2017. Although higher abundances were reported there, these populations were found to be statistically significantly smaller in size. This demographical disparity between the two study sites may be a natural function of increase exposure at Nash Point. Literature suggests that limpets have been found to be smaller yet more numerous at more wave-exposed sites, though variation in food sources may also be an important influence on these populations (review by Burrows *et al.,* 2008).

The highest mean CI values for *P. vulgata* in August were observed at sites closest to the outfall at Limpert Bay (EO and LE) in both 2016 and 2017 and not at the reference site. This pattern was also apparent for *L. littorina*, where the highest mean CI values were observed at LE across both years. During station operation, higher temperature, lower pH conditions and higher heavy metal concentrations (e.g. mercury) would be expected within Limpert Bay, with the extremes of these conditions located closest to the outfall (Jacobs, 2016b). Gastropod populations in closest proximity to the outfall could directly or indirectly benefit from the thermal plume, whereby the plume provides a buffering effect against the seasonal decline in sea temperature (and potential cessation in growth) (Jacobs, 2016b). Considering the temporal and spatial variation in CI across all sites, any decreases in pH from the outfall has so far had no tangible detrimental effect on *P. vulgata* and *L. littorea,* and any variation observed can be attributed to natural fluctuations.

Bamber (1997) reported an absence of *Nucella lapillus* in the locality of the outfall, and this is concurrent with the 2017 and the 2015-2016 assessments where none were recorded within the 0.25 m^2 quadrats at all shore levels at EO and LE (except a single juvenile at LE mid in August 2017). Subsequent community analysis had reported *N. lapillus* to be a characterising species at HO, LW and at the reference site NP. In April 2017, timed searches were conducted across the four transect sites of Limpert Bay, during collection of *N. lapillus* to assess the viability of the natural population present for removal as requirement of the evaluation of metal uptake in biota (Jacobs, 2017). Although there was no statistically significant difference between all four sites based on five replicate 3-minute timed searches (see MarClim, 2008 for methodologies), the highest mean number collected per search was from LW (87.4 individuals) and the lowest by the outfall at EO (61 individuals). A sub-sample of these individuals that had been collected had also been measured and extracted from their shells prior to tissue analysis for CI interpretation, and it was found that the population sampled from EO had significantly higher CI than the other four populations sampled (One-Way ANOVA, $p < 0.05$); a result mirroring that for *P. vulgata* and *L. littorea* in this study*. N. lapillus* and other mobile gastropods are gregarious in nature so a recorded absence may also be compounded by any smaller scale distribution patterns. However, the broad distribution patterns may be related to exposure and resource exploitation. The higher numbers of dogwhelks at Nash Point and at the more exposed outer areas of Limpert Bay (LW, HO), mirrors the higher abundance of barnacles (notably at NP); barnacles are an important and common food source for these carnivorous gastropods (Crowthers, 1985).

5. Conclusions

- The benthic communities across Limpert Bay and at the reference site Nash Point, as determined from the transect assessments, are reflective of the natural environmental conditions experienced across the two sites. Variations between the two sites were characterised by greater abundances of barnacles and dogwhelks, and lower fucoid cover at the reference site. Barnacles are a primary prey group for dogwhelks and increased exposure favours smaller sized organisms and prevents establishment of large algae species such as fucoids. The variations observed can be attributed to the naturally differing conditions (e.g. exposure, substratum type)..
- Limpert Bay supports extensive colonies of *Sabellaria alveolata* across the lower shore, with a notable landward extension of these beds on the western side of the bay. The beds mapped in 2017 are reflective of those mapped in the initial pH variation assessments of 2015 -2016, with evidence of developing tubes on the large areas of sandy deposits that interrupt the beds, within the western area of the bay.
- The beds to the east of the outfall and towards the old (redundant) outfall structures, though narrow, show a greater than previously recorded horizontal extent. It is recommended that any future monitoring of these areas is conducted at low water to maximise the data collected, as these beds have historically been recorded as absent by NRW.
- Across Limpert Bay, the type of colonies ranged between patchy sheet-like crusts up to ball-like hummock forms. Where continuous uninterrupted forms were present these formed reefs of low elevations (<20cm height). This range in formations was also reflected at the area of bed mapped at the reference site Nash Point. An absence of large elevated classic ‘reef’ like structures at both Limpert Bay and Nash Point may be reflective of the degree of exposure at these locations. These formations mirror historic descriptions of *S. alveolata* in this region of the Bristol Channel.
- There was no significant spatial difference in the benthic flora and fauna associated with *S. alveolata* colonies across Limpert Bay. The opportunistic macroalgae species *Ulva lactuca* was widespread across all beds, with the low shore fucoid *Fucus serratus* also commonly recorded. However, there were higher relative abundances of *N. lapillus* and lower abundances of *F. serratus* recorded at the reference site; a result concurrent with the community data determined from the quadrat assessments.
- Populations of periwinkles and limpets revealed some spatial variation in their health in both August 2016 and August 2017, with a general pattern of higher CI values at sites adjacent to the outfall. This may be a consequence of the effects of the thermal plume buffering the seasonal influence of colder winters on growth rates.
- Overall, it is considered that there are no ecological significant variations between the distribution, abundance and overall condition of the intertidal benthic communities as monitored in 2017 to those recorded 2015-2016. As such, it is considered that the communities are reflecting both natural variability and any local and established patterns relating to the discharge from the power station, and not from any variation in its pH conditions.

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Appendix A. Historic NRW *S. alveolata* biotopes (2004)

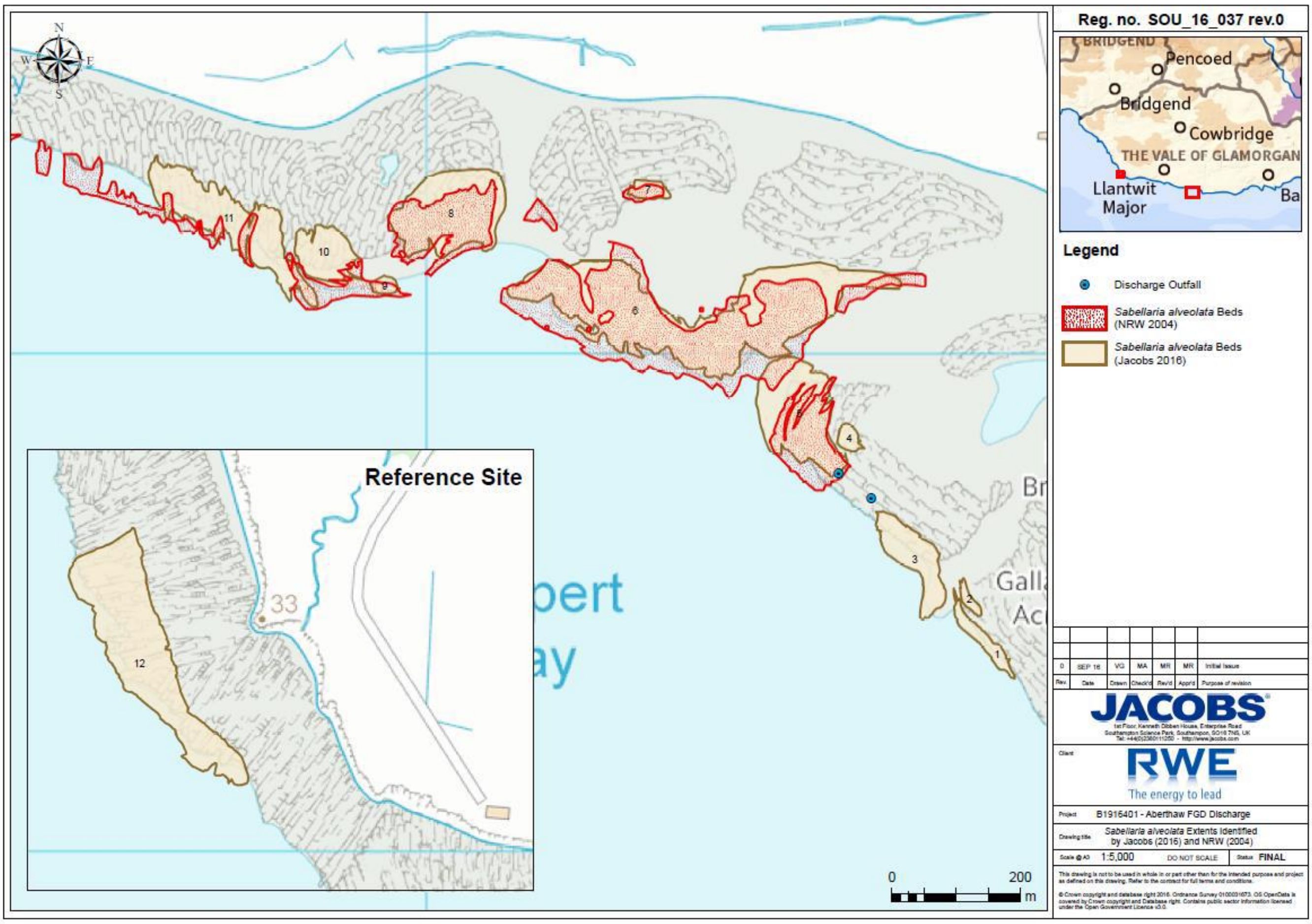


Figure A.1 : Historic *Sabellaria alveolata* LS.LBR.SabSalv biotope (indicated in red) as mapped by NRW (2004) across Limpert Bay, overlaid by the 2015-2016 pH variation study (Jacobs 2016a) shown in yellow at Limpert Bay and at the Reference Site (Nash Point).

Appendix B. Target transect positions

Table B.1 : Target transect positions at Limpert Bay and at the reference sites, Nash Point.

Shore	Transect	Shore Elevation	NGR
Limpert Bay	**HO -** Historic Outfall	Upper	ST 02391 65645
		Mid	ST 02406 65541
		Low	ST 02469 65438
	LE - Limpert East	Upper	ST 02125 65719
		Mid	ST 01932 65616
		Low	ST 01882 65564
	EO - East Outfall	Upper	ST 02073 65996
		Mid	ST 01857 65819
		Low	ST 01775 65746
	LW - Limpert West	Upper	ST 00840 66316
		Mid	ST 00827 66205
		Low	ST 00799 66106
Reference Site	**NP -** Nash Point	Upper	SS 91440 68371
		Mid	SS 91335 68314
		Low	SS 91295 68269

Appendix C. Survey dates

Table C.1 : Survey dates between November, 2015 (pre-trial monitoring period) and August, 2017 (post- trial monitoring period). Surveys undertaken, and tidal conditions are also listed. * Avonmouth tide tables.

Survey dates	Benthic Community Assessments	*S. alveolata* bed assessments	Gastropod health assessments	Physico-chemical water quality	pH Trial phase	Season	Spring Low water conditions*
24.11.2015 – 25.11.2015	•	•	•		Pre-trial period	Autumn ‘15	1.0 – 1.5 m
08.03.2016 – 09.03.2016	•	•	•	•	Trial period	Spring (post Winter) ‘16	0.6 – 1 m
06.04.2016 – 07.04.2016	•	•	•	•	Trial period	Spring ‘16	0.4 – 0.9 m
05.05.2016 – 06.05.2016	•	•	•	•	Trial period	Spring ‘16	0.5 – 1 m
03.08.2016 – 04.08.2016	•	•	•	•	Post-trial period	Summer ‘16	0.8 – 1.6 m
22.08.2016 – 23.08.2016		•		•	Post-trial period	Summer ‘16	1.3 – 1.6 m
24.07.2017 – 26.07.2017		•		•	Post-trial period	Summer ‘17	0.6 – 0.8 m
21.08.20017 – 23.08.2017	•	• (bed 1 only)	•	•	Post-trial period	Summer ‘17	0.4 – 0.9 m

Appendix D. Modified SACFOR scale for *S. alveolata*

Table D.1 : Comparison and standardisation of several categorical scales for measuring the abundance of *Sabellaria alveolata* and biogenic reefs. 'SACFOR' = modified from the MNCR SACFOR scale. 'Type' = used by Natural England and Natural Resources Wales (previously CCW), related to SACFOR abundances by size and coverage 'Reef'= defines a reef, corresponding to 'Common' to 'Superabundant' categories. 'PA' = presence /absence data (review by Bush, 2015).

SACFOR		Type		Reef		PA
Superabundant (7)	Massive reefs 2-3 ft thick. >50% cover at maximum abundance.	Type 1	Individual reefs <10 m^2, generally >30 cm height (always >10 cm). >90% coverage.	Reef-forming (2)	Solid, massive structures. Clearly forming a substantial, discrete community or habitat.	Present (1)
		Type 2	Individual reefs >10 m^2, and >30 cm height. >90% coverage.			
Abundant (6)	Hummocks >1 ft. across. >20% cover at maximum abundance.	Type 3	>10 m^2 patchy area. Reef[s] >10 cm diameter/height >50% coverage.			
		Type 4	>10 m^2 very patchy area. Reef[s] >10 cm diameter/height 20-50% coverage			
Common (5)	Large sheets or patches. No large hummocks.	Type 5	>10 m^2 extremely patchy area. Recognisable area of proper reef. Reef[s] >10 cm diameter/height <20% coverage			
		Type 6	Low lying patches/areas			
Freq-uent (4)	Many individuals. Small patches.	Type 7	Low lying, heavily silted and predominantly dead areas	Non-reef-forming (Encrusting) (1)	Not as above (i.e. sparse cover, isolated small patches or individuals)	
Occas-ional (3)	Scattered individuals. No patches					
Ra-re (2)	<10 found in search					
Remains (1)	No living individuals found. Tube remains present	-	-	Assumed Absent (0)	-	Assumed Absent (0)
Not Seen (0)	None found.					

Appendix E. Statistical glossary

E.1 Multivariate statistical analysis in PRIMER v6

Plymouth Routines In Multivariate Ecological Research (PRIMER) (www.primer-e.com) is a program designed to analyse datasets where samples contain several variables. The following descriptions of the various procedures and tests used for the data analysis (E.1.1 to E.1.6 below) are all summaries of the full descriptions provided in the PRIMER manual (Clarke and Warwick, 2001). The full manuals should be consulted for detailed descriptions of each test undertaken.

E.1.1 Transformation of data in PRIMER

Data transformation is used to remove the weighting of common or rare species within a sample when undertaking statistical analysis. The type of transformation used depends on the biological (not statistical) questions being asked of a dataset and whether a broad or specific approach is required. The more severe the transformation, the broader the answer as all species become more equal, thus giving a greater weighting to species with low abundances.

For analysis in PRIMER, 4th Root transformation was selected for the multivariate analysis of the community data.

E.1.2 Bray-Curtis similarity

Before any of the analyses can be undertaken in PRIMER a similarity matrix must be constructed. This creates a matrix containing a value for every pairwise (between species) comparison possible between the samples. The higher the value the more similar the comparison is. This matrix is used for comparison of samples in subsequent statistical tests. PRIMER uses the Bray-Curtis coefficient (S') which is particularly common in ecological analyses.

E.1.3 ANOSIM

Analysis of Similarity (ANOSIM) tests are a form of hypothesis testing for differences between pre-defined groups e.g. sites/times of sampling. ANOSIM tests can be applied to multivariate datasets and are not restricted to balanced designs i.e. equal numbers of replicate samples within sites or treatments or both.

ANOSIM tests provide two results; R-values and *p*-values. Of these two values, R is often the most useful to use for interpreting the data as it is not affected by the number of replicates but by actual differences between the two or more groups of data. On the other hand, *p* is always influenced by the sample size and might mask confidence in the results obtained from smaller datasets.

R-values lie between -1 and 1. R = 1 only when all replicates within groups are more similar to one another than any replicates from different groups. R = 0 when similarities between all replicates regardless of groupings are the same on average.

- $0.75 < R < 1$ - highly different
- $0.5 < R < 0.75$ - different
- $0.25 < R < 0.5$ - different with some overlap
- $0.1 < R < 0.25$ - similar with some differences (or high overlap)
- $R < 0.1$ - similar

E.1.4 Multi-dimensional scaling

Multi-dimensional Scaling (MDS) plots provide a visual representation of the relationships between samples and can be useful for data interpretation. The Bray-Curtis similarity matrix described above can be used to create a multi-dimensional scaling (MDS) plot of the sample similarities. Samples with greater similarities are placed closer to one another with more dissimilar samples placed further away.

The usefulness of the plots is indicated by a stress value. If stress values in a 2-D plot are too high, a 3-D plot can be generated which might provide a better representation as there is more dimensional space in which to plot the samples and their relative distances to each other. Stress values should be considered as follows:

- <0.05 – excellent representation of the relationships between the data;
- <0.1 – good plot with little prospect of a misleading interpretation;
- <0.2 – potentially useful although for values toward the upper end of this range too much emphasis should not be placed on the detail of the plot;
- 0.2 – 0.3 – treat these points with scepticism and consider plots at higher dimensions;
- >0.3 – the points are close to random. Consider plots at higher dimensions.

E.1.5 Cluster and SIMPROF analysis

Cluster analysis aims to find “natural groupings” of samples by carrying out a simple agglomerative, hierarchical clustering, where the output is a dendogram, displaying groupings of samples. This routine can be run alongside the ‘similarity profile’ (SIMPROF) permutation test which looks for statistically significant evidence of genuine clusters in samples. If in the test results there are samples connected by red lines, then they cannot be significantly differentiated.

E.1.6 SIMPER analysis

When differences have been detected between groups of samples, Similarity Percentage (SIMPER) tests can be used to determine the individual species that contribute to the differences between groups of samples and the similarities between samples within a group. The SIMPER test identifies species that typify a group and/or potentially an environmental condition or impact.

E.2 Univariate statistical analysis in SigmaPlot

E.2.1 Two-Way ANOVA test

Analysis of Variances (ANOVA) is a parametric test that is used to test whether the mean of more than two groups are equal (e.g. sampling sites). It assumes a normal data distribution and equality of variances. If these assumptions are not met, the level of significance is increased to $p < 0.01$ from $p < 0.05$ to reduce the risk of a Type I error.

E.2.2 Holm-Sidak Pairwise comparison test

Holm-Sidak Pairwise comparison test can be used as a post hoc ANOVA test. If a significant effect is detected following ANOVA, then the pairwise comparison test will be undertaken to reveal where there is a significant difference between pairs of samples (e.g. sites). It is more powerful than the Tukey and Bonferroni tests and, consequently, is able to detect differences that these other tests do not. When performing the test, the *p*-values of all comparisons are computed and ordered from smallest to largest. Each *p*-value is then compared to a critical level that depends upon the significance level of the test (set in the test options), the rank of the *p*-value, and the total number of comparisons made. A *p*-value less than the critical level indicates there is a significant difference between the corresponding two groups

Appendix F. Upper shore taxa – quadrat data 2015-2017

Table F.1 : Upper shore taxa recorded across all sites between November 2015 and August 2017. Taxa are ranked alphabetically within each of their major taxonomic groupings.

Taxa			
CNIDARIA	**MOLLUSCA - Polyplacophora**	**ALGAE - Rhodophyta**	**LICHEN**
ACTINIARIA	POLYPLACOPHORA	*Catenella caespitosa*	*Verrucaria maura*
Anemonia viridis		*Chondrus crispus*	
	MOLLUSCA - Bivalvia	*Corallina* sp.	**OTHER**
ANNELIDA	*Mytilus edulis*	*Lithophyllum*	*Anurida maritima*
Arenciola marina	*Mytilus edulis* #juv	*Porphyra* sp.	
Lanice conchilega			
Phyllodocidae indet.	**MOLLUSCA - Gastropoda**	**ALGAE - Phaeophyceae**	
Serpulidae indet.	*Gibbula* #juv	Brown algae mats indet.	
Spirorbinae indet.	*Gibbula* sp.	*Fucus* sp. indet	
	Littorina #juv	*Fucus spiralis*	
CRUSTACEA	*Littorina* #spat	*Fucus vesiculosus*	
Carcinus maenas	*Littorina fabalis*	*Pelvetia canaliculata*	
Carcinus maenas #juv	*Littorina littorea*		
CARIDEA indet	*Littorina obtusata*	**ALGAE - Chlorophyta**	
CIRRIPEDIA	*Littorina saxatilis*	Dark Green encr.	
CIRRIPEDIA #spat	*Nucella lapillus*	*Prasiola* sp.	
Crangon sp.	*Patella* #juv	*Ulva intestinalis*	
GAMMARIDEA	*Patella* spp.	*Ulva lactuca*	
	Phorcus lineatus		

Appendix G. Upper shore communities 2015-2017

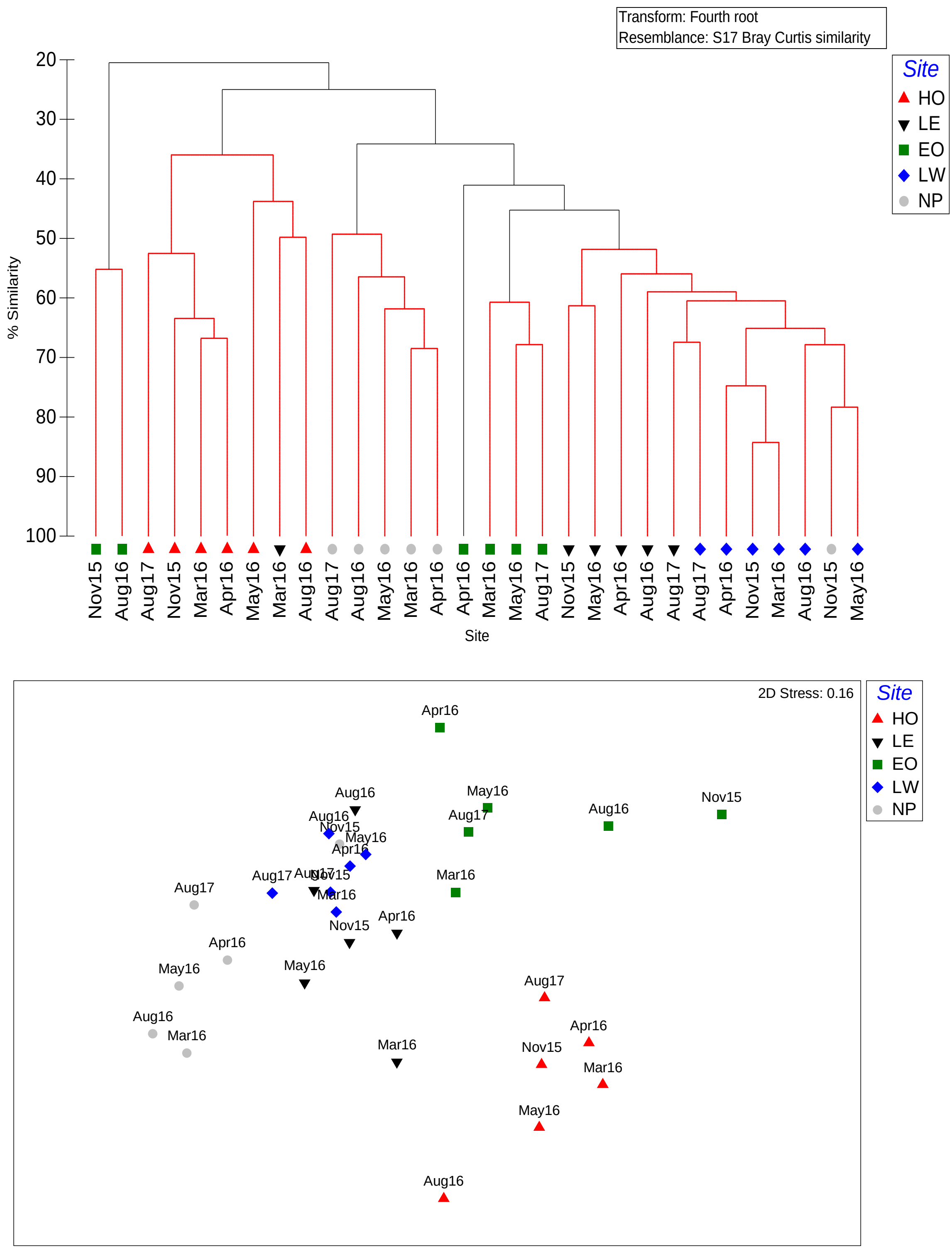


Figure G.1 : Above: Multivariate analysis of communities sampled across the upper shore sites assessed between November 2015 and August 2017 (4th root transformed mean abundance data with Bray-Curtis similarities), with dashed lines on the dendogram indicating those communities not significantly different from one another (SIMPROF, *p* = >0.05). Below: a two-dimensional MDS plot also represented (stress = 0.16).

Appendix H. Mid shore taxa – quadrat data 2015-2017

Table H.1 : Mid shore taxa recorded across all sites between November 2015 and August 2017. Taxa are ranked alphabetically within each of their major taxonomic groupings

TAXA			
PORIFERA	**MOLLUSCA - Polyplacophora**	**ALGAE - Rhodophyta**	**LICHEN**
Porifera	POLYPLACOPHORA	*Catenella caespitosa*	*Verrucaria mucosa*
		Chondrus crispus	
CNIDARIA	**MOLLUSCA - Bivalvia**	*Corallina* sp.	**OTHER**
ACTINIARIA	*Mytilus edulis* #juv	*Lithophyllum*	*Anurida maritima*
Anemonia viridis		*Osmundea pinnatifida*	
	MOLLUSCA - Gastropoda		
ANNELIDA	*Gibbula* #juv	**ALGAE - Phaeophyceae**	
Lanice conchilega	*Gibbula* sp.	*Ascophyllum nodosum*	
Phyllodocidae indet.	*Littorina* #juv	Brown algae mats indet.	
Sabellaria alveolata	*Littorina fabalis*	*Fucus serratus*	
	Littorina littorea	*Fucus* sp. indet	
CRUSTACEA	*Littorina obtusata*	*Fucus spiralis*	
Carcinus maenas	*Littorina saxatilis*	*Fucus vesiculosus*	
CIRRIPEDIA	*Nucella* #juv		
CIRRIPEDIA #cyprid	*Nucella lapillus*		
CIRRIPEDIA #spat	*Patella* #juv		
GAMMARIDEA	*Patella* spp.		
Idotea sp.	*Phorcus lineatus*		
ISOPODA	*Tritia reticulata*		
Portuninae #juv			

Appendix I. Mid shore benthic communities 2015-2017

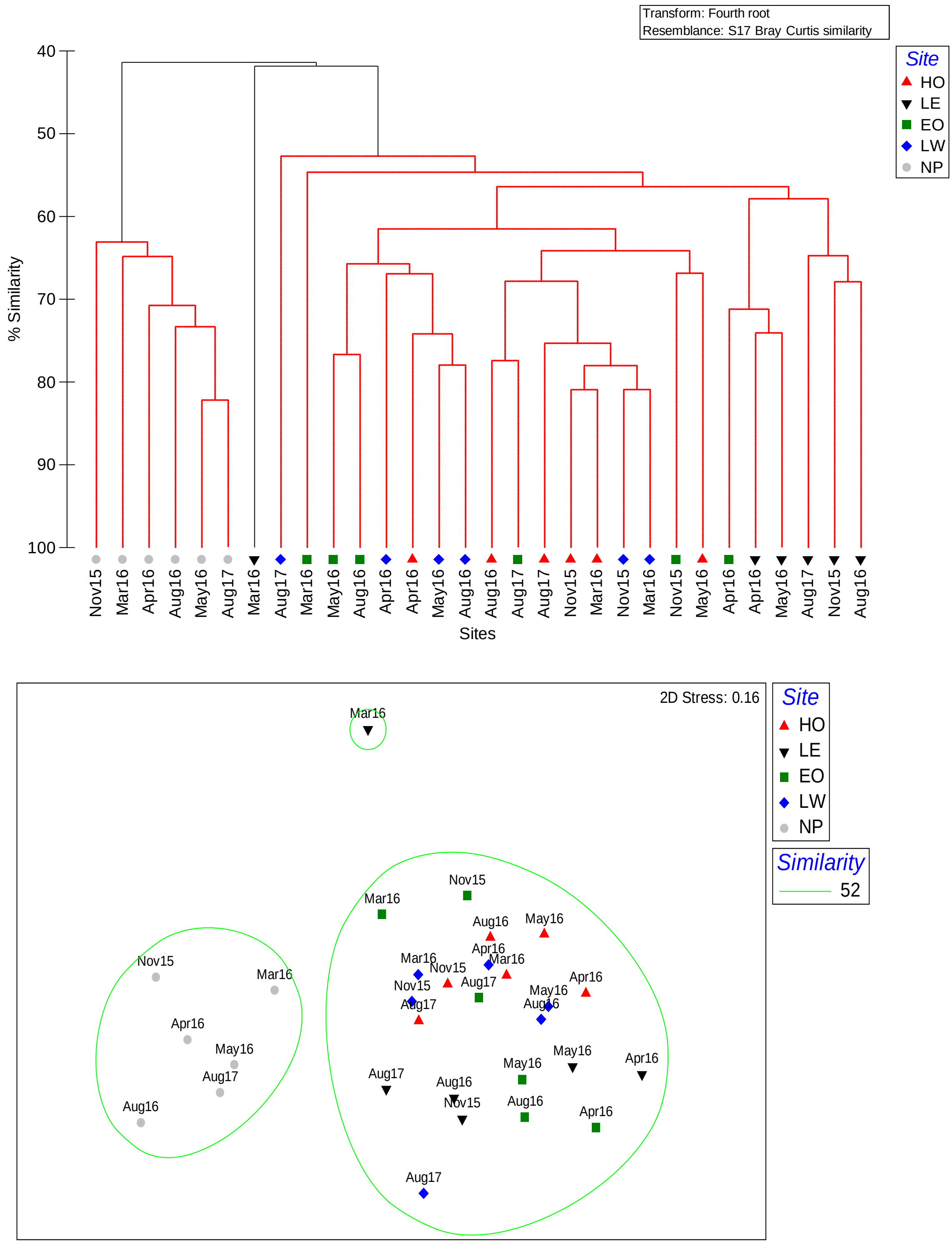


Figure I.1 :Above: multivariate analysis of communities sampled across the mid shore sites assessed between November 2015 and August 2017 (4th root transformed mean abundance data with Bray-Curtis similarities), with dashed lines on the dendogram indicating those communities not significantly different from one another (SIMPROF, *p* = >0.05). Below: two-dimensional MDS plot represented with the similarity clusters at 52% shown (stress = 0.16).

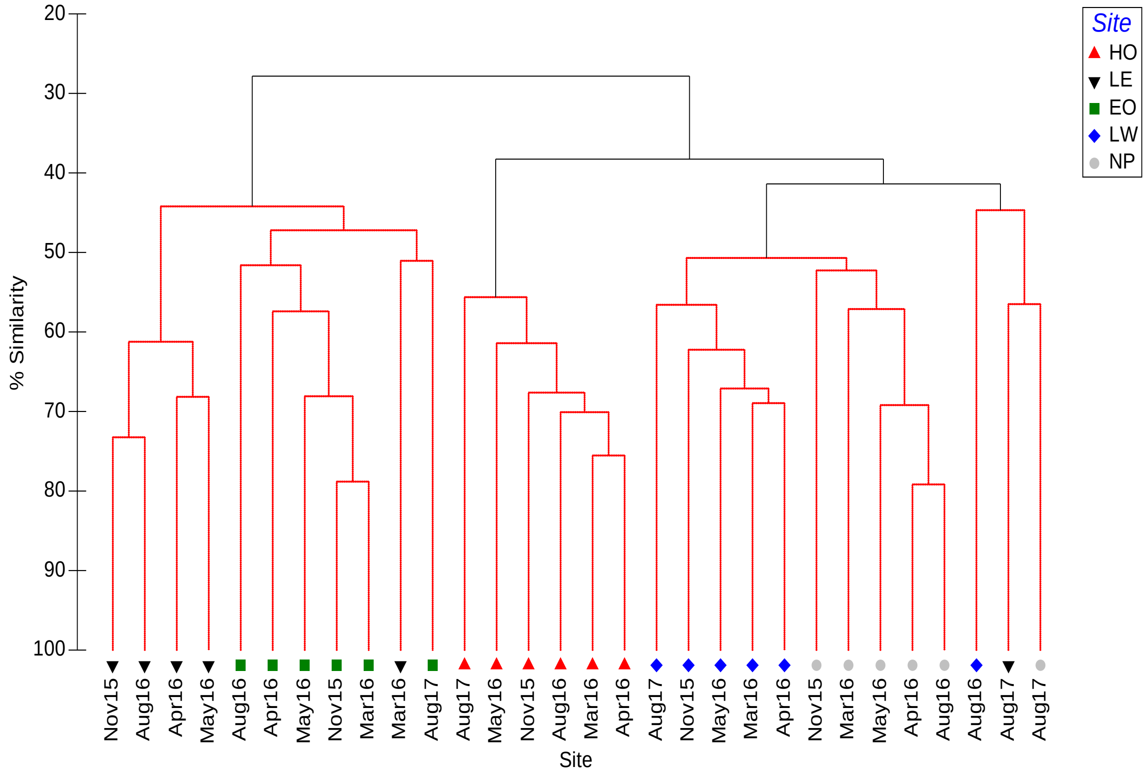
JACOBS

Appendix J. Low shore taxa – quadrat data 2015 – 2017

Table J.1 : Low shore taxa recorded across all sites between November 2015 and August 2017. Taxa are ranked alphabetically within each of their major taxonomic groupings

Taxa			
PORIFERA	**MOLLUSCA - Bivalvia**	**ALGAE - Rhodophyta**	**LICHEN**
Halichondria sp.	*Barnea candida*	*Catenella caespitosa*	*Verrucaria mucosa*
PORIFERA	Mytilus edulis #juv	*Chondrus crispus*	
		Corallina sp.	
CNIDARIA	**MOLLUSCA - Gastropoda**	*Dumontia contorta*	
ACTINIARIA	*Capulus ungaricus*	Fine filamentous red indet.	
Anemonia viridis	*Gibbula* #juv	*Hildenbrandia rubra*	
HYDROZOA	*Gibbula* sp.	*Lithophyllum*	
	Littorina #juv	*Osmundea pinnatifida*	
ANNELIDA	*Littorina littorea*	*Polysiphonia* spp	
Lanice conchilega	*Littorina obtusata*	*Porphyra* sp.	
Phyllodocidae indet.	*Nucella* #juv		
POLYCHAETA indet	*Nucella lapillus*	**ALGAE - Phaeophyceae**	
Sabellaria alveolata	*Patella* #juv	*Cladostephus spongiosus*	
Serpulidae indet.	*Patella* spp.	*Fucus serratus*	
Spirorbinae indet.	*Tritia reticulata*	*Fucus* sp. indet	
		Fucus vesiculosus	
CRUSTACEA	**BRYOZOA**		
Cancer pagurus	*Electra pilosa*	**ALGAE - Chlorophyta**	
Cancer pagurus #juv		*Cladophora* spp.	
Carcinus maenas	**ECHINODERMATA**	Dark Green encr.	
Carcinus maenas #juv	*Asterias rubens*	*Prasiola* sp.	
CIRRIPEDIA		*Ulva intestinalis*	
CIRRIPEDIA #spat	**PISCES**	*Ulva lactuca*	
GAMMARIDEA	Gobiidae		
ISOPODA			
Paguridae indet.			

Appendix K. Low shore benthic communities 2015-2017



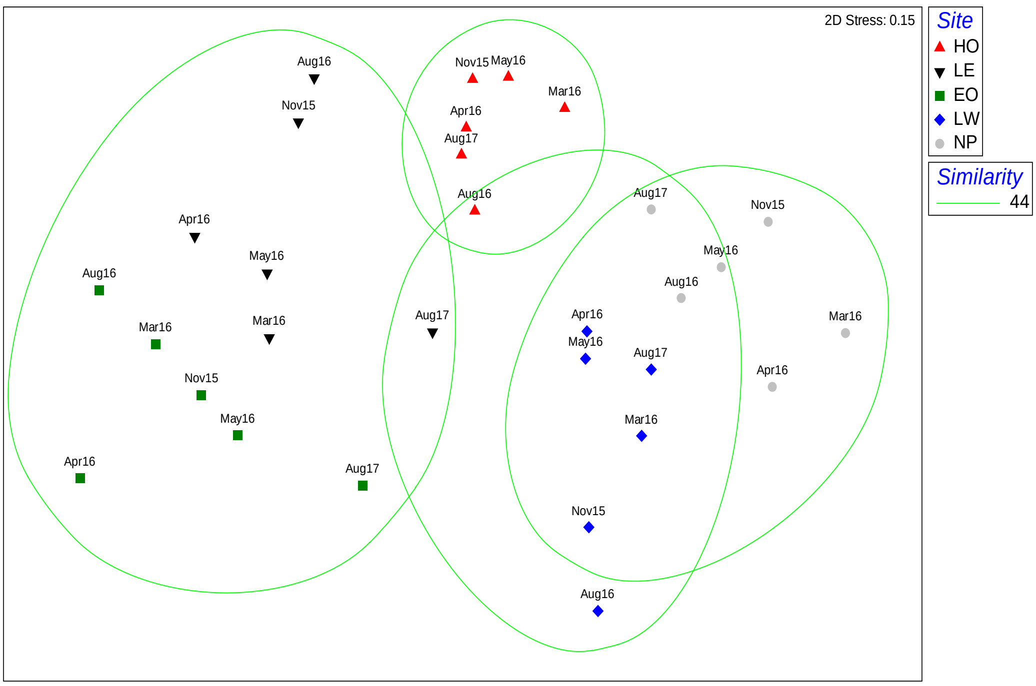


Figure K.1 : Above: Multivariate analysis of communities sampled across the low shore sites assessed between November 2015 and August 2017 (4th root transformed mean abundance data with Bray-Curtis similarities), with dashed lines on the dendogram indicating those communities not significantly different from one another (SIMPROF, *p* = >0.05). Below:a two-dimensional MDS plot represented with the similarity clusters at 44% shown (stress = 0.15).

Appendix L. *Sabellaria alveolata* beds east of outfall structures

Bed Number Location	Approx. Coverage and SACFOR	Description	Images
Bed 1 Gallant Acre	0.25 ha (2016) **SACFOR: 'Common' ('Type 5') to 'Abundant' ('Type 4')**	**Thin sheets** along a distinct, thin continuous band on the rock ledges. The formations are a mixture of encrusting and poorer growths less than 10 cm height, under *F. serratus* and *F. vesiculosus,* and red algae **Hummocks** in the western area, increased elevations with up to 20 cm in height under fucoids	 **July 2017** – looking east across top of bed, lower part of bed covered by tide  **Aug 2017** – looking west across lower part of bed exposed by tide  **Aug 2016** – looking east lower part of bed exposed by tide  **Aug 2017** –Quadrat 1A  **Aug 2017** –Quadrat 1B

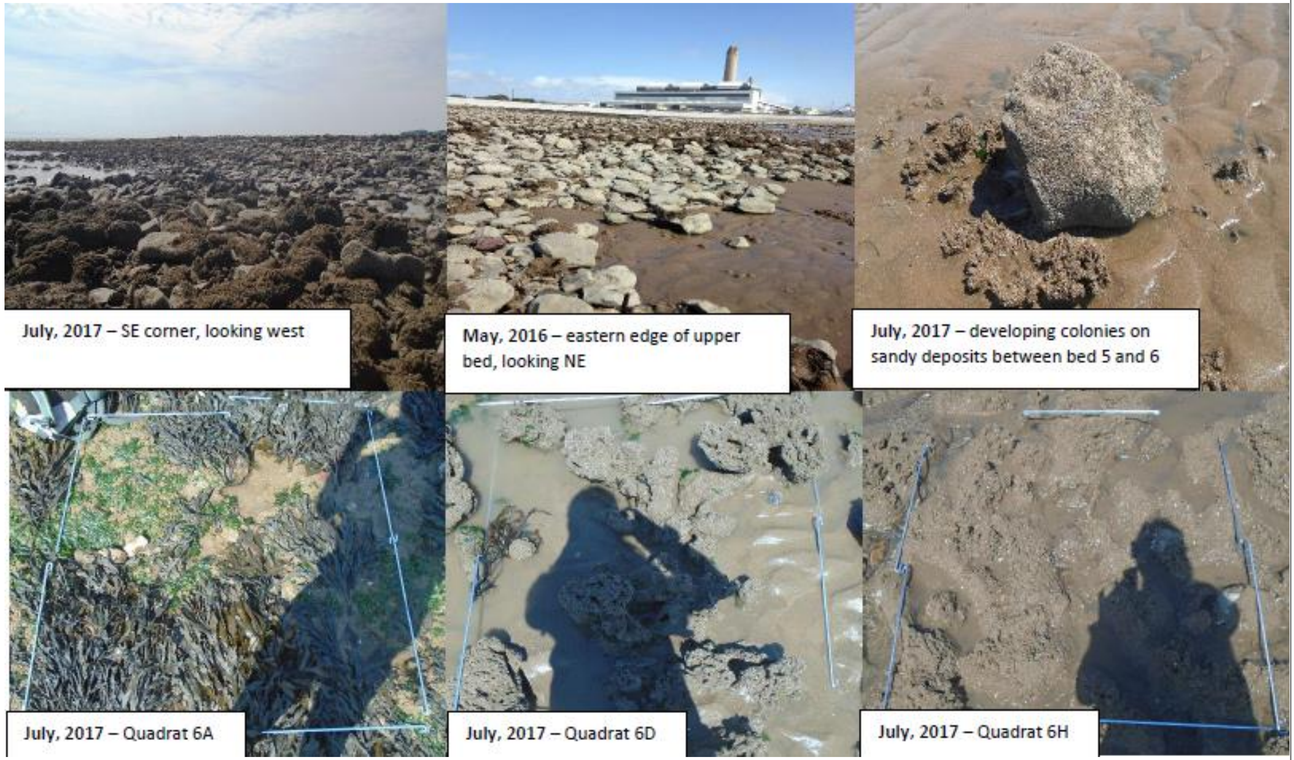
Bed Number Location	Approx. Coverage and SACFOR	Description	Images
Bed 2 Gallant Acre (above bed 1)	0.08 ha (2016) **SACFOR: 'Common' ('Type 5')**	Small area of **sheets** and **patchy** formations of low mounds and thin crusts. Of lower elevation that for bed 1. On bedrock under *F. serratus* and *F. vesiculosus.* *S. muticum* present in rock pools.	 July 2017 – looking west across bed  Aug 2016 looking east across bed  July 2017 – Quadrat 2A

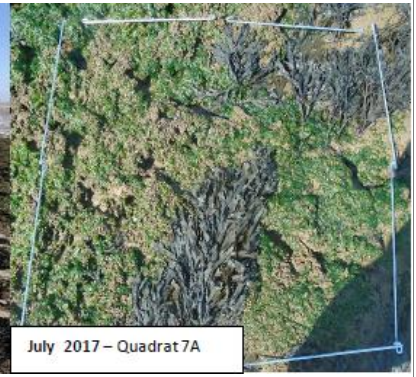
Bed Number Location	Approx. Coverage and SACFOR	Description	Images
Bed 3 East of eastern outfall (at Transect EO)	0.74 ha (2016) **SACFOR: 'Common' ('Type 5') to 'Abundant' ('Type 4'**	A large bed comprising a lower part and upper part, demarked by ridge Lower part is **hummocks** 25-30 cm in height and low mounds on cobbles under *F. serratus.* Upper part is a **sheet**, lower encrusting that the lower part of the bed, but in part continuous on a wide bedrock platform, under dense fucoids. Swathes of *S. muticum* in pools connected to sea.	 **July 2017** – looking south across western edge of of bed along eastern outfall channel **Aug 2016** – looking NW across western edge of bed along eastern outfall channel **Aug 2017** – Quadrat 3C **Aug 2017** – Quadrat 3D

Appendix M. *Sabellaria alveolata* beds west of outfall structures

Bed Number Location	Approx. Coverage and SACFOR	Description	Images
Bed 4 Immediately north west of western OF structure	0.11 ha (2016) **SACFOR: 'Common' ('Type 6)**	Small **sheet** bed with low growths < 5 cm in height on exposed rocky platform, under fucoids.	 July 2017 – looking south to western OF structure  May, 2016 – looking north from western OF structure  Aug 2017 – Quadrat 4A

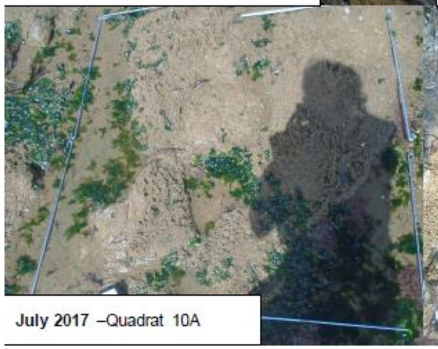
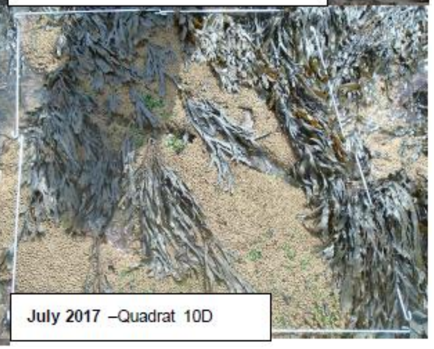
Bed 5 Immediately west of western OF structure	1.64 ha (2016) **SACFOR: 'Common' ('Type 5'') To 'Abundant ('Type 3')**	Large continuous bed, but interrupted by rows of large boulders. Low growth **hummocks** on boulders and bedrock on upper area, under fucoid algae. By outfall ball shaped **hummocks** apparent <15-20 cm in height. Mixtures of **sheet** formations and **hummocks** but with continuous **low reef** formations apparent. Western edge of bed meets a large expanse of sandy deposits.	 July 2017 – eastern edge of bed by western OF structure  July 2017 –looking SE towards western OF structure  July 2017 – looking NW  May 2016 – looking west along northern edge of bed  March 2016 – looking west  July 2017 – quadrat 5C  July 2017 – quadrat 5E

Bed 6 West of sandy deposits and the OF structures	4.91 ha (2016) **SACFOR: 'Common' ('Type 6') to Abundant ('Type 4')**	Very large bed but discontinuous, in-dispersed with boulders in upper zones with a **Patchy** distribution < 10cm height. Lower zone with denser aggregations of **hummocks** < 15 cm in height under macroalaae (*Fucus* spp., *U. lactuca*) in tide swept platform. Western edge of bed meets a large area of sandy deposits.	 July, 2017 – SE corner, looking west May, 2016 – eastern edge of upper bed, looking NE July, 2017 – developing colonies on sandy deposits between bed 5 and 6 July, 2017 – Quadrat 6A July, 2017 – Quadrat 6D July, 2017 – Quadrat 6H

Bed 7 Landward of bed 6 and east of culvert.	0.14 ha (2016) **SACFOR: 'Common' ('Type 6')**	Small **sheet** bed situated towards the upper shore, on bedrock, under moderate fucoid cover and *Ulva lactuca*.	 July 2017 – looking west  May 2016 – looking east along northern edge of bed  July 2017 – Quadrat 7A

Bed 8 West of outfall and west of large area of sandy deposits	1.89 ha (2016) **SACFOR: 'Common' ('Type 5') to 'Abundant' ('Type 3')**	A large bed comprising both **sheets** and **hummock** (< 15 cm in height) with continuous uninterrupted low elevated **reef** formations on rocky platforms and boulders. Dense fucoid cover on upper areas and *U. lactuca* also common throughout.	 July 2017 – lower bed looking west  May 2016 – looking north up the shore from the eastern side of bed along northern edge of bed  Aug 2016 –upper western areas of bed looking NE up shore  July 2017 – Quadrat 8A  July 2017 – Quadrat 8B  July 2017 – Quadrat 8C

Bed 9 Southwest of bed 8	0.09 ha **SACFOR: 'Common' ('Type 6')**	Small **sheet** like bed, with low encrusting colonies under *F. serratus* and *U. lactuca.* Connection to Bed 10 in the west.	 July 2017 –looking east towards bed  July 2017 –Quadrat 9A

Bed 10 East of transect line LW	0.64 ha (2016) **SACFOR: 'Common' ('Type 5') to 'Abundant '(Type 4').**	Upper area is a **sheet** with abraded low structures on bedrock, but interspersed with boulders. **Hummocks** within the lower area, fucoid on tide-swept fissures and bedrock. Connection to bed 9 in the east.	 July 2017 –looking east along bed  Aug 2016 –looking west towards bed  July 2017 –Quadrat 10A  July 2017 –Quadrat 10D

Bed 11 Eastern edge is located on transect LW	1.75 ha (2016) **SACFOR: 'Common' ('Type 6') to 'Abundant' ('Type 4')**	A very large bed that extends westwards, interrupted at the lower shore by narrow sandy gullies. **Sheet** formations common along eastern area, under fucoid algae and *U. lactuca.* **Hummocks** common along western areas < 10 cm in height under fucoid algae.	 July 2017 –looking NW along bed  April 2016 –western areas of lower bed looking west  July 2017 – Quadrat 11A  July 2017 – Quadrat 11D

Bed 12 Nash Point, reference site	3.25 ha (2016) **SACFOR: 'Common' ('Type 5') to 'Abundant' ('Type 3')**	**Sheets** of low elevation on broken platforms of the lower shore under algae and sponges. **Hummocks** throughout the middle area, with ball morphologies present (< 20 cm height) and with variable coverages including **patchy** formations. In gullies, and more sheltered areas larger formation area present and are abundant in *Nucella lapillus*. Dominant algae include *Cladostephus spongiosus* and *Osmundea pinnatifida.*	 July 2017 –looking west along bed  July 2017 –looking east along the bed  July 2016 –looking south down the bed  July 2017 –Quadrat 12B  July 2017 –Quadrat 12  August, 2016 –*Mytilus edulis* juveniles

Appendix N. *Sabellaria alveolata* quadrat assessments 2017

Figure N.1 : *Sabellaria alveolata* quadrat assessment locations undertaken at Limpert Bay and at the reference site Nash Point, July- August 2017.

Appendix O. *Sabellaria alveolata* bed communities

Table O.1 : Total number of taxa recorded within each bed, and the taxa recorded across the quadrats within each bed. Taxa are listed taxonomically. Site LB = Limpert Bay and NP = Nash Point.

Site:		LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	LB	NP
Bed:		1	2	3	4	5	6	7	8	9	10	11	12
Total Number of taxa per bed:		**6**	**6**	**11**	**8**	**21**	**22**	**4**	**5**	**6**	**14**	**19**	**21**
Number of quadrats assessed:		2	1	4	1	6	10	1	3	1	4	4	6
Taxa													
Porifera	PORIFERA												
Cnidaria - Hydrozoa	HYDROZOA												
Cnidaria - Hydrozoa	ACTINIARIA												
Annelida - Polychaeta	Phyllodocidae indet.												
	Sabellaria alveolata												
	Lanice conchilega												
	Serpulidae indet.												
Arthropoda	CIRRIPEDIA												
	GAMMARIDEA #tubes												
Mollusc - Gastropod	*Gibbula* sp.												
	Patella spp.												
	Littorina littorea												
	Nucella lapillus												
	Tritia reticulata												
Bryozoa	*Alcyonidium diaphanum*												
	Electra pilosa												
Echinodermata	*Asterias rubens*												
PISCES	Gobiidae												
Rhodophyta	*Porphyra* sp.												
	Palmaria palmata												
	Corallina sp.												
	Lithophyllum												
	Chondrus crispus												
	Membranoptera alata												
	Osmundea pinnatifida												
	Polysiphonia spp.												
Phaeophycea	*Cladostephus spongiosus*												
	Fucus sp. indet												
	Fucus serratus												
	Fucus vesiculosus												
	Pelvetia canaliculata												
Chlorophyta	*Ulva lactuca*												
Lichen	*Verrucaria mucosa*												

Appendix P. Raw physico-chemical Data 2016

Table P.1 : Raw physico-chemical data collected between March 2016 and August 2016. Sites pH_01 to pH_12 are located at Limpert Bay, and pH_13 at the reference sites Nash Point (see map in Figure 2.1).

Site	Timestamp	Temp (C)	Cond (mS/cm)	Salinity	DO (%)	DO (mg/L)	pH	NGR
pH_01	03/08/2016 12:14	17.38	n/a	28.62	100.31	8.0977497	7.86	ST 02382 65411
pH_01	05/05/2016 10:43	11.91	31.564	26.976	113.388	10.334756	8.03	ST 02390 65379
pH_01	06/04/2016 10:32	9.25	29.207	26.631	108.225	10.479204	7.92	ST 02422 65474
pH_02	03/08/2016 12:55	18.72	n/a	30.284	94.1254	7.3313437	7.92	ST 01928 65510
pH_02	05/05/2016 11:17	12.56	33.463	28.278	135.321	12.0645	7.84	ST 01918 65507
pH_02	06/04/2016 12:02	13.71	33.506	27.474	98.6915	8.6332569	7.77	ST 01904 65525
pH_02	08/03/2016 11:01	12.34	32.628	27.659	105.756	9.5094795	7.44	ST 01899 65523
pH_03	03/08/2016 13:13	18.80	n/a	30.513	93.6912	7.2766309	8	ST 01798 65650
pH_03	22/08/2016 16:03	18.7	40.45	29.87	91.5	7.15	8.05	ST 01778 65617
pH_03	05/05/2016 11:53	15.22	35.499	28.176	104.181	8.7997007	7.49	ST 01798 65650
pH_03	06/04/2016 12:16	16.25	34.918	26.952	93.0582	7.7570286	7.57	ST 01795 65650
pH_03	08/03/2016 11:16	14.25	33.394	26.993	95.0748	8.249568	7.36	ST 01790 65642
pH_04	03/08/2016 13:58	18.49	n/a	31.421	96.0581	7.4647102	7.55	ST 01757 65709
pH_04	22/08/2016 16:21	18.7	40.249	29.7	107.8	8.43	8.14	ST 01726 65700
pH_04	05/05/2016 12:12	18.64	37.838	27.784	102.406	8.10921	7.35	ST 01762 65715
pH_04	06/04/2016 12:29	14.11	33.763	27.425	105.8	9.1831999	8.1	ST 01769 65714
pH_04	08/03/2016 11:32	11.19	31.282	27.231	109.278	10.098494	8.29	ST 01761 65719
pH_05	03/08/2016 14:44	18.29	n/a	33.028	95.0964	7.3465247	7.53	ST 01613 65845
pH_05	22/08/2016 16:38	19.3	41.435	30.26	98.6	7.6	8.31	ST 01612 65842
pH_05	05/05/2016 12:30	21.27	39.277	27.214	95.5379	7.2277231	6.79	ST 01627 65823
pH_05	06/04/2016 12:52	17.88	36.025	26.798	109.157	8.8214951	7.02	ST 01635 65835
pH_05	08/03/2016 11:56	16.20	34.208	26.382	91.9068	7.6954517	6.78	ST 01624 65835
pH_06	03/08/2016 14:10	18.68	n/a	29.792	92.4071	7.2241726	7.71	ST 01684 65861
pH_06	22/08/2016 16:34	19.7	39.102	28.09	103.5	8.02	7.99	ST 01675 65857
pH_06	05/05/2016 12:22	21.43	39.316	27.142	96.7043	7.2978692	7.02	ST 01681 65858
pH_06	06/04/2016 12:42	19.80	37.167	26.493	98.3756	7.6803765	6.69	ST 01677 65853
pH_06	08/03/2016 11:41	17.62	35.044	26.157	98.7285	8.0500345	6.56	ST 01677 65852
pH_07	03/08/2016 14:51	16.94	n/a	30.995	99.8293	8.011323	7.78	ST 01582 65951
pH_07	05/05/2016 12:57	19.24	38.082	27.585	110.712	8.6790819	7.36	ST 01556 65879
pH_07	06/04/2016 13:01	14.01	33.516	27.271	104.016	9.0544281	7.6	ST 01573 65870
pH_07	08/03/2016 12:06	15.75	33.839	26.365	99.4738	8.4060192	7.29	ST 01569 65901
pH_08	03/08/2016 14:59	17.95	n/a	33.174	109.611	8.5150852	7.66	ST 01570 66046
pH_08	05/05/2016 13:22	21.63	41.119	28.393	108.44	8.0933924	8.55	ST 01572 66029
pH_08	06/04/2016 13:22	11.37	31.640	27.439	103.401	9.5051117	8.04	ST 01520 66008
pH_08	08/03/2016 12:20	9.50	29.766	26.998	106.019	10.181879	8.24	ST 01526 66022
pH_09	03/08/2016 15:40	18.93	n/a	30.063	94.1012	7.3107848	8.4	ST 01350 66241
pH_09	08/03/2016 14:28	8.24	28.242	26.398	108.563	10.768776	8.1	ST 01349 66264
pH_10	03/08/2016 15:18	18.03	n/a	31.829	93.5017	7.311235	8.14	ST 01158 66205
pH_10	05/05/2016 14:16	15.21	35.298	28.006	115.783	9.7909813	7.98	ST 01109 66236
pH_10	06/04/2016 14:04	11.05	29.199	25.331	100.81	9.4570732	8.02	ST 01100 66191
pH_10	08/03/2016 13:08	8.48	23.505	21.43	106.098	10.809468	8.1	ST 01097 66200
pH_11	03/08/2016 16:16	17.54	n/a	31.458	96.3798	7.6242003	7.76	ST 00816 66196
pH_11	05/05/2016 14:25	14.52	35.248	28.458	114.388	9.7815399	7.76	ST 00881 66166
pH_11	06/04/2016 14:24	10.64	31.465	27.823	101.34	9.4426937	8.19	ST 00871 66159
pH_11	08/03/2016 13:37	8.81	28.641	26.384	110.279	10.800058	8.52	ST 00861 66169
pH_12	04/08/2016 13:25	19.28	n/a	31.731	102.246	7.8132811	8.22	ST 00730 66181
pH_12	06/04/2016 14:43	9.85	25.573	22.624	104.142	10.206167	8.02	ST 00724 66232
pH_12	08/03/2016 13:54	7.78	27.806	26.293	107.268	10.760956	8.09	ST 00720 66214
pH_13	07/04/2016 13:40	9.13	31.088	28.626	104.737	10.038669	8.04	SS 91447 68149
pH_13	23/08/2016 17:27	19.2	43.140	31.68	98	7.5	8.03	SS 91350 68230
pH_13	06/05/2016 13:36	13.64	36.399	30.176	101.533	8.7477083	8.03	SS 91447 68149
pH_13	09/03/2016 11:50	7.38	29.638	28.535	105	10.476799	8.08	SS 91441 68143

Appendix Q. Raw physico-chemical Data 2017

Table Q.1 : Raw physico-chemical data collected between July 2017 and August 2017. Sites pH_01 to pH_12 are located at Limpert Bay, and pH_13 at the reference sites Nash Point (see map in Figure 2.1) Note: Salinity readings are not listed here as the instrument had failed the internal QA/QC checks for salinity.

Site	Timestamp	Temp(C)	Cond (mS/cm)	DO (%)	DO (mg/L)	pH (Units)	Latitude (WGS84)	Longitude (WGS84)
pH_01	25/07/2017 17:06	22.2	39.073	125.1	9.35	8.46	51.37921	-3.40459
pH_01	22/08/2017 13:30	19.5	35.588	101.4	8.01	8.14	51.379431	-3.40376
pH_02	25/07/2017 16:51	20.9	38.523	95.7	7.3	8.17	51.38085	-3.41169
pH_02	21/08/2017 14:46	24.1	41.472	165.3	11.9	9.33	51.380205	-3.410545
pH_03	25/07/2017 16:42	22.2	39.759	94.7	7.06	8.17	51.38111	-3.41202
pH_03	21/08/2017 15:01	20.4	38.563	139	10.68	8.21	51.381512	-3.412224
pH_04	25/07/2017 16:26	21.6	38.954	94.5	7.13	8.17	51.38165	-3.41303
pH_04	21/08/2017 15:08	20.6	38.641	99.3	7.62	8.2	51.382043	-3.412819
pH_05	25/07/2017 15:25	19.4	34.832	98.7	7.84	8.18	51.38261	-3.41483
pH_05	23/08/2017 12:46	18.5	37.299	110.5	8.79	8.17	51.383228	-3.414763
pH_06	25/07/2017 15:35	19.1	34.825	93.8	7.48	8.16	51.38292	-3.4143
pH_06	23/08/2017 12:43	18.3	36.834	111.4	8.9	8.09	51.383206	-3.414256
pH_07	25/07/2017 15:22	22.7	38.637	104.4	7.75	8.42	51.3829	-3.41609
pH_07	23/08/2017 12:52	18.6	33.384	101.3	8.2	8.18	51.38355	-3.415405
pH_08	24/07/2017 16:22	22.8	42.192	127	9.28	8.65	51.38525	-3.41649
pH_08	23/08/2017 12:59	19.5	37.502	101.1	7.91	8.25	51.385206	-3.414717
pH_09	24/07/2017 16:12	21.5	40.113	115.2	8.66	8.34	51.38521	-3.41929
pH_09	23/08/2017 13:10	18.8	37.784	112.6	8.9	8.26	51.38485	-3.419354
pH_10	24/07/2017 13:13	23.4	39.951	101.6	7.43	8.31	51.38585	-3.42277
pH_10	23/08/2017 13:18	19.1	33.561	97.5	7.82	8.14	51.386237	-3.421881
pH_11	24/07/2017 14:42	21.8	35.199	89.1	6.81	8.13	51.38516	-3.42635
pH_11	23/08/2017 13:30	19.2	35.887	117.7	9.33	8.22	51.385464	-3.42576
pH_12	24/07/2017 15:29	20.3	38.092	97.5	7.52	8.14	51.38602	-3.4287
pH_12	23/08/2017 13:36	18.9	37.139	97.8	7.74	8.12	51.385958	-3.428162
pH_13	26/07/2017 16:15	18.9	38.191	92.3	7.26	8.09	51.40233	-3.56303
pH_13	21/08/2017 13:19	18.7	38.048	100.3	7.93	8.05	51.401949	-3.562367