Aberthaw Power Station Cooling Water pH Variation

RWE Generation UK Plc

Environmental Report

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Contents

Executive Summary

Aberthaw Power Station 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 at low water near Breaksea Point. Due to possible changes in the coal feed to the station, it is anticipated that increased sulphur levels in the coal will result in a lowering of the pH of the discharge.

In advance of this, RWE are seeking a variation of their discharge conditions to accommodate the possible lowering of the pH of the discharge from a current instantaneous pH 5.8 to proposed pH 5.6. Through consultation, the Environment Agency agreed to a trial of a different coal feed for a limited period, subject to an agreed ecological monitoring programme being in place to inform any application for a permanent permit variation. This report presents the results of the desk and field based work to support the assessment of the ecology in the vicinity of the discharge, and in particular consideration of effects, if any, of the variation in discharge quality as a result of the trial.

Predictive modelling has indicated that an area of the intertidal to the east and north-east of the outfall may be potentially subjected to reduced pH conditions, although no difference in the current and proposed pH regimes is predicted to be evident beyond a distance of 350 m from the outfalls. The model predicted that the area potentially subjected to reduced pH conditions will be limited to the intertidal habitats in the immediate vicinity of the outfalls. The modelling predictions were also supported by the patterns of metal levels recorded in biota as part of the long term flue-gas desulphurisation (FGD) monitoring programme. Using this information it was concluded that an *in situ* assessment of the intertidal rocky shore communities of Limpert Bay would provide a suitable monitoring tool to enable identification of any potential effects as a result of the pH trial. The agreed programme of field work included an assessment of the intertidal rocky shore communities, an assessment of the 'health' (as measured by a condition index) of target gastropod species, and an assessment of the extent and features of the *Sabellaria alveolata* (honeycomb worm) beds, during the pre-trial (November 2015), trial, and post-trial periods (August 2016). A site at Nash Point was also monitored as a control.

Analysis of the resulting data showed that the temporal and spatial distribution of the intertidal rocky shore communities to be mainly attributable to natural physical and biological influences. Characteristic zonation patterns demarked the upper, mid and lower shore areas, and statistical analysis showed that physical exposure towards the outer areas of the shore was important for the horizontal spatial structuring of the communities. Lower species richness was recorded immediately east of the outfall (site EO), however, as there was no significant change reported during the trial period this was indicative of little influence of the varied discharge conditions.

Spatial and temporal differences were observed in the distribution patterns and health of the dominant gastropod populations (*Littorina littorea* (periwinkle) and *Patella vulgata* (limpet), however none were considered beyond that expected as a result of seasonal and physical fcators. Higher conditioning index values were reported for *L. littorea* at the site closest to the outfall, whereas the values for those populations remote to the discharge has showed a natural pattern of winter growth cessation had occurred. The influence of the thermal plume from the discharge was considered to be maintaining the values for those populations close to the outfall. For limpets there was a general temporal trend of increasing health of the populations across the site, with no patterns in relation to proximity to the outfall.

No observable changes were recorded in the extent or characteristics of the *S. alveolata* beds, both at Limpert Bay and at Nash Point, over the trial period. When compared with the historical data recorded Natural Resources Wales over a decade ago, these biotopes features remained identified as LS.LBR.Sab.Salv ('*Sabellaria alveolata on sand-abraded eulittoral rock*'). Some of the beds appear to have undergone horizontal extensions landward, and new beds appear to have developed immediately to the east of the outfall where the shore was previously dominated by fucoid algae (e.g. *Fucus serratus*). These changes probably reflect a period of favourable conditions and increased sand availability, allowing development of the beds into new areas.

The hydrodynamic modelling showed the important saline lagoon and saltmarshes habitats to the east of the station such to be subject to very limited influence of the varied discharged. During high-water spring conditions when water may be exchanged with these features, the predictive modelling showed the pH of the water adjacent to these habitats to exceed 8.01, which is well within the normal conditions experienced at present.

Overall, it is considered that the reduction in pH of the discharge from 5.8 to 5.6 during the trial had limited effects on the biota and habitats in the vicinity of the outfalls. The dispersive nature of the discharge plume into the wave swept exposed shores of Limpert Bay and the large dilution capacity provides an almost instant buffering and mixing of the discharge with the seawater. During periods of reduced tidal exchange/mixing, any zone of influence from the low pH conditions is likely to small and limited to an area immediately east of the outfall. The study has shown that the benthic communities in the study appear to be unaffected by the short term reduction of the pH of the discharge during the trial.

1. Introduction

1.1 Overview

Aberthaw Power Station 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 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). However, due to possible changes in the coal supply to the station, it is anticipated that increased sulphur levels in the coal will result in a lowering of the pH of the discharge.

In advance of this, RWE are seeking a variation of their discharge conditions to accommodate the possible lowering of the pH of the discharge. The current permit allows for an instantaneous pH of 5.8, with the proposed variation seeking a reduction of this to 5.6. Through consultation, the Environment Agency agreed to a trial of a different coal feed and hence a lowered pH for a limited period (Jan-July 2016), subject to an agreed ecological monitoring programme being in place to inform any application for a permanent permit variation.

This report presents the results of the field and desk based work to support the ecological assessment of potential effects resulting from the trial variation of the discharge.

1.2 Study Aims and Objectives

The aim of the study was to complete an ecological assessment of the receiving environment, identifying the likely key receptors, including fish, invertebrate biota, and designated sites and associated features, and the potential effects associated with a variation in the pH of the discharge. In achieving the study objectives, the following tasks have been undertaken:

1. Identification of the **baseline conditions** of the area and surrounding environment, identifying potential marine ecological receptors (Section 2).

2. A **targeted field assessment** of the key marine benthic receptors most likely to be impacted by the variation in the discharge, and to include pre-trial, trial and post-trial conditions (Section 3 to 5).

3. **Identification and assessment of potential effects** using both the evidence collated during the desk based review and the field studies (Section 6).

2. Baseline Conditions

2.1 Statutory Designations

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

2.1.1 Severn Estuary SAC

The station is located 16 km to the west of the Severn Estuary Special Area of Conservation (SAC), which includes five Habitats Directive Annex I habitat types, three of which are primary reasons for site designation, including:

- Estuaries;
- Mudflats and sandflats not covered by seawater at low tide; and
- Atlantic sea meadows.

Two further Annex 1 habitat types which are present, but do not qualify as primary reasons for site designation, include:

- Sandbanks which are slightly covered by seawater all the time; and
- Reefs.

Annex II species that are a primary reason for designation of the site include:

- Sea lamprey (*Petromyzon marinus*);
- River lamprey (*Lampeta fluviatilis*); and
- Twaite shad (*Alosa fallax*).

The Annex II species, Atlantic salmon (*Salmo salar*), is also listed, though is not a primary reason for the site designation. It is, however, a primary reason for SAC designation of both the rivers Wye and Usk, and fish migrating to and from these sites will migrate through the Severn Estuary and Bristol Channel.

2.1.2 Severn Estuary SPA

The site is also located to the west of the Severn Estuary Special Protection (SPA), designated under the EC Directive on the Conservation of Wild Birds. The site supports an internationally important population of the Annex I species Bewick's swan (*Cygnus columbianus bewickii*) and also of the European white-fronted goose (*Anser albifrons*), dunlin (*Calidris alpina alpine*), redshank (*Tringa tetanus*), shelduck (*Tadorna tadorna*), curlew (*Numenius aquata*) and pintail (*Anas acuta*). The site is also important for the ringed plover (*Charadrius hiaticula*) on passage during its winter migration.

2.2 Non-statutory sites of interest

2.2.1 Aberthaw lagoon

The Aberthaw saline lagoon which is approximately 1.67 ha in size is situated to the east of the power station (3°22'W, 52°25'N). The lagoon is of a habitat type that is listed as a priority SAC Annex I habitat, but the site has not been selected as an SAC site owing to its artificial nature. It is, however, only one of four habitats of this type in Wales. The lagoon supports a population of *Ecrobia ventrosa* (mud snail) which is classified as a Species of Conservation Concern (SoCC) and included in the Draft Habitats and Species of Principle Importance for Wales.

2.2.2 Other sites

The station is also adjacent to the East Aberthaw coast Site of Special Scientific Interest (SSSI).

2.3 Benthic Habitats and Species

The seabed in the upper Bristol Channel and lower Severn Estuary are predominantly hard, with rock outcrops and areas of clean sand or mixed sand/gravel. Muddy habitats are present in the shallow sublittoral zone between Cardiff and Newport, and extensively off Bridgwater Bay. The hard substrates support an impoverished fauna characterised by the anemone *Sagartia troglodytes* and amphipod *Gammarus zaddachi,* while the muddy substrates also support an impoverished community characterised by polychaete worms species such as the cirratulid *Aphelochaeta marioni* and the tube building grapple worm *Melinna* sp. (Warwick and Davies, 1977).

In the sublittoral zone off Aberthaw the exposed rock and hard gravelly sediment supports a community characterised by the honeycomb worm *Sabellaria alveolata,* the polychaetes *Eulalia tripunctata* and *Syllis armillaris,* and the bivalve *Sphenia binghami* (Mettam *et al.,* 1994). These impoverished communities are a result of the naturally high turbidity which restricts light penetration, the variable or low salinity conditions and the strong tidal currents.

The intertidal zone in the vicinity of Aberthaw is predominantly formed of rock pavements, ledges, and outcrops, but also with a range of other habitats, including sandflats, shingle ridges, sand dunes, saltmarshes and a saline lagoon. The rocky shore intertidal communities are characterised by macroalgae such as *Fucus serratus, Fucus vesiculosus, Corallina* sp. and *Ulva lactuca*; the fauna include the limpet (*Patella vulgata*), periwinkles (*Littorina littorea*), top shell (*Gibbula cineraria*), dog whelk (*Nucella lapillus*) and barnacle (*Semibalanus balanoides*) (Bamber, 1997).

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, the reef habitat is included on the Section 42 list of habitats of principal importance for conservation of biodiversity in Wales under the Natural Environment and Rural Communities (NERC) Act 2008. Countryside Council for Wales (CCW) biotope maps indicate 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. This latter report stated that the condition of the reefs were a mixture of low encrusting veneer growth, ‘ball’ formations, and the beginnings of taller reefs. In general the reefs were reported as being smaller than might be expected under optimal growing conditions, though generally in good condition and it was assumed that its proliferation in Limpert Bay was due in part to the elevated temperatures caused by the CW discharge. However, it was noted that growth was noticeably poorer in the immediate vicinity of the western outfall. The honeycomb worm *S. alveolata* is also known from subtidal habitats in the Bristol Channel with reefs present 3 km south of Aberthaw (Innogy, 2003).

The saline lagoon at Aberthaw is an artificial feature that was created during the development of the second Aberthaw power station in the 1970’s, when a sea wall was constructed across the former mouth of the River Thaw that had been canalised to run directly into the sea. The lagoon is maintained by seawater via percolation through the wall at high tides, via a pipeline used to drain excess water out to sea, and by freshwater from a stream to the north of the site (Vale of Glamorgan Council, 2002). The lagoon supports a characteristic lagoonal assemblage of benthic taxa including specialist taxa, *Ecrobia ventrosa* (mud snail), *Cerastoderma glaucum* (lagoon cockle), *Conopeum seurati* (an encrusting bryozoan)[1] and the amphipod *Corophium insidiosum.* The site has been classified as being of “low salinity good quality” (Bamber, 2010). The site is a remnant of the River Thaw Estuary having an annual salinity cycle dependent upon seasonal inputs and with higher recorded salinities, thus debating this categorisation by Bamber (2010) (Wildlife Trust for South and West Wales, *pers. com.* 7th September 2016).

[1] *C. seurati* has not been recorded since Bamber in 2000 and The Wildlife Trust is seeking to undertake monitoring of lagoon to identify its presence (Wild Life Trust for South and West Wales *pers. com.* 7th September 2016).

2.4 Fish

The waters of the upper Bristol Channel and Severn Estuary are home to a diverse range of fish, with over 100 species recorded (Potts and Swaby, 1993). This list includes seven migratory species which is more than any comparable environment in the UK. Catches on the cooling water screens at power stations in the Bristol Channel indicate that the fish communities are dominated by 10 species making up 90% of all fish caught (Bird, 2008). At Hinkley Point, 80 species have been caught on the stations intake screens with whiting (*Merlangius merlangus*), bass (*Dicentarchus labrax*) and sprat (*Sprattus sprattus*) the most commonly reported; dab (*Limanda limanda*) was the most commonly reported flatfish (Henderson *et al.,* 2007). Generally, the intake biomass is dominated by juveniles, probably due to their weaker swimming speeds. Considering the extensive habitat available in the upper Bristol Channel and Severn Estuary it is accepted that this area represents an important nursery area for juvenile fish (Langston *et al.,* 2003).

The Bristol Channel and Severn Estuary is a vital route used by many migratory fish species. These species are features of statutory designations, both in the Severn Estuary and the tributaries of the River Severn. Both twaite shad and allias shad (*Alosa alosa*) are known to return from coastal waters to the tributaries of the River Severn in spring to spawn. Spawning stocks of the twaite shad are only known from a few rivers in Wales and on the England/Wales border, particularly in the Usk and Wye. Similarly, the allias shad has been reported from the Severn catchment, although this is no longer considered to be a viable breeding population.

The river lamprey is widespread in the UK, although the main populations are reported as those which migrate into the Severn Estuary from the Bristol Channel and adjacent offshore waters. The sea lamprey is less common in the UK and although found around the coast, the main population centres are concentrated on the Bristol Channel (Bird, 2008). Both species migrate up rivers to spawn, with the important period for river lamprey being late autumn, while the sea lamprey migration occurs in spring.

Atlantic salmon utilise the Severn Estuary and Bristol Channel as a migratory route as they return from the sea in spring and summer to spawn in the Severn, Usk and Wye. Similarly smolts use the same route as they migrate to the sea, usually in late spring.

The River Thaw has a small but sustainable run of the sea trout (*Salmo trutta*) and salmon are occasionally recorded in the lowermost reaches of the river (Innogy, 2003). Both species are known to run up the Taff at Cardiff, and are likely to be present in other rivers in the area, so it is likely that they frequently occur in the waters adjacent to Aberthaw.

In late autumn adult eel (*Anguilla Anguilla*) migrate from freshwater to spawn in the Sargasso Sea, with elvers returning in early spring. Eel are common in the Severn Estuary, although numbers have been declining in recent years (Langston *et al.,* 2003). Historically there was an important eel fishery in the Severn, and the River Parrett still supports a small commercial fishery.

2.5 Marine Mammals

The greatest numbers of cetaceans in southern UK waters are reported in the Western Approaches, although diversity and abundance decrease up the Bristol channel towards the Severn Estuary, with only odontocetes (i.e. toothed whales) being recorded (Sea Watch Foundation, 2015). The harbour porpoise (*Phocoena phocoena*) is relatively common around UK coasts and have been reported from the Bristol Channel (Reid *et al.,* 2003), usually being observed in small groups close to the shore between October and March (Sea Watch Foundation, 2015). Although not commonly recorded in the Severn Estuary, this species has been reported as far upstream as Elmore, only 7 km from the tidal limit at Maisemore Wear (BDMIR, 2015). Other cetaceans recorded in the Bristol Channel are bottlenose dolphin (*Tursiops truncates*), short-beaked common dolphin (*Delpinius delphis*) and Risso's dolphin (*Grampus griseus*). Although these three species are generally common in waters around Wales and south-west England (DeBoer and Simmonds, 2003), they have only been rarely reported from the Bristol Channel (Reid *et al.,* 2003).

The grey seal has been reported in the outer Bristol Channel, particularly around Lundy Island where there is a breeding colony (Westcott, 2009). However, seal sightings are rare in the upper Bristol Channel and Severn

Estuary where there are no known haul out of breeding sites, although seals have been reported as far upstream as Purton in Gloucestershire (Glaucus, 2016)

Data on marine mammals (primarily seals, dolphins and porpoises) in the vicinity of Aberthaw are sparse; it can be assumed that such species, if not resident, are at least occasional visitors.

2.6 Water Quality

The Bristol Channel/Severn Estuary system is dominated by the second largest tidal range observed in the world, resulting in high current velocities which are orientated parallel to the channel axis and locally parallel to coastlines, high mixing rates and high sediment loads. Vertical stratification is not observed in the Bristol Channel/Severn Estuary due to the intense vertical mixing (Uncles, 1983). The water quality of the Bristol Channel/Severn Estuary is relatively homogenous, with gradients in pH and metals being small to negligible. This is probably due to a combination of high lateral mixing rates, high sediment loads influencing dissolved concentrations and the general improvement in water quality since the early 1990’s (Ellis, 2002; Langston *et al.,* 2003).

The high sediment loads in the water column result in low light penetration, a situation that limits total biological production. As a result the limited biological production, nutrient concentrations, though showing anthropogenic enrichment, also show relatively restricted depletion compared to other estuaries. The low salinity, high current velocities and low light penetration also provides a range of relatively uncommon habitats which contribute to the conservation importance of this environment. Anthropogenic influence on water quality has historically included both industrial and diffuse sources of metals and nutrients. However, distinguishing the anthropogenic influence from the natural background is complicated by a number of factors. Despite such influence on the water quality, there is no evidence of a widespread influence on the fauna and flora in the Severn Estuary, the composition of which is related principally to: current velocities, suspended sediment and sediment particle size (Langston *et al.,* 2003).

2.7 Station Operation

The pH variation trial ran over six months, between the end of January and end of July 2016 and Table 2.1 summarises the station activity (load factor) over this time[2]. 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.

Table 2.1 : Station operation pre, during and post-trial (supplied by RWE, August 2016).

Month	Load Factor (%) *
November 2015	46
December 2015	42
January 2016	68
February 2016	81
March 2016	70
April 2016	74
May 2016	19
June 2016	51
July 2016	6

[2] All three unites were off 7th May to 16th May with no CW discharge. Since 16th May at least one CW pump was running even if units were not operating (a safety issue at the outfalls).

2.7.1 pH plume modelling

Predictive hydrodynamic modelling data of the discharge plume under the proposed trial conditions (pH of 5.6) depicts the extent of the mixing zone of the discharge for low water (LW), mid tide flood (MW) and high water (HW) spring tide conditions at both the surface and bed (Appendix A).

The modelling shows the plume extent and resulting pH levels vary during the tidal cycle, with generally lower pH values around LW and higher, nearer ambient pH values around HW. The LW spring scenario showed the lowest predicted pH value of 5.6 in a small zone immediately east of the outfall. The mid flood tide showed pH values ranging between 7.92-7.97, the resulting plume influencing an area to the east towards 'The Leys'. The HW spring scenario showed the plume to the west the outfalls, with a pH ranging from 7.99-8.00.

The modelled data showed little or no differences between the surface and bed pH conditions at LW and during mid flood, although under HW conditions the extent of the area subject to the lowest pH values (7.99-8.00) was reduced across the bed compared to the surface.

3. Rationale for Field Assessments

3.1 Modelling

The predictive hydrodynamic modelling has indicated that an area of the intertidal ledges to the east and north-east of the outfall may be potentially subjected to reduced pH conditions, although no difference in the current and proposed pH regimes is evident beyond a distance of 350 m from the outfalls. The model predicts that the area potentially subjected to reduced pH conditions will be limited to the intertidal habitats in the immediate vicinity of the outfalls, but principally to the east (see Appendix A).

The predictive modelling also supports the long term study of metal levels in biota as part of the station's annual flue-gas desulphurisation (FGD) monitoring programme. The FGD programme has shown a wide variability in the metal concentrations across the shore at Aberthaw, although higher levels have been recorded in biota sampled in the vicinity of the discharge and sites to the east (Jacobs, 2016).

3.2 Benthic fauna and habitats

Combining the output of the predictive modelling and the trends identified during the FGD programme, it was concluded that of the key receptors identified in Section 2, 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 the intertidal benthic communities, their proximity to the outfall, and their limited mobility in comparison to other organisms (birds, fish and marine mammals) 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 pre-trial, trial, and post-trial data.

During consultation with NRW, concerns were raised that a reduction in the pH of the discharge may affect the populations of the honeycomb worm *Sabellaria alvaeolata* that currently inhabit areas influenced by the cooling water plume. Significant areas of the intertidal zone to the west of the discharges 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 resides across much of the shore, although abundant populations of gastropod molluscs can be 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* (common periwinkle) and *Patella vulgata* (limpet) are 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 study at Aberthaw since 2007 (Jacobs, 2016).

The shore at Nash Point has been included in the present study as a reference site. Nash Point is located some distance from the Aberthaw, but is within the same geographical area so as to take into account natural spatial and temporal patterns in recruitment, and any seasonal growth/declines of intertidal communities that will be independent of power station operational activities.

3.3 Field assessments

On the basis of the rationale laid out above, and following submission to (Jacobs, 2015) and approval from NRW, the following assessments of the intertidal shores at Limpert Bay and Nash Point were undertaken:

- Assessment the intertidal rocky shore benthic community of the upper, mid and lower shores to identify any spatial and temporal changes in the community that could be independent of the expected seasonal variations.

- Assessment and mapping of the intertidal *Sabellaria alveolata* beds to record any gross changes to the extent and features of the beds.

- Assessment of the health of target gastropod populations (*Patella vulgata* and *Littorina littorea*).

4. Methodology- Field assessments

4.1 Site Selection

The intertidal transects lines at Limpert Bay were selected based on those sampled annually as part of the Aberthaw FGD monitoring work (Jacobs, 2016), and comprised of upper, mid and low shore sites, as shown in Figure 4.1 (grid reference positions given are Appendix B). The transects were denoted as follows:

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

The Nashpoint (NP) (SS 91440 68371) reference site lies approximately 10 km west of the Aberthaw power station, and is also shown in Figure 4.1.

Between November 2015 and August 2016, all shore levels across all five transects lines were sampled. The specific survey dates are listed in Table 4.1. November 2015 represents the pre-trial monitoring period, March to May 2016 the trial monitoring period, and August 2016 the post-trial monitoring period.

Table 4.1 : Survey dates and tidal conditions between November 2015 and August 2016. (*Avonmouth tide tables)

Survey dates	pH Trial phase	Season	Spring Low water conditions*
24th to 25th November 2015	Pre-trial period	Autumn	1.0 – 1.5 m
8th to 9th March 2016	Trial period	Spring (post Winter)	0.6 – 1 m
6th to 7th April 2016	Trial period	Spring	0.4 – 0.9 m
5th to 6th May 2016	Trial period	Spring	0.5 – 1 m
3rd to 4th, and 22nd to 23rd August 2016.	Post-trial period	Summer	0.8 – 1.6 m

4.2 Benthic Community Assessment

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 to avoid 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). In addition, the frequency of occurrence of each of taxa was recorded across the 25 squares of each quadrat (from March 2016 onwards at the request of NRW). 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.

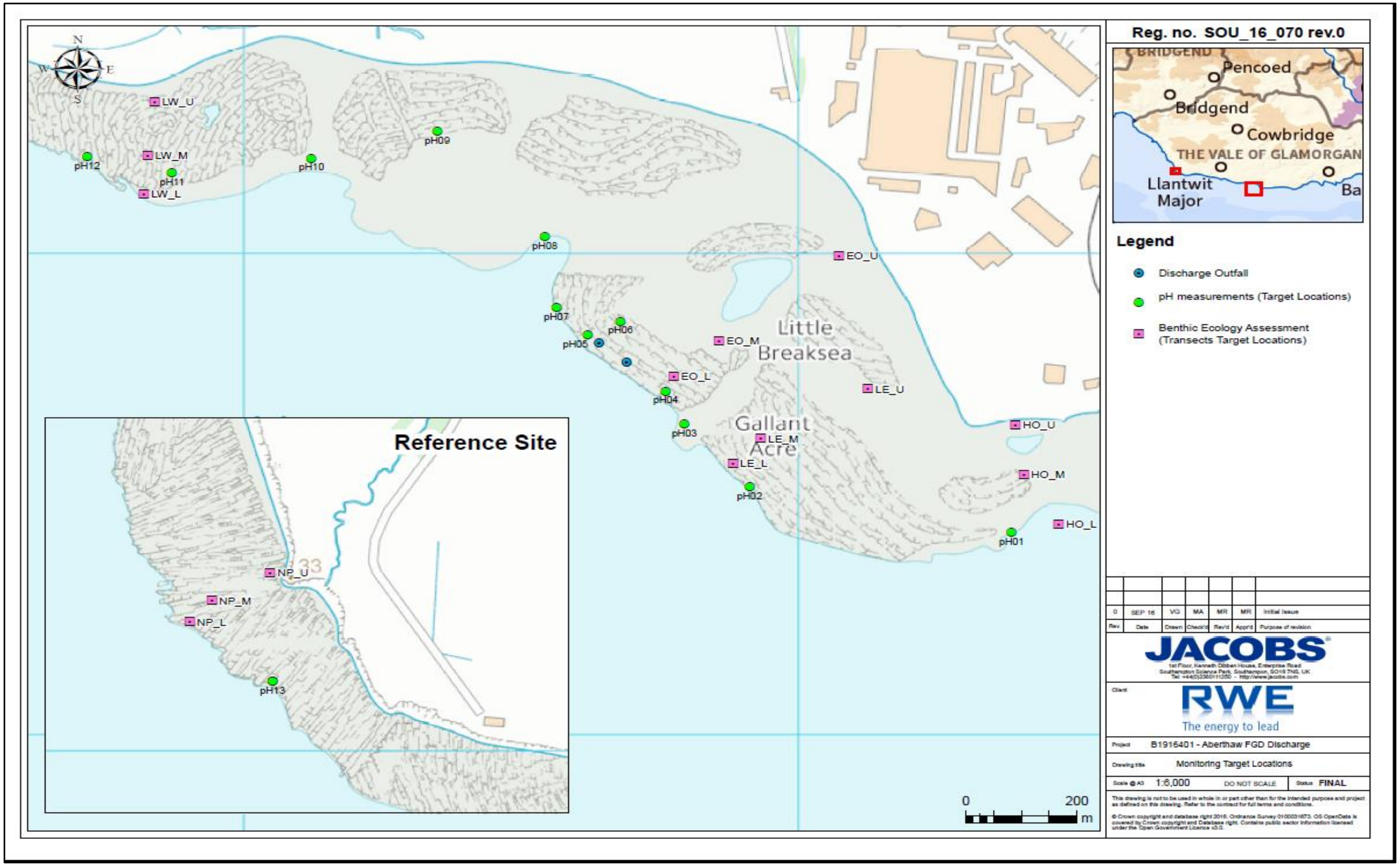


Figure 4.1 : Transect site positions and target pH measurement sites at Limpert Bay and Nash Point sampled between November 2015 and August 2016. (U = upper, M = mid and L = low shore positions).

4.3 *Sabellaria alveolata* Assessment

NRW (Natural Resource Wales, previously known as Countryside Council for Wales) previously mapped *Sabellaria alveolata* across the Aberthaw area. For the purposes of this study, any *S. alveolata* beds present between Transect HO in the east, to beyond Transect LW in the west, were mapped. At Nash Point a sub-area of the beds were 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 shore line in this area supports extensive Sabellariidae beds, and mapping the whole area would not have provided additional reference information.

At low water, the perimeter of the *S. alveolata* beds was tracked on foot using a handheld GPS (Garmin 76Cx) or with a Trimble® Yuma 2 tablet to a +/- 3 m accuracy. The tablet was equipped with a differential GPS and the navigational software HYDROpro®, with a local Ordnance Survey map preloaded.

Photographs and target notes on the bed features were recorded. General observations were also recorded, including the height of the structures, their overall condition and any associated biota. This data, in conjunction with their extent/coverage, was used to classify colonies as a particular broad ‘formation’ type (see Table 4.2).

Table 4.2 : Descriptions of different formation types used to categorise *Sabellaria alveolata* colonies (Egerton, 2014 after Gruet, 1986).

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

4.4 Gastropod Health Assessment

Fifty individuals of the target species *Patella vulgata* (limpet) and *Littorina littorea* (periwinkle) were collected from each of the five intertidal transects from the mid to lower shore zone during each monitoring event. 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 width and blotted tissue wet weight of each individual periwinkles (*L. littorea)* was measured. The same was completed for the limpets (*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.

4.5 Physico-chemical water quality

From the March 2016 monitoring event onwards, single point readings of physico-chemical water quality parameters were recorded across Limpert Bay (Figure 4.1) and at a single point at Nash Point 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.

4.6 Data Analysis

4.6.1 Benthic Communities

Prior to analysis, the rocky shore taxa recorded during the surveys were checked for the most up to date nomenclature information using the World Register of Marine Species online database (WoRMS Editorial Board, 2016).

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 on taxa abundance and distribution using the PRIMER (Plymouth Routine in Marine Ecological Research) software programme. The replicate quadrats sampled in each shore level were averaged, and non-parametric multi-dimensional (MDS) ordination with a Bray-Curtis similarity measure and cluster analysis (with SIMPROF) performed on the 4^{th} transformed mean data to visualise patterns in community data. 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 because of their scale (Boaventrura, 2000, after Anderson and Underwood, 1997) (see C.1 for full details).

Using the replicate data, the ANOSIM routine was then used to identify differences between sites/groups of sites over time, where groupings had been initially identified via the graphical representation in the MDS ordinations and cluster dendograms. Where differences were detected the taxa most important for distinguishing between ‘groups’ and contributed to within ‘group’ similarities was undertaken using the SIMPER (see C.1 for full details). Taxa contributing to at least 10% of dissimilarity were considered to be important differentiators.

Analysis of mean univariate data (e.g. diversity indices) was also undertaken to reveal any spatial and temporal changes across the study area (see C.2 for details), with mean values and associated standard error (S.E) and standard deviations (St.dev) calculated.

4.6.2 Gastropod Health Assessment

Condition Indices (CI) were calculated for all samples using a relationship between tissue weight and shell size, status. High values indicate a better condition or health. The calculation of CI is given as:

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

(Lundebye *et al.,* 1997)

As wet weight had been recorded for each specimen, the values were converted to dry weight. For *Littorina littorea,* wet weight:dry weight ratios were derived by data reported by Langston *et al.,* 2012, and for *Patella vulgate,* values were converted using the average ratios for all gastropods detailed by Rumohr *et al.,* 1987.

5. Results – Field assessments

5.1 Benthic Communities

5.1.1 Diversity patterns

A total of 74 taxa were recorded across the five sites sampled at Limpert Bay and Nash Point between November 2015 and November 2015 and August 2016; a full taxa list is provided in Appendix D. Figure 5.1 shows the mean number of taxa recorded at the low, mid and upper shore zones for each of the five transect sites across the study period.

Table 5.1 provides the results of the Two-Way ANOVA analysis of the change in species richness spatially and temporally. The results indicate a temporal and spatial variation in species richness, but with no consistency in the temporal patterns reported. For each of the three shore zones, a significant statistical spatial difference in mean richness is reported (

Table 5.1 'Transect'). Appendix E shows the interaction plots for the mean number of taxa recorded for each shore zone.

The low shore reported the lowest mean number of taxa at site EO which is situated just to the east of the outfall. The highest mean number of taxa was recorded at the western transect site LW at Limpert, and at the reference transect at Nash Point (NP). There was no statistically significant temporal change in the mean number of taxa reported for any of the sites during the survey period (

Table 5.1, 'Time'). Although there appears to be a consistent spatial pattern in declining richness from the east of the shore towards the outfall, followed by an increase west of this, any changes in richness with time at the lower shore was not consistent. Similarly, there was no statistically significant temporal change in diversity at any of the sites during the monitoring period. However there were inter-site differences detected between the five transects with significantly lower measures of diversity at EO, HO and LE, compared to the western sites LW and NP.

The mid shore communities did not reveal such depressed species richness values for the EO site, relative to sites to the east and west of the outfall as reported for the low shore zone. However, the mid shore still showed a general pattern of increasing richness east to west. Unlike the low shore, the mid shore communities did exhibit an overall statistically significant temporal variation in richness (

Table 5.1, 'Time'). There was a significant temporal change detected at site LE, and there was a significant statistical fluctuation in richness between November 2015 and April 2016 with a significantly lower mean number of taxa reported for March 2016. At sites EO, LW and NP there appeared to be a general increase in species richness with time between the months of March and August 2016. However, at EO this pattern was not, in itself, statistically significant and as with the lower shore, any temporal change were not consistent between all five sites (

Table 5.1, 'Transect*Time'). The mid shore showed no statistically significant spatial variation, but there was a slight temporal variation with a significant decrease in diversity between the November 2015 and March 2016 sampling periods. However, there was both significant spatial and temporal change, with a spatial difference detected between the eastern sites (HO, LE and EO) and the western ones (LW and NP).

The mean number of taxa reported at the upper shore communities did not vary significantly with time and overall, both the lowest and highest mean numbers of taxa were reported in the same month (November 2015) at EO and LE, respectively; both sites lying to the east of the outfall. On examination of the interaction plot for the upper shore (Figure E.3), the spatial change in species richness appears to be similar for the months of November 2015 (pre-trial period), April 2016 (trial period) and August 2016 (post-trial period), with a reduction at site EO and relatively higher values to the east and west of the transect. However, any patterns of temporal change at each site were not consistent (

Table 5.1, 'Transect*Time').

Table 5.1: Two-Way ANOVA for mean number of taxa recorded across the five transect sites during the survey period (November'15 – August '16) for the low, mid and upper shore communities at Limpert Bay and Nash Point. (* indicates a significant value)

		Df	F value	*p-value*
Low shore	Transect	4	23.54	<0.001*
	Time	4	0.28	0.891
	Transect*Time	16	2.63	0.002*
Mid shore	Transect	4	8.08	<0.001*
	Time	4	8.58	<0.001*
	Transect*Time	16	3.59	<0.001*
Upper shore	Transect	4	15.18	<0.001*
	Time	4	2.35	0.062
	Transect*Time	16	6.24	<0.001*

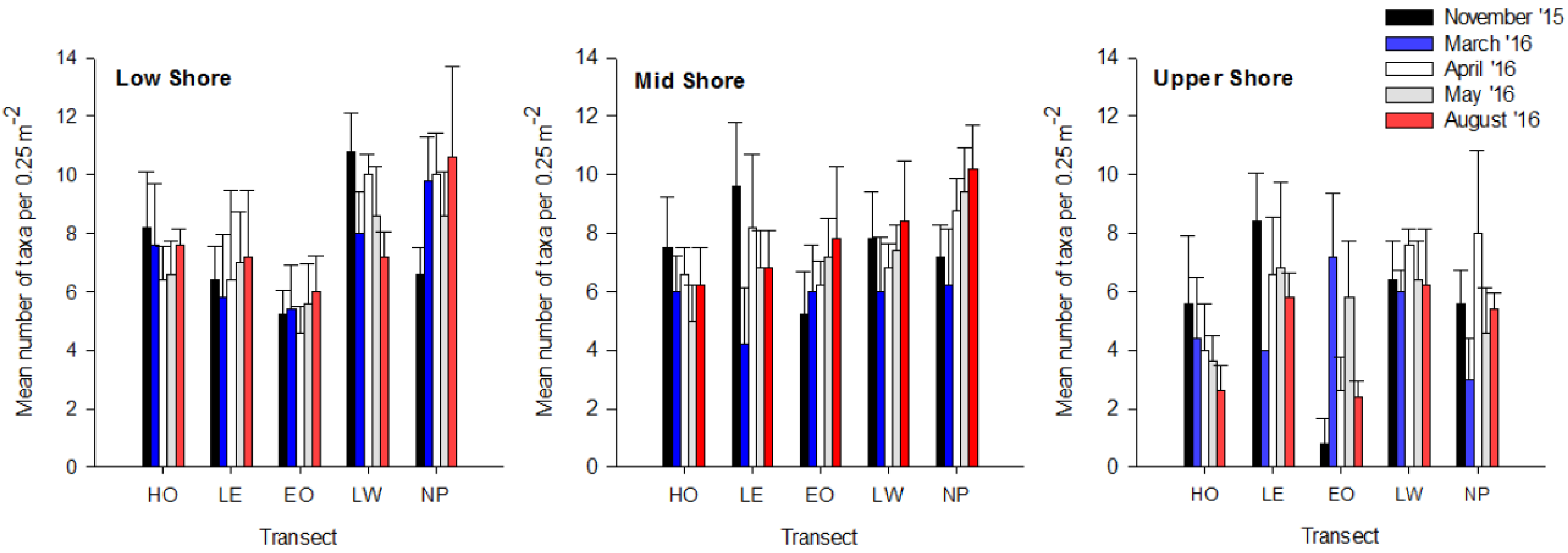


Figure 5.1 : Mean Number of taxa (± S.D, per 0.25 m^{-2} quadrat, n = 5) across the low, mid and upper shore at transects HO, LE, EO, LW (Limpert Bay) and NP (Nash Point) between November 2015 and August 2016. Note: n = 4 at HO mid shore in November 2015.

5.1.2 Low shore community patterns

An initial examination of the similarity in the mean low shore community data (Figure 5.2 and Appendix F) shows differences on a spatial scale between the different site locations, with clear distinctions with regard to their orientation to the outfall. Generally, the sites west of the outfall (LW and NP) and furthest east (HO) show the most dissimilarity from the community structure at the outfall. LE is more similar to EO being the closest site east, but is still clustered (similarity = 48%) as having a different benthic community. This was confirmed by the two-way crossed ANOSIM (see Appendix G) which found a significant ecological difference in community structure (for all data) between the transect sites (R = 0.875; *p* = 0.001). The spatial distribution of taxa across the lower shore was explored with SIMPER analysis, revealing which taxa contributed most to within site similarities, and between site dissimilarities (see Appendix G). The site closest to the outfall (EO) was characterised by high average abundances of the taxa: *Fucus serratus (*toothed wrack), *Catenella caespitose,* and *Fucus vesiculosus.* The bubble plots in Figure F.3 (Appendix F) summarise the spatial distribution of key biota across the lower shore study sites. They illustrate a dominance of *S. alveolata* and *C. spongiosus* at sites in the west (LW, NP) and a dominance of gastropod molluscs and fucoid algae cover at sites in the eastern areas (EO, LE, HO).

The largest significant ecological difference in community structure was found between EO and the reference site NP (R = 1.000, *p* = 0.001). This was attributed to *F. serratus, C. caespitosa* and Actiniaria (sea anemones) being reported at EO, but being virtually absent at NP. Conversely, *Nucella lapillus, C. spongiosus* and Serpulidae tube worms were recorded as being absent at EO, whereas at NP these species were present.

Some temporal differences in the benthic community are evident (Figure 5.2), but these are not well defined, with the exception of site LW in August. The greatest difference in community structure across the sites was seen between the months November and March. March was characterised in the SIMPER analysis as having higher abundances of Serpulidae tube worms and *Nucella lapillus,* but having lower abundances of *Littorina littorea* and *Patella* spp*.*

Little temporal difference was seen in the community pattern at site EO. No significant difference was detected between the pre-trial community in November 2015 and the community sampled one month after the trial had commenced in March 2016: (R = 0.15, *p* = 0.13). A slight significant difference was reported between March and the end of the trial in May 2016 (R = 0.33, *p*= 0.048). The largest temporal difference was detected between May and August 2016 (R = 0.77, *p* = 0.008), and this was attributed to an absence of *Sabellaria alveolata* in the low shore quadrats in August 2016 (12.43% contribution to overall dissimilarity). Across EO, the *S. alveolata* beds were not observed to be continuous, and although present, were patchy in places. The low shore quadrats were situated within the upper areas of the beds, where the tube structures were not as well developed as the tube structures in the lower areas.

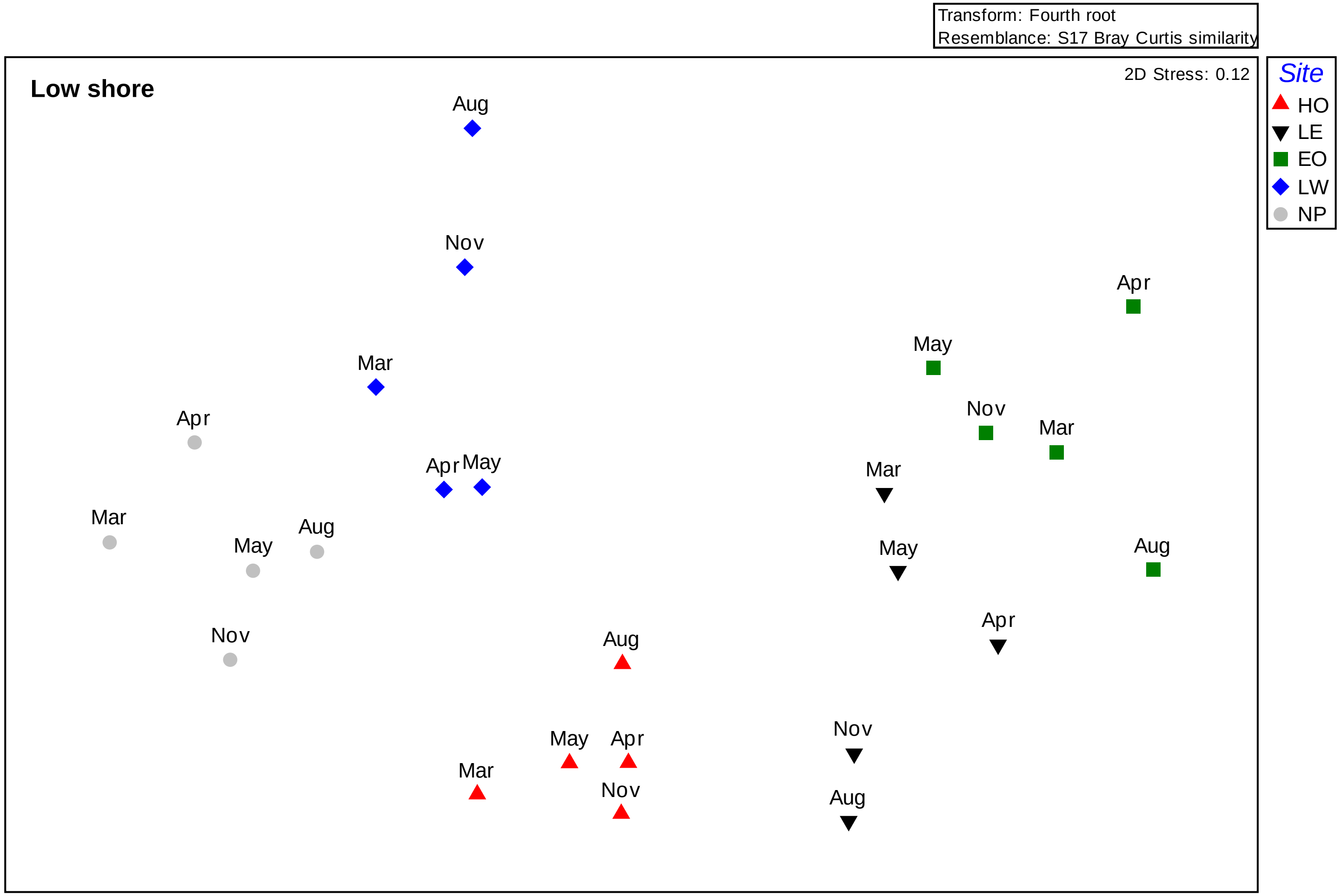


Figure 5.2 : Two-dimensional MDS ordination of all low shore communities sampled between November 2015 and August 2016 across Limpert Bay (HO, LE, EO and LW) and Nash Point (NP) based on 4th root transformed and Bray-Curtis similarities of mean community data (n= 5 replicate 0.25 m^{-2} quadrats). Stress = 0.12.

5.1.3 Mid shore community patterns

Unlike the lower shore, the mid-shore communities across Limpert Bay are not distinguished from one another at such a spatial scale. Broad differences were found between the Limpert Bay communities and the reference site NP, with the March 2016 community at LE identified as an outlier (Figure 5.3 and Appendix H). The two-way ANOSIM test detected a statistical difference in the community structure at NP and the sites at Limpert Bay (Global test, $R = 0.66$, $p = 0.001$).

In comparison to Limpert Bay, Nash Point was characterised as having greater mean counts of *Gibbula cineraria, Nucella lapillus,* very small juvenile *Littorina* spp. (present in empty barnacle shells), adult *Littorina littorea*, sea anemones, and a greater coverage of barnacles (Cirripedia), *Osmundea pinnatifida* and of the calcareous encrusting algal Lithophyllum. Conversely, higher overall counts of *Patella vulgata* and coverage of the by *Fucus vesicolosus* were reported at Limpert Bay (see SIMPER analysis, Appendix I).

Closer examination of the community at LE sampled in March 2016 showed that it was both an outlier to the rest of Limpert Bay mid shore communities and the reference site community. Pair-wise One-way ANOSIM comparisons of sites revealed significant differences between the March sampling and the other four months (all at $p = 0.008$). A lower mean number of taxa were reported in March at LE (see Figure 5.1), and SIMPER reported that the March communities were only characterised by three taxa- *Patella vulgata*, *L. littorea* and barnacles (>90% cumulative contribution to overall similarity). The number of important taxa for the other four sampling months ranged between five in April and August 2016, to seven in November 2015.

Further examination of the site closest to the outfall (EO) identified significant differences between March and the months of April, May and August ($R = >0.75$). In March, the community at EO was characterised by gastropods, notably juvenile littorinid snails (contribution to similarity 30.46%). In the subsequent months, no juvenile littorinids were recorded and this contributed most to overall dissimilarity between months (SIMPER, 15.57 to 21.71%).

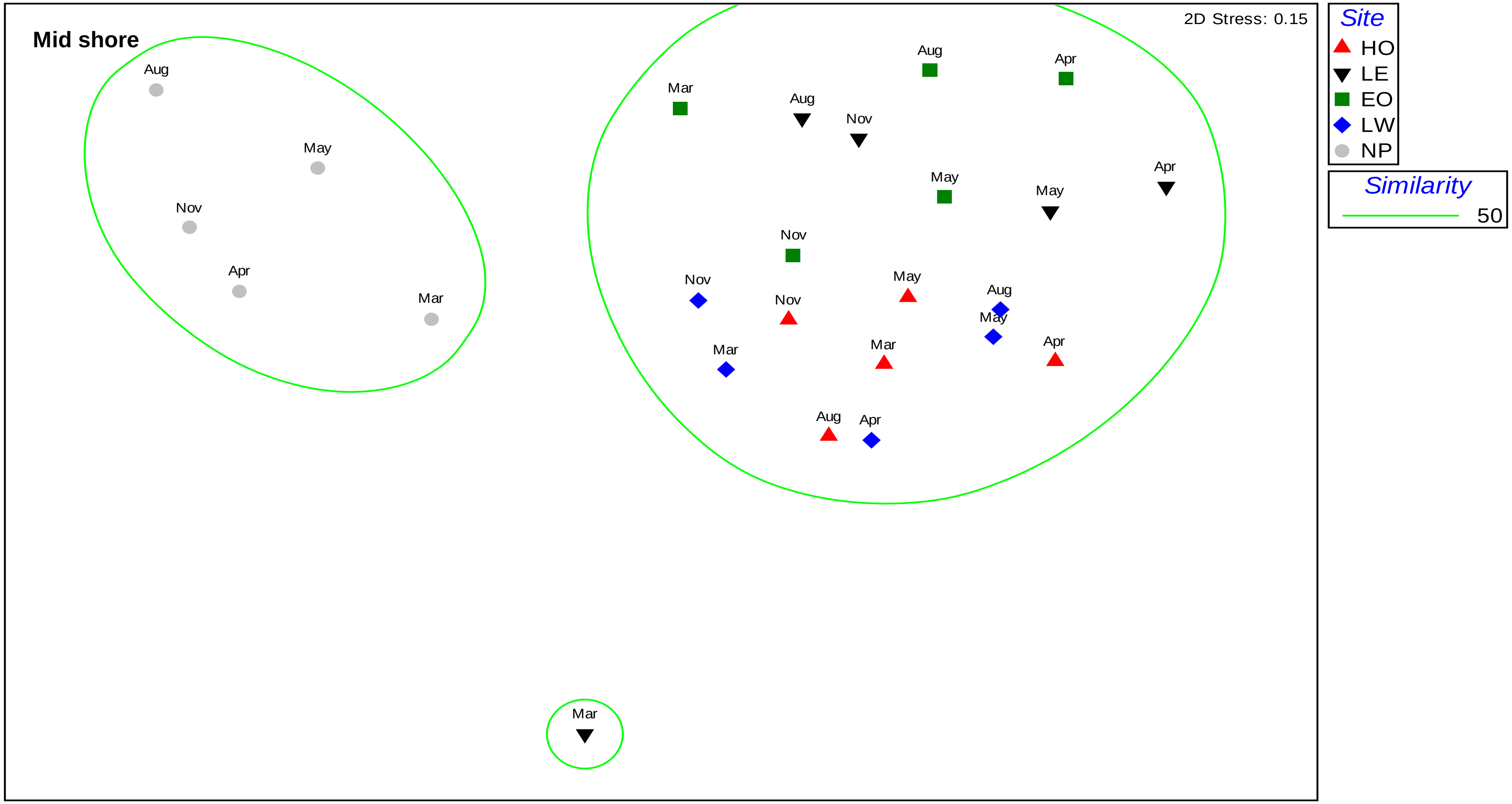


Figure 5.3 : Two-dimensional MDS ordination of all mid shore communities sampled between November 2015 and August 2016 across Limpert Bay (HO, LE, EO and LW) and Nash Point (NP) based on 4th root transformed and Bray-Curtis similarities of mean community data (n= 5 replicate 0.25 m^{-2} quadrats). Stress = 0.15 and clusters based on 50% similarity.

5.1.4 Upper shore community patterns

The upper shore benthic community showed spatial differences (Figure 5.4 and Appendix J), with a cluster of sites closest to the outfall (EO, LE, LW), and HO and NP being defined as having distinct communities. The spatial difference between the five individual transect sites (ANOSIM Global Test R = 0.77, *p* =0.0001) was found to be significant (Appendix K).

Analysis of the upper shore communities based on the cluster groups identified in Figure 5.4 identified the taxa characterising site HO as fucoids (*Fucus vesiculosus* and *Fucus spiralis*), gut weed *Enteromorpha* spp. (synomym *Ulva* spp.) and the sand mason worm *Lanice conchilega.* In contrast, the communities at LE and LW, and at EO (spring 2016) were characterised by a range of taxa, including gastropods (*Littorina littorea, Patella vulgata* and *Gibbula cineraria*), barnacles and the encrusting algae Lithophyllum. The community at EO reported in November 2015 and August 2016 were characterised by gastropods (*L. littorea* and *G. cineraria*) and by *L. conchilega.*

In contrast to Limpert Bay, the upper shore at the reference site NP was characterised by small Littorinids, ('*Littorina* juv'), *P. vulgata* and a higher mean percentage cover of barnacles (78%). Bubble plots in Appendix J summarise the spatial distribution of some of the key biota across the upper shore sites, illustrating a dominance of barnacles (cirripedia) at NP and relative dominance of *P. vulgata* at NP and the other western site LW. The sandmason worm *L. conchilega* characterises both EO and HO communities.

Some temporal differences can be observed in Figure 5.4, the most obvious dissimilarity between the benthic communities occurring at site EO pre trail and during the trial period. Although significant temporal differences were detected (all *p* values <0.0001), the associated R values were relatively lower than those computed for spatial differences and indicate some overlap in community features. Analysis of EO only between the trial (spring 2016) and the pre-trial (November 2015) and post-trial (August 2016) communities, showed that the temporal difference was attributed to *L. conchilega* still being present during the trial period at a higher average abundance. The comparison also showed that overall species richness and abundances were lower in November and August.

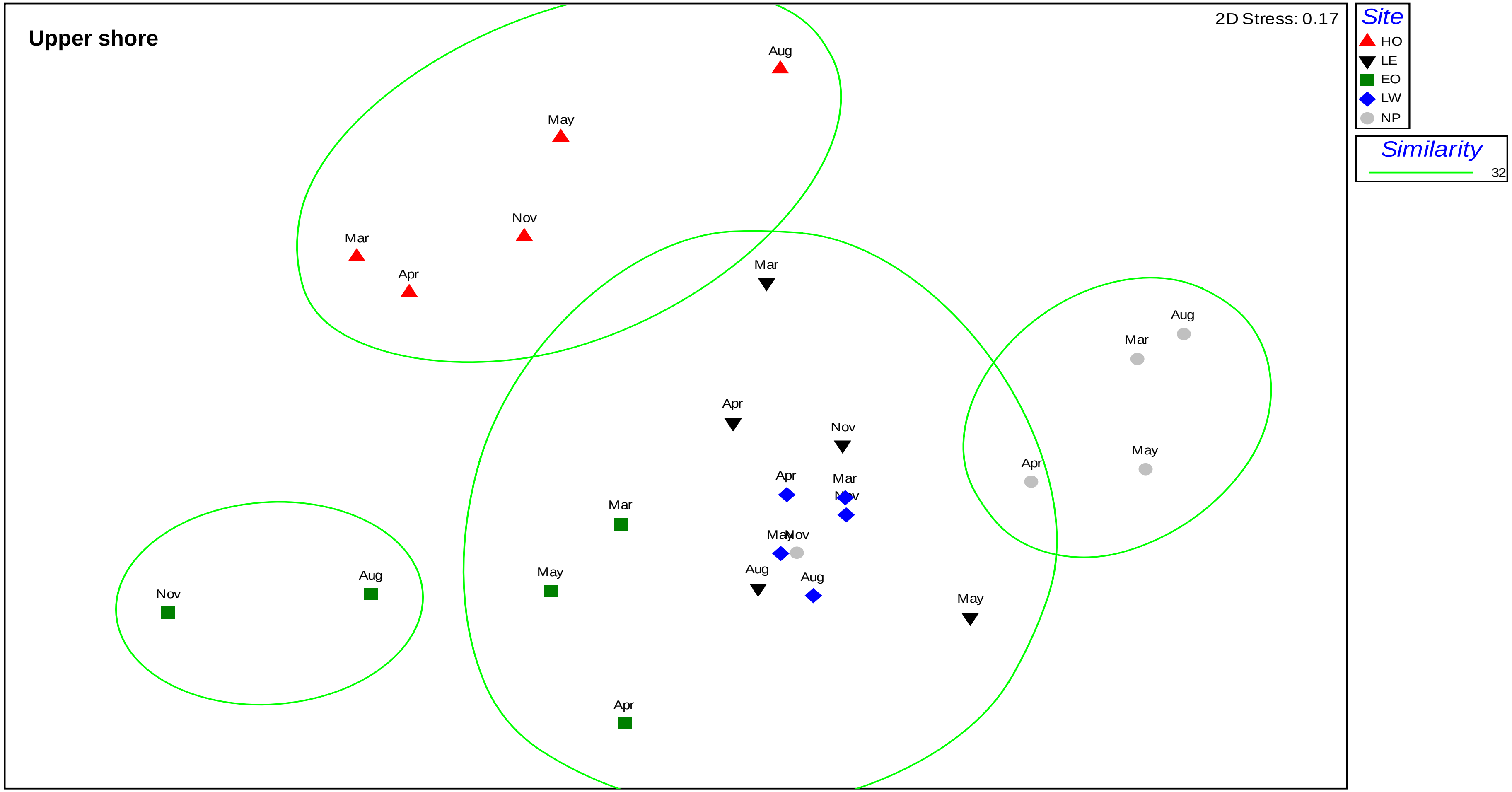


Figure 5.4 : Two-dimensional MDS ordination of all upper shore communities sampled between November 2015 and August 2016 across Limpert Bay (HO, LE, EO and LW) and Nash Point (NP) based on 4th root transformed and Bray-Curtis similarities of mean community data (n= 5 replicate 0.25 m^{-2} quadrats). Stress = 0.17 and clusters 'I' to 'IV' based on 32% similarity.

5.2 *Sabellaria alveolata* Assessments

Mapping of the *Sabellaria alveolata* bed tracking data has provided an overview of the extent of the beds present across the study area (Figure 5.3). A summary description of the beds mapped across both the study shore and the reference shore is provided below and is discussed in relation to their proximity to the transect sites and to the outfall structures (see Figure 4.1 above).

Where possible, the lowest spring tide was always selected for each planned survey month, but unavoidable temporal variation in tidal conditions resulted in some restriction in mapping the extreme tidal fringes of the beds on some occasions. Figure 5.3 shows the total area of beds mapped between November 2015 and August 2016 at Limpert Bay and Nash Point, with each bed numbered from east to west. A total of 11 beds were identified across the study area at Limpert Bay, and a sub-area of the extensive bed at Nash Point recorded.

This data can be compared to available NRW information of these habitats. The NRW Phase 1 intertidal habitat mapping of Limpert Bay and Nash Point is shown in Figure 5.4 with the biotope LS.LBR.Sab.Salv (‘*Sabellaria alveolata on sand-abraded eulittoral rock’*) identified, and the current mapping data overlaid. The scale of mapping undertaken in the present study appears to be in line with the approach undertaken by NRW in terms of demarcation of each individual bed and is that the *S. alveolata* biotope classification remains at LS.LBR.Sab.Salv. The intertidal beds are not in their entirety developed enough in terms of both height of bed structure and coverage to be classified as ‘reefs’, LSLBR.Sab (*‘Littoral Sabellaria honeycomb worm reefs*’). Despite the similarities, temporal differences between the studies are evident and these discussed further in Section 6.2.5.

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 out discrete sub-areas of a given bed.

There was a wide spatial variation in the distribution of *S. alveolata* across the study area, as detailed in the results of the quadrat assessment survey of percentage cover at each of the transect sites. Figure 5.3 shows a general pattern of lower relative coverage across the sites to the east of the outfall (LE and EO). The high variability (as depicted by the standard deviation bars) may be indicative of the patchy nature of the beds across the shoreline, rather than a temporal variation. Overall, increased community richness was observed across areas where there was relatively higher percentage cover of *S. alveolata* (Section 5.1.1).

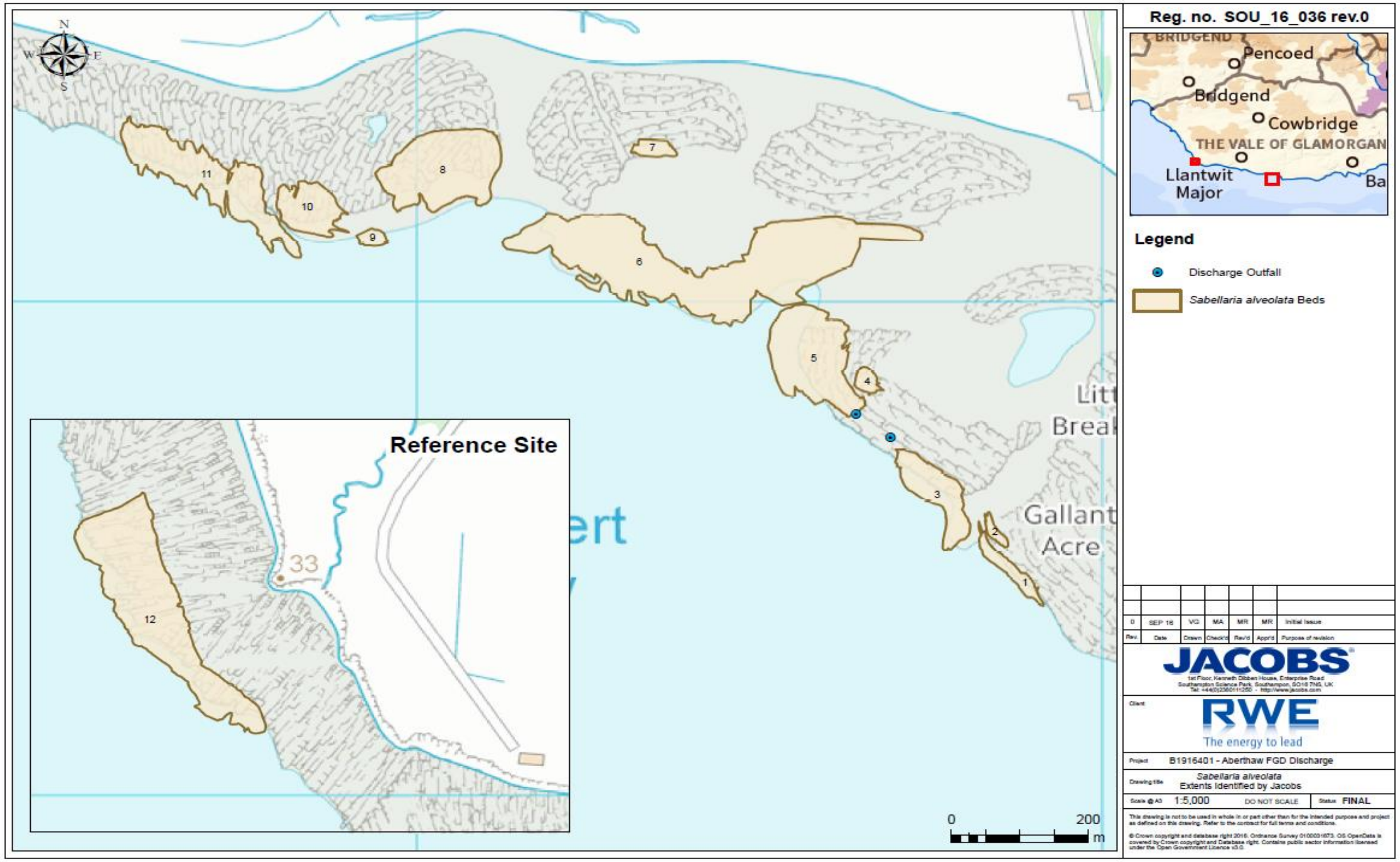


Figure 5.3 : *Sabellaria alveolata* beds across Limpert Bay, surveyed between November 2015 and August 2016.

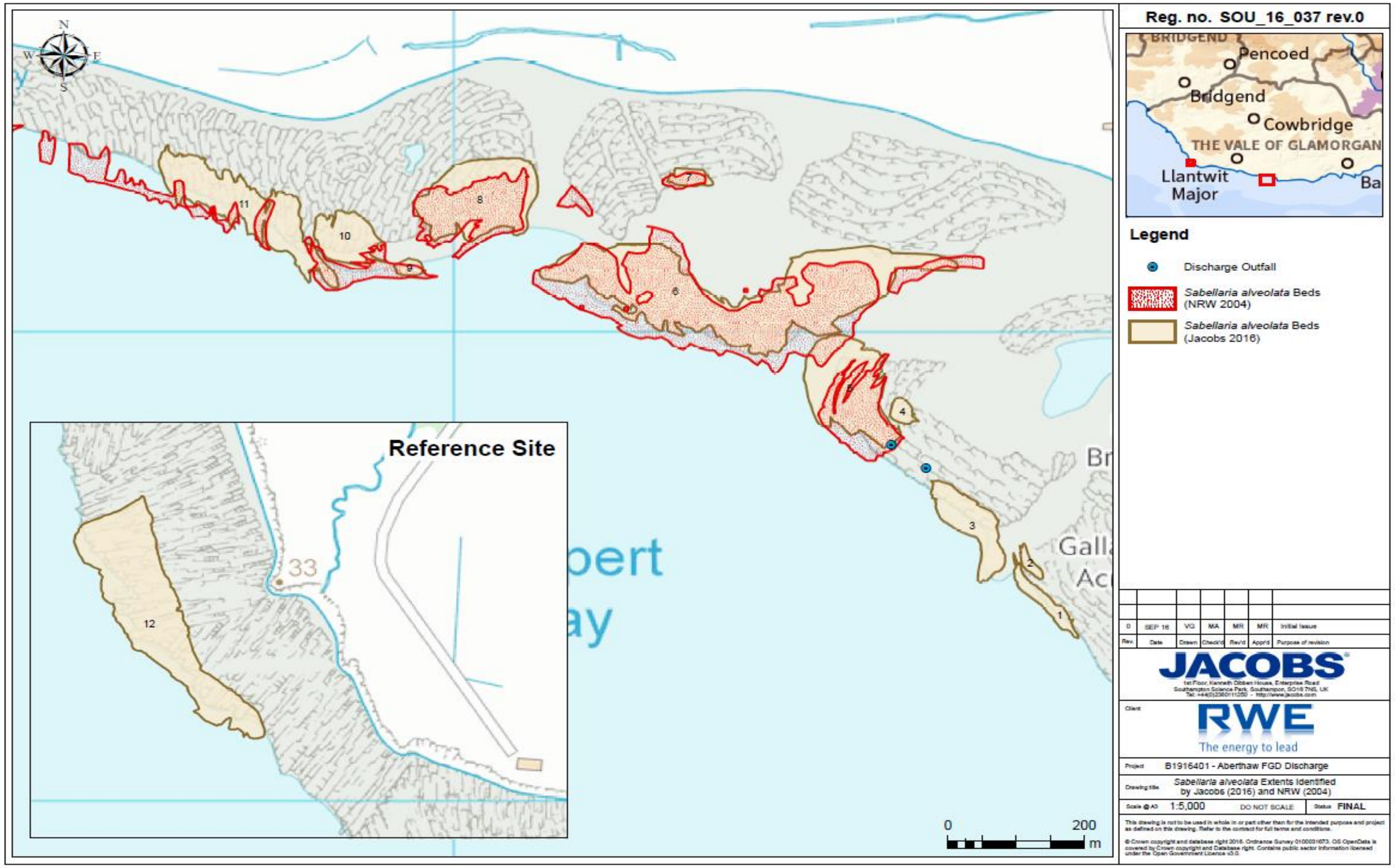


Figure 5.4 : Historic *Sabellaria alveolata* LS.LBR.Sab.Salv biotope (indicted in red) as mapped by NRW (2004) across Limpert Bay overlaid by the current study (2015-2016) shown in yellow.

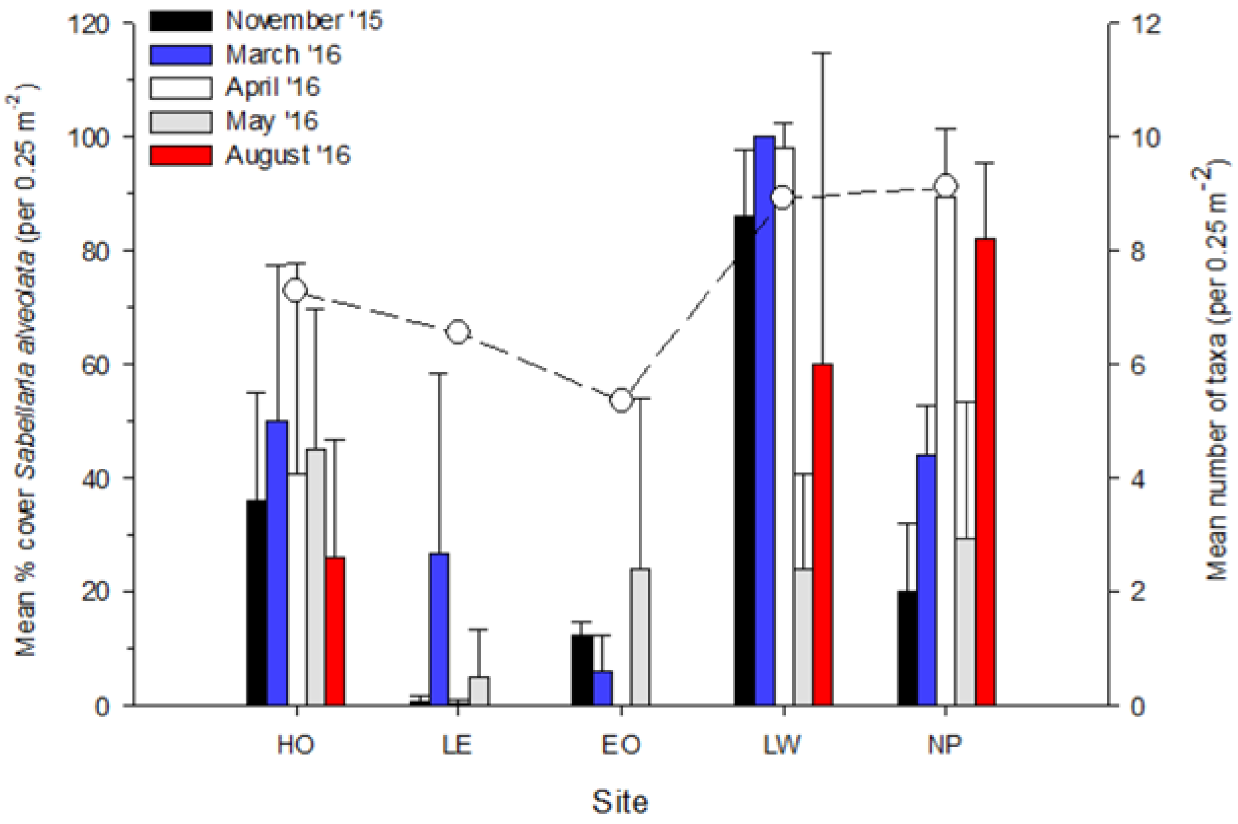


Figure 5.5 : Mean percentage cover (bars) of *Sabellaria alveolata* (± S.D, per 0.25 m^{-2} quadrat, n = 5) across the low shore at Limpert Bay (HO, LE, EO and LW) and at Nash Point (NP) between November 2015 and August 2016 with overall mean number of taxa per low shore site (open circles) also plotted (pooled months, n = 25, S.D not shown).

5.2.1 Limpert Bay - beds east of the outfall

Fewer beds were recorded to the east of the current cooling water discharge structures, and those recorded were less extensive than those to the west.

To the east of the old (redundant) outfall structure (by transect line HO) an area of large broken reef was recorded. Within the old outfall structures themselves, *S. alveolata* formations were also present growing within the openings of the structures. These features were not mapped during the survey period as they were east of the transect line (HO) (Figure 5.6).

Between the two old outfall structures themselves, there was very little *S. alveolata,* with only small patches present, interspersed with boulders, and a virtual absence towards the western outfall structure. These features were not deemed suitable to map and their presence only noted during the study.

To the west of the redundant outfall structures, the isolated poor growths of low lying crusts with only very patchy distribution were not mapped (Figure 5.6). These patchy crusts were less than 5 cm in height, often under dense swathes of *Fucus serratus.* These patches reduced in number in a westerly direction towards transect line LE.

There were in total three broad beds mapped to the east of the current cooling water outfall structure, and the details of each bed are summarised further in Table 5.2 below.

Data gathered along transect LE reported obvious settlements of *S. alveolata* under fucoids on the lower shore, with thinner crusts on the upper areas of the beds.

To the east of the current cooling water discharge, the non-native brown algae *Sargassum multicum* is present in the large rock pools towards the mid shore zones. These shallow pools are connected to the discharge channel.

Low but continuous beds were recorded by the outfall, under growths of fucoid algae.

Figure 5.6 : Reef eastwards of the transect HO (left) and beds growing within the redundant outfall structures (middle) and an example of the 'patchy' *S. alveolata* formation west of the redundant outfall structures (photo taken May 2016).

5.2.2 Limpert Bay - beds west of the outfall

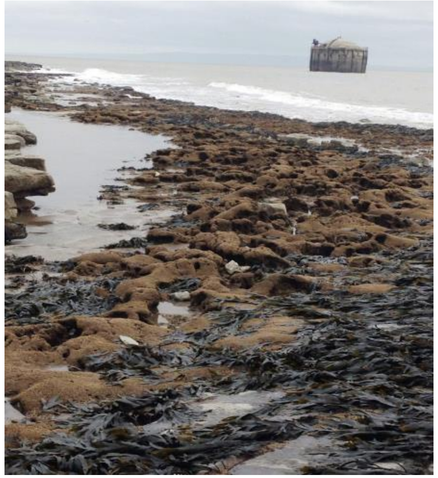
Table 5.3 summarises the beds in the west of Limpert Bay. In comparison to the east of the Bay, more extensive and developed beds were present to the west of the cooling water discharge; often extending further up the shore. These beds were interrupted by sand flats (or at a smaller scale by rows of large boulders lying perpendicular to the shore line) and narrow sandy gullies.

Moving westwards the shore becomes more exposed with bedrock marked by fissures. Evidence of both abraded and relic tubes structures are visible at the edges. The upper areas of the beds are generally less elevated in comparison to the less exposed lower shore zones. In the spring and summer months blooms of the opportunistic macroalgal species *Ulva lactuca* was recorded present on the beds, and a pattern of increased presence of the hairy sand weed *Cladostephus spongiousus* towards the western areas of the bay.

5.2.3 Nash Point

A sub-area of the beds present at Nash Point was mapped. Even within the sub-area mapped, there were differences observed in terms of height of the tube structures and evidence of abrasion (Table 5.3). Mirroring the western areas of Limpert Bay, *C. spongiousus* was also present across the beds and with populations of dogwhelks commonly observed.

Table 5.2 : Summary table of the *Sabellaria alveolata* beds east of the cooling water outfall at Limpert Bay.

Bed Number location	Approx. Coverage	Description	Images
1 Gallant Acre	0.25 ha	The eastern areas are **sheet** structures, 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 (in spring-summer) (left image, August 2016), In the western area, bed elevations increase with **hummocks** up to 20 cm in height under fucoids (right image, looking east, August 2016).	 
2 Gallant Acre (above Bed 1)	0.08 ha	**Sheet** and **patches** - low mounds and thin crusts (lower than observed for bed 1) on bedrock, under *F. serratus* and *F. vesiculosus* *S. multicum* present in rock pools.	 

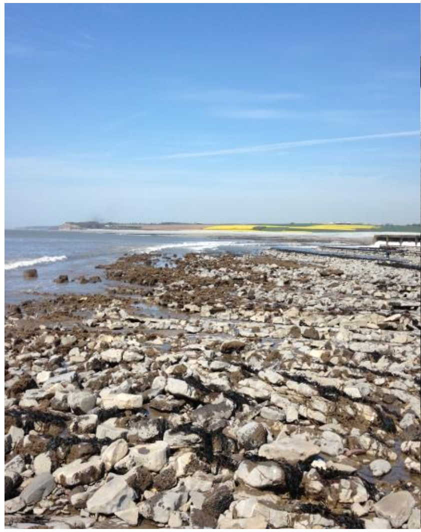
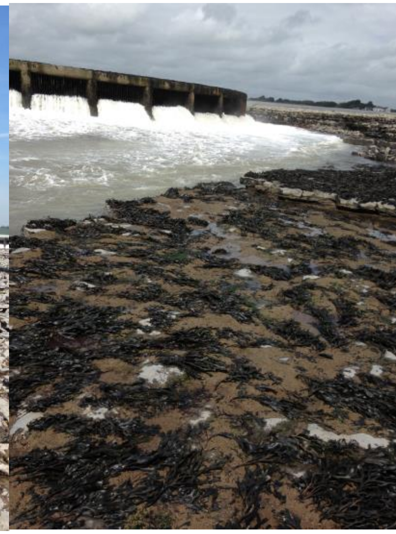
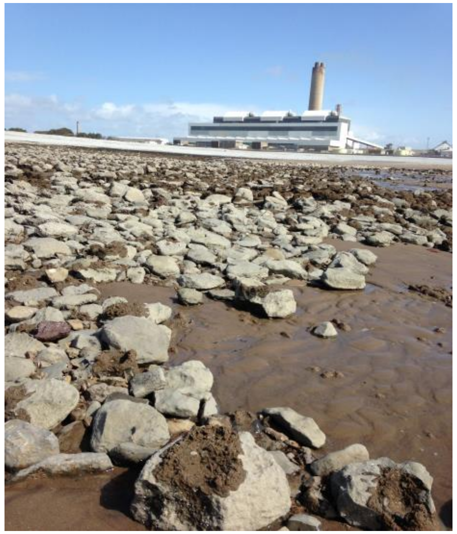
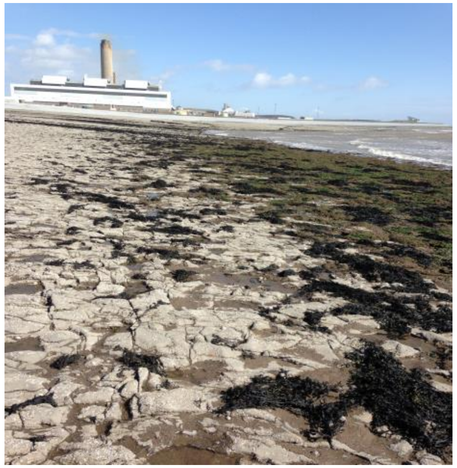
Bed Number location	Approx. Coverage	Description	Images
3 East of the eastern outfall at transect line EO	0.74 ha	A large bed comprising of a lower part and upper part demarked by a ridge. Lower part is a low **reef,** approximately 25 -30 cm in height and low mounds on cobbles, under *Fucus serratus* (left image looking westwards). Landward area becoming more eroded Upper part is a **sheet** , low encrusting but in parts continuous on a wide bedrock platform, under dense fucoids. Dense *S. multicum* growing in the rock pools connected to the sea (middle and right image , taken from western end of bed by eastern outfall structure)	  

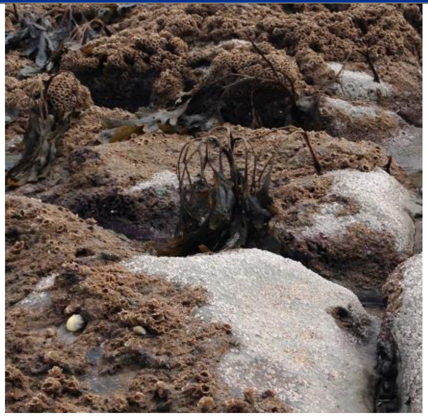
Table 5.3 : Summary observations of *Sabellaria alveolata* beds west of the outfall at Limpert Bay and at the reference site, Nash Point.

Bed number/Approximate location	Approx. Coverage	Descriptions	Images
4 Immediately west of western outfall structure	0.11 ha	A small **sheet** type bed with low growth crusts <5cm height on an exposed rocky platform, interspersed with boulders under fucoids. Left image shows low growths immediately next to cooling water discharge structure. Right image shows the rest of the bed looking north.	 
5 Immediately west of outfall (SW of bed 4)	1.64 ha	Large continuous bed, but interrupted by rows of large boulders. The northern edge of the bed are **hummocks** with low growth interspersed with boulders on bedrock (left image, May '16), under sparse fucoid algae. The seaward edge of the bed is a **reef** and more continuous in extension, with ball growths < 15-20cm in height, interspersed with boulders, cobbles and fucoids. Red algae growth observed in spring and summer. Right image shows an example of a row of large boulders separating out the bed (March'16). The western edge the bed meets a sand flat.	 

Bed number/Approximate location	Approx. Coverage	Descriptions	Images
6 West of a sandy inlet and the outfall.	4.91 ha	An extremely large bed. Much of the bed is discontinuous in the upper zone, interspersed with boulders. **Patchy** distribution < 10cm height (left image – at eastern edge of upper area, looking back towards power station (May 2016)). Lower zone has a more dense aggregation of **hummocks** < 15 cm in height under macroalgae (*U. lactuca, Fucus* spp.) on a tide swept platform. Western edge of the bed meets a wide sand flat.	
7 West of outfall and landward of bed 6, and east of the culvert structures.	0.14 ha	A small local area of **sheet** bed situated towards the upper shore, on bedrock, under moderate fucoid cover (*F. serratus* and *F. vesiculosus*) and *Ulva lactuca* (spring-summer) Image of northern edge of bed looking east back towards the power station on a flood tide (May 2016).	

Bed number/Approximate location	Approx. Coverage	Descriptions	Images
8 West of outfall and west of a large sandy inlet.	1.80 ha	A large **reef** and **sheet** bed Left image looking north up the shore on eastern side (May 2016). The SE corner of the bed is very small area of tall termite mound tube features. Majority of bed is low-lying and encrusting, in dispersed with occasional ball morphologies (< 15 cm in height) and boulders on rocky platforms. SW corner of bed is characterised by abraded tubes and relic tubes, and *U. lactuca* dominant on beds throughout much of western area (mid image of upper western side, right image relic tubes, August 2016).	  
9	0.09 ha	Small **sheet** bed. Low encrusting under *F. serratus,* with some tubes protruding	NO IMAGES AVAILABLE

Bed number/Approximate location	Approx. Coverage	Descriptions	Images
10 East of transect line LW	0.64 ha	Upper area is a **sheet** with abraded low encrusting structures on bedrock, interspersed with boulders (image of northern eastern corner of bed, August 2016). Lower area with **hummocks**, some abraded tubes, under fucoid on tide-swept fissures and bedrock.	
11 Eastern edge is located on transect line LW	1.75 ha	A very large bed extending westwards. interrupted at the lower shore by narrow sandy gullies (top right image shows an example of one, August 2016). The eastern area of the bed at low shore is **sheet** settlements (eroded in places) and, discontinuous under *U. lactuca* and *F. serratus.* Moving westwards, the low shore features **hummocks** < 10cm in height under *F. vesiculosus* (top left image). The upper area of bed is very abraded with low **sheet** crusts on tide swept platforms**.** The middle of the bed is **sheet** and **hummocks** < 10cm in height, with the lower areas under *F. serratus* and *Cladostephus spongiosus.*	 

Bed number/Approximate location	Approx. Coverage	Descriptions	Images
		The lower western area of the bed is low **hummock** mounds up to 10 cm in height, on bedrock, interrupted by fissures, under *F. serratus* and *C. spongiosus*. The upper area of western bed is low encrusting **sheet,** under *Condrus crispus F. vesiculosus* and *U. lactuca.* The bottom left image is of abraded tubes on the upper shore, and the bottom right image is of hummocks on fissures (August, 2016). **Note:** Beds present to the west of this point were not mapped. .	 
Nash Point (reference site)	3.25 ha	On the lower shore on broken platforms, colonies of low crusting **sheets** under algae and sponges. Throughout much of middle area of the bed are **hummocks**, upright discrete ball morphologies up to 20 cm height, with variable coverage densities between 30 and 80 %. Within sheltered gullies, larger morphologies present supporting abundant gastropod fauna (e.g *Nucella lapillus*). On the more exposed areas at the top of the bed, lower height features present < 10 cm, with a lower density coverage (10 – 30 %). Dominant algae species were fucoids, *Osmundea pinnatifida* and *C. spongiosus.* **Note:** area mapped formed part of a much larger bed.	 

5.3 Gastropod Health Assessment

5.3.1 *Littorina littorea*

Figure 5.7 shows the calculated mean Condition Index (CI) values for *Littorina littorea* sampled across Limpert Bay and the reference site Nash Point (NP). Although the data displays a lot of variability, a difference is detected between NP and sites within Limpet Bay. In all instances, NP had a lower least square mean values (14.18 ±0.38 (S.E)), which is in contrast, for example, to the site closest to the outfall (EO) which had a value of 18.82 ±0.41(S.E). The differences observed were found to be statistically significant (p<0.05), revealed by the post-hoc test (Holm-Sidak method) across the pre-trial (excluding HO and LE), trial, and post-trial periods (excluding HO). The post-hoc test was run following the results of the General Linear Model (GLM), which was unable to be properly interpreted as a statistically significant interaction (p<0.001, df = 8) between trial period and transect site was found.

Furthermore, statistical significant differences (p>0.001) in CI values within Limpet Bay itself were found during the trial period. This included EO, the closest site to the outfall, and the adjacent sites to the west and east, LW and LE respectively, where mean values were lower than at EO. Additionally, the difference between the two sites furthest from each other, LW and HO, was also statistically significant, as was HO and LE, with greater CI values at HO.

An element of temporal change can be also seen in

Figure 5.7, with lower CI values in the initial part of the trial period (March and April 2016), most notably for sites LE and NP. This was confirmed in the post-hoc test which showed a significant difference (p<0.05) between pre-trial, trial and post-trial periods at sites LE, LW, and NP, but not including HO where the difference was only between the pre-trial and trial periods. Interestingly, this is with the exception of the site closest to the outfall, EO, which showed no significant difference (p>0.05) in the CI across the sampling periods.

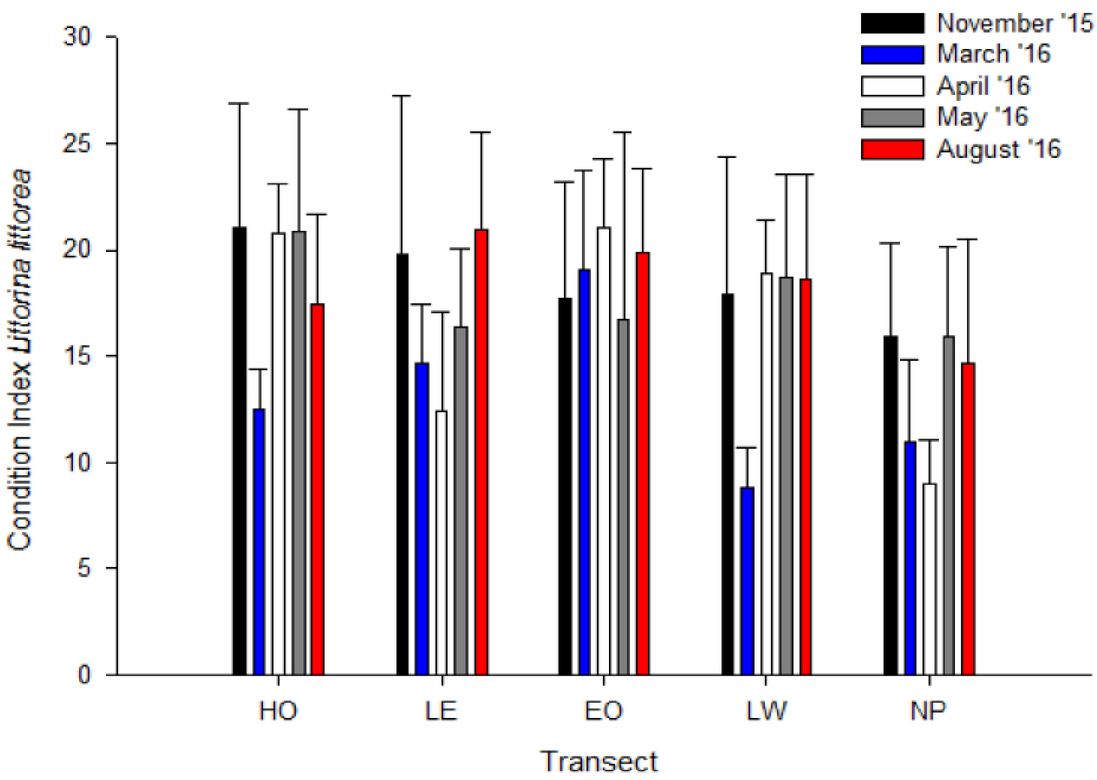


Figure 5.7 : Mean Condition Index (CI) of *Littorina littorea* (±StDev, n = 50*) sampled across Limpert Bay (Transects HO, LE, EO and LW) and at Nash Point (NP) between November 2015 and August 2016.* HO n = 29 and EO n = 38 in November 2015.

5.3.2 Patella vulgata

Figure 5.8 shows the calculated mean CI values for *Patella vulgata* populations sampled across Limpert Bay and at the reference site, Nash Point (NP). On examination of the data there is a high degree of spatial variability in the CI values for *P. vulgata* with the mean values ranging from 78.90 (at LW in November 2015) to 165.79 (at EO in May 2016), with no clear pattern across the Limpert Bay sites. This is supported in the General Linear Model (GLM) post-hoc test (Holm-Sidak method) where no statistically significant spatial difference (p=<0.05) for either the post-trial (August 2016) and pre-trial (November 2015) periods were found; with the exception of EO verses LW. However, this was not the case during the trial period (March – May 2016) where NP was significantly lower compared to the outfall site EO (p<0.001), and at the sites LE (p<0.001) and LW (p=0.004). The population at HO, the site furthest to the east, had significantly lower CI values than the other eastern sites, EO (p= 0.004) and LE (p= 0.002). A post-hoc test was used following the results of the GLM which found a statistically significant interaction between site location and trial period (p= 0.001, df = 8).

A degree of temporal change can be observed in Figure 5.8, with a general trend of increasing CI values with time. An example where this change is more defined is at the site HO, where the values of least square means increased from 101.0, 121.2, to 144.5 (from the pre-trail, trial and post-trial respectively), the post-hoc test finding a significant difference (p<0.05) between all periods. This was not the case for all sites. A significant increase in CI (p>0.05) was found between the pre-trial and trial periods at all sites, with the exception of NP where there was a significant increase from the trial to the post trial period (p<0.001).

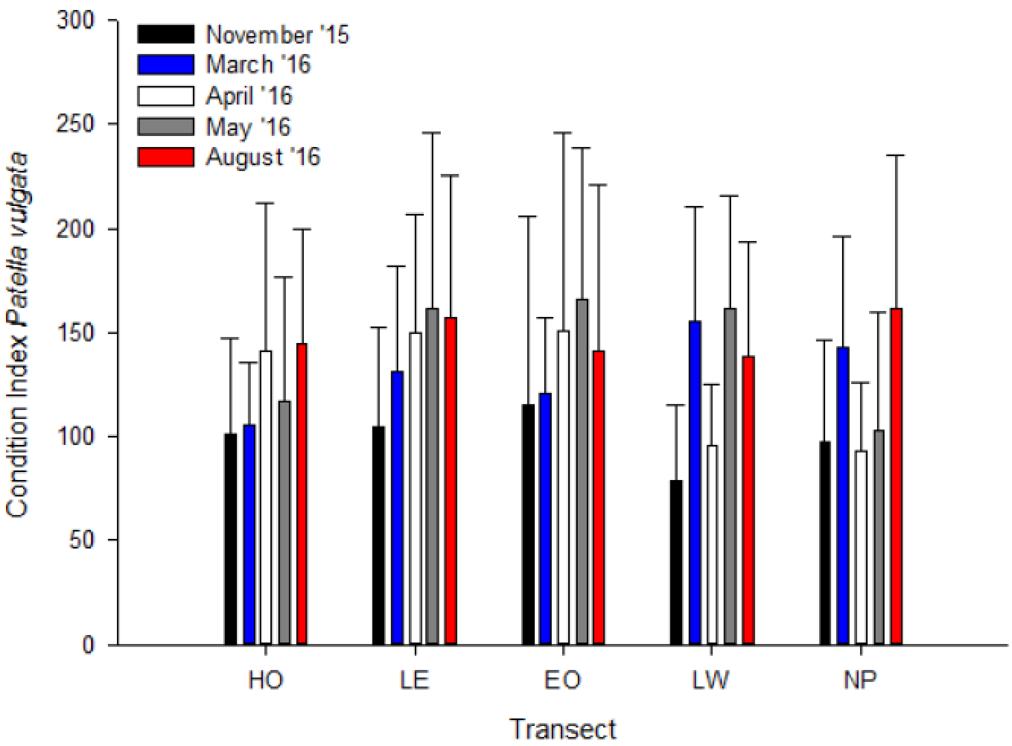


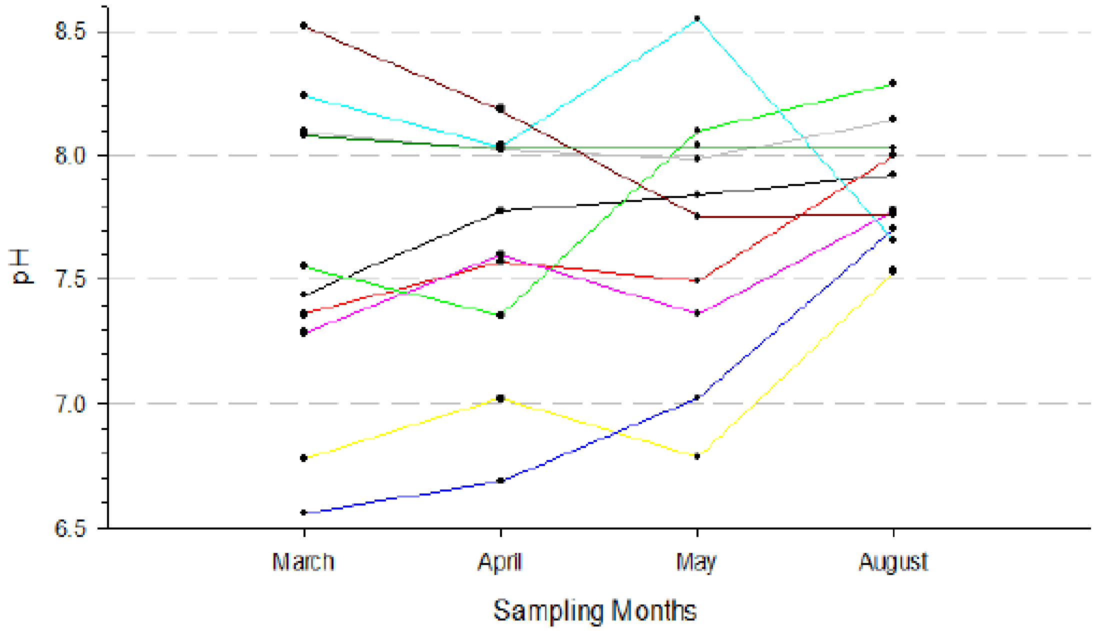
Figure 5.8 : Mean Condition Index (CI) of *Patella vulgata* (±StDev, n = 50) sampled across Limpert Bay (Transects HO, LE, EO and LW) and at Nash Point (NP) between November 2015 and August 2016.

5.4 Physico-chemical water quality

The physico-chemical data have provided indicative information about the spatial variation in water quality conditions across the study area. Figure 5.9 shows the pH and temperature data from nine of the 11 sites at Limpert Bay and at the reference site at Nash Point (referred to as 'pH_13') during the trial and post-trial in August 2016. All recorded parameters are listed in Appendix L (e.g. salinity, DO %).

The two sampling sites closest to the cooling water outfall structures ('pH_5'and 'pH_6') both reported the lowest pH and highest temperatures values. During the trial, pH values ranged between approximately 6.5 and 7. Maximum water temperatures were also reported at 'pH_5'and 'pH_6' throughout the trial period, with a decrease in August as station activity reduced. Increasing temperatures were reported at those sites remote from the effects of the discharge's thermal plume, which were linked to seasonally increasing water temperatures.

The reference site exhibited stable pH conditions over the monitoring period, with values ranging between 8.03 and 8.08. The reference site recorded the lowest surface temperature readings recorded in March, but temperatures were generally within the range of those recorded at sites remote from the cooling water discharge at Limpert Bay.



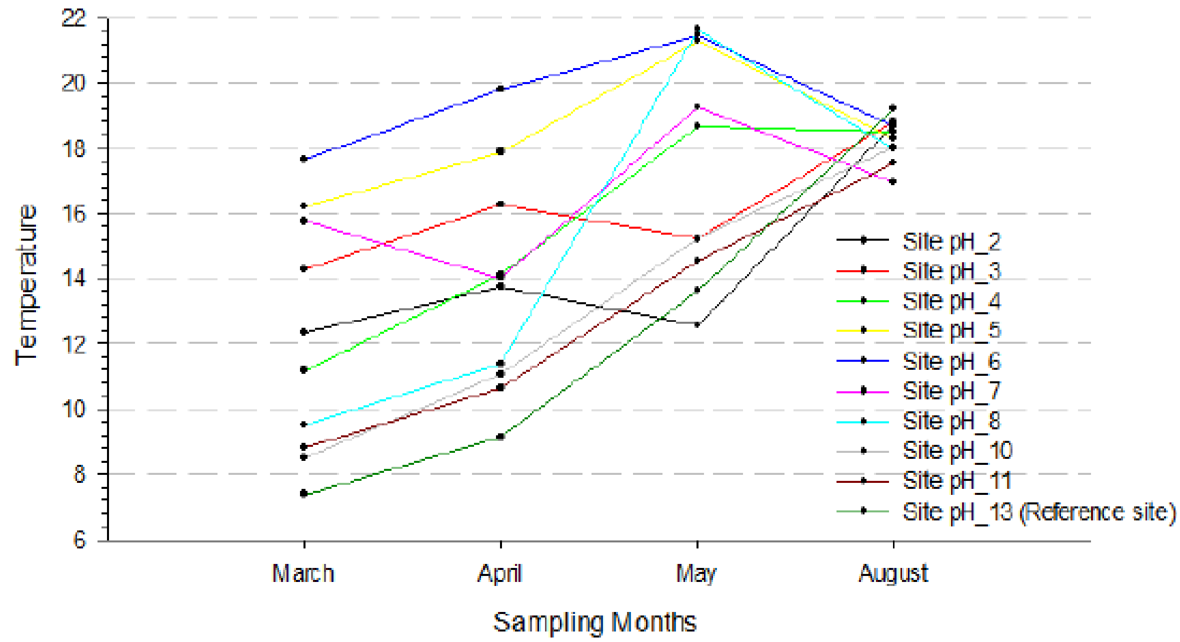


Figure 5.9 : pH and temperature measurements at Limpert Bay and Nash Point (site 'pH_13') sampled between March and August 2016. (data for 'pH_1', 'pH_9' and 'pH_12' are not shown here as data was not available for all four months)

5.5 Additional field observations

In addition to the formal monitoring procedures, surveyors also recorded incidental and seasonal changes observed across the study area during the monitoring period. Observations included:

- Increased growth of the opportunistic macroalgae (e.g. Sea lettuce *Ulva lactuca*) was notable towards the west of Limpert Bay and at Nash point from the April sampling period onwards. This was commonly observed on top of *Sabellaria alveolata* beds.
- Non-native invasive algae Sargassum multicum was found growing in the large shallow rock pools just to the east of the outfall in March 2016. Subsequent surveys found increased coverage (longer fronds), but still within a limited area east of the discharge.
- Settled sporelings of fucoid algae were apparent across rocks during the August surveys.
- The calcareous algae Corallina sp. was recorded across the mid and lower shore transects. However, the data does not reflect the presence of this species across the mid to lower shore areas at both Limpert Bay and Nash Point. This species was commonly found inhabiting the large shallow rock pools at Limpert Bay; a microhabitat avoided when situating quadrats.
- Rock pools are a common feature across Limpert Bay providing refuges for other species of macroalgae and gastropods. During the August surveys gobies and carideans (shrimps and prawns) were commonly observed in the pools.
- In May 2016 at Nash Point where the greatest densities of barnacles were observed, barnacle cyprid larvae were observed across the rocks. In the following survey, three months later these were absent and a greater proportion of barnacle spat were recorded. In addition to this in the upper to mid shore zones at Nash Point, very small littorinids were observed, often refuging within dead barnacle shells.
- Juvenile mussels were observed settled within the fissures of the upper and mid shores zones at Nash Point, flush with the rock surface and larger individuals within the lower region of the shore.

6. Potential Effects

Typical pH levels in UK estuaries range between 7.0 - 8.3 (Wolff *et al.,* 1988). The pH of the Bristol Channel/ Severn Estuary remains fairly constant, ranging between 8 - 8.2 (Ellis, 2003). Ambient pH conditions reflect the equilibrium between atmospheric carbon dioxide levels and levels of aqueous carbon dioxide, carbonate and bicarbonate. Small variations in the pH of seawater can occur on a diurnal and seasonal basis, which are generally associated with phytoplankton activity. Elevated pH levels result from increased photosynthetic activity and the associated increase in the uptake of aqueous carbon dioxide. The rate of photosynthesis is affected by the supply of nutrients, organic carbon and turbidity (UK Marine SAC, 2015; Middleboe and Hansen, 2007).

The discharge of effluents containing acids and alkalis can affect the pH of seawater, although the generally high buffering capacity of seawater ensures that pH levels return to ambient relatively quickly. Any variations in pH arising from a discharge are therefore likely to be local to the discharge point.

The direct effects of a change in pH in the marine environment can include:

- The potential for the release of CO_2 following the rapid release of acids;
- Influence on the speciation and toxicity of substances, such as ammonia, silicate, phosphate, borate, metals and some phenolic organic compounds; and
- Lethal and sub-lethal effects on marine organisms (both direct and indirect).

At pH 8, bicarbonate is the predominate carbonate species, but below pH 6, CO_2 predominates, so that the rapid discharge of acids to tidal waters may result in the liberation of sufficient CO_2 to be lethal to aquatic life. pH also affects the equilibrium position of other chemical reactions, such as that for silicate, phosphate, borate and ammonia. For example, at a high pH the proportion of the toxic unionised form of ammonia increases and may cause water quality problems. Conversely, a low pH can increase the solubility of toxic metals, such as cadmium, copper, lead, aluminium, mercury and zinc. However, the degree of metal mobilisation in high alkalinity saline waters is low compared to that of freshwaters.

Modelling undertaken for the Aberthaw pH variation indicates that with a discharge of pH 5.6[3], a mixing zone would extend over an area approximately 900 m long and 400 m wide before ambient conditions re-establish themselves. A similar area has been modelled for the existing discharge conditions (i.e. pH 5.8). The model also indicates that differences between the predicted surface pH with a discharge of 5.8 (current limit) and a discharge of 5.6 (trial limit) are small and limited to the immediate vicinity of the outfall, with pH values ≥ 7 predicted within 350 m of the discharge.

Overall, the modelled data indicates that conditions are on the whole not measurably different between the current and the trial discharge pH condition. This indicates that the cooling water discharge is rapidly mixed and buffered within a short distance of the outfalls.

As a result of the monitoring undertaken and the apparent localised mixing zone, it is considered that a discharge with a lower pH will not be an important issue in the context of the wider geographic area of the Severn Estuary/Bristol Channel. As a consequence, it is considered that the proposed change in the discharge is unlikely to affect the marine ecological receptors and/or sites of conservation importance that have been previously identified, although these are discussed in more detail below.

A number of example lethal and sub-lethal threshold pH values for fish and other marine organisms are given in Table 6.1. Although not all the species listed are present at Aberthaw, the data presented indicates the potential

[3] For the purpose of this report the pH of the actual cooling water discharge into the Bristol Channel remains as the Seal Pit discharge pH value. A limited data set obtained via spot sampling of the discharge at low tide suggest that the pH is somewhat higher, typically 0.2 pH units higher due to the continued oxidation process that occurs during the passage of the effluent along the 300m pipe between the Seal Pit and the outfall. This statement is yet to be fully qualified, however it would suggest that the assumption that no additional oxidation occurs during passage along the 300m pipeline is a conservative approach.

for impacts associated with low pH seawater and will be discussed in detail below. Laboratory studies do not always afford potential acclimation periods (Gazeau *et al.,* 2013), that in nature, organisms may then utilise to adapt to changing environmental conditions, hence, the values listed may be an underestimate of natural threshold values.

Table 6.1 : Reported critical pH levels for lethal and sub-lethal effects. Data from Bamber (1985, 1987, 1990), Batten and Bamber (1996), Langford and Bamber (1984), Bibby *et al.* (2007) and Bonner *et al.* (1993) (review by Innogy, 2003).

BIOTA		Threshold of lethal effects	Threshold of sub-lethal effects
ANNELID WORM	King ragworm (*Nereis virens*)	-	≤ 6.5
BIVALVE MOLLUSC	Blue mussel (*Mytilus edulis*)	6.6	≤7
	Native oyster (*Ostrea edulis*)	6.9	≤ 7
	Pacific oyster (*Crassostrea gigas*)	6.0	≤7
	Grooved carpet shell (*Ruditapes decussata*)	-	≤7
GASTROPOD MOLLUSC	Common limpet (*Patella vulgata*)	-	5.5
	Common periwinkle (*Littorina littorea*)	-	6.6
FISH	Bass (*Dicentrarchus labrax*)	5.6	6.3
	Rock goby (*Gobius paganellus*)	5.0	5.85
	Plaice (*Pleuronectes platessa*)	5.5	6.0
	Dab (*Limanda limanda*)	5.5	5.5
	Thick-lipped grey mullet (*Chelon labrosus*)	5.17	5.17
	Sea trout (*Salmo trutta*)	6.0	6.0

6.1.1 Heavy metals

Seawater contains a very wide array of trace metals and other substances, from both natural and anthropogenic sources. The pH of water determines the solubility and the biological availability of chemicals, including certain heavy metals. The acidity of the water drives equilibrium to be rapidly reached, through buffering, chelation, reaction to form insoluble salts, and inclusion in sediment layers. A reduced pH can lead to increased metal toxicity and increased availability to aquatic organisms from both the water and associated sediment layers.

Trace metals, with their ability to be concentrated up through the food chain are a group of contaminants of some concern. Many of these substances are liable to bioaccumulation, with potentially serious consequences for higher trophic levels in the food web (including man). In addition, raised levels of trace contaminants can lead to growth inhibition and many other sublethal effects in marine algae, phyto- and zooplankton and macro-invertebrates, and promote changes in the food web by favouring the growth of species and forms tolerant of raised trace metal levels.

Owens (1984) reviewed metal concentrations in the Severn Estuary and Bristol Channel and concluded that while concentrations were higher than in some other estuaries, there was no evidence of any impact on the zooplankton community and metal concentrations in some commercial fish and shellfish were no higher than in other coastal waters. However, in some non-commercial species, such as limpets and winkles, increased metal concentrations have been recorded while elevated levels of mercury were also recorded in dogwhelks, limpets and fucoid algae from the immediate vicinity of the discharge at Aberthaw (Jacobs, 2016).

The predicted concentration of metals in the cooling water discharge with the new coal source is less than the MAC (Maximum Allowable Concentrations) concentrations for the key elemental components of the diet. For chromium the predicted discharge concentration of 0.87 µg/l is greater than the Annual Average EQS of

0.6 µg/l. However, as the chromium EQS is for chromium VI, whereas the predicted concentration is for all chromium species, it is anticipated that chromium VI concentrations will be lower than the predicted discharge concentration of 0.87.

As dissolved trace metals concentrations in the discharge are not anticipated to exceed the EQSs, the discharge itself will not result in significant changes to the background levels in the receiving environment. However, there is the potential for the reduced pH plume to alter the availability of existing metal loads in the waters and sediments adjacent to the discharge.

Based on the modelling output and the conservative approach taken to predicting the pH at the point of discharge, it is considered that there will little or no discernible change in the pH conditions in the vicinity of the outfall, and hence no change to availability of dissolved metals.

6.1.2 Dissolved Oxygen

The FGD Process technology employed at Aberthaw Power Station uses seawater and its natural capacity to absorb and neutralise a high percentage of SO_2 from the flue gases. After seawater passes through the plant it is aerated to reduce chemical oxygen demand (COD) and acidity before being returned to the sea. The process operates by using the natural alkalinity of seawater to convert the acidic components of the flue gas into the minerals sodium and calcium sulphate and sodium and calcium chloride; the sulphates are naturally occurring minerals and are already present in seawater at high concentrations, while the chlorides are naturally present at very high levels. Using a coal source with increased sulphur load will result in higher levels of sulphites thus increasing the COD of the effluent from the plant. This could have implications of lowering the dissolved oxygen of the final discharge to sea.

The lethal and sub-lethal effects of reduced levels of dissolved oxygen are related to the concentration of dissolved oxygen and period of exposure of the reduced oxygen levels. A number of animals have behavioural strategies to survive periodic events of reduced dissolved oxygen. These include avoidance by mobile animals, such as fish and marcoinvertebrates, shell closure and reduced metabolic rate in bivalve molluscs and either decreased burrowing depth or emergence from burrows for sediment dwelling crustaceans, molluscs and annelids. Stiff et al. (1992) and Nixon et al. (1995) identified crustacea and fish as the most sensitive organisms to reduced dissolved oxygen levels with the early life stages of fish and migratory salmonids as being particularly sensitive.

Data from the station seal pit discharge sampling point indicates that oxygen saturation levels are at 100% prior to discharge to sea under current conditions. However, dissolved oxygen levels will vary with temperature and salinity. For a maximum temperature change of 13.5ºC across the cooling water system the dissolved oxygen content will change by approximately 15% assuming the oxygen saturation level is kept at 100%. The modelling predicted there will be not changes as a result of the proposed variation to the discharge.

The intertidal habitats to the east and north-east of the outfall may be subject to any decrease in dissolved oxygen in the discharge. However, due to mixing and dilution, the area will be limited and, if as predicted, there is no change in dissolved oxygen discharge conditions, no increased effects are expected across the intertidal habitats. Spot sample DO readings taken during the present study were very variable across all sites, reflecting the natural fluctuating conditions of the shallow tidal waters. Measurements taken directly by the eastern outfall appeared relatively stable, ranging between 98.38% and 98.73% during the trial period. As detailed previously, mobile species, particularly fish and mammals, will show avoidance response to areas of low dissolved oxygen, consequently no increased impacts on fish or marine mammals are anticipated.

The sections below provide details of the potential effects on the marine receptors identified related to changes in the pH of their environment.

6.2 Benthic communities and habitats

The intertidal rocky shore communities and their general spatial patterns across Limpert Bay as described by Bamber (1997) were largely corroborated by the field assessments undertaken for this study. Fucoids, coralline algae, *Ulva lactuca* and gastropod and barnacle fauna characterised the shore community, with localised shifts in structure with distance from the outfall and as a result of natural influences. The benthic community recorded across Limpert Bay are on the whole representative of the natural environmental conditions and seasonal patterns. There are some localised distribution patterns that may be as a result of the long term activity of the station, but the results of recent study indicate no short term temporal alterations due to the variation in the pH of the discharge.

6.2.1 Low shore

The discharge modelling has shown that an area in the immediate vicinity of the outfalls will be exposed to effluent with a lower pH, particularly at low water due to the reduced amount of seawater available for mixing and buffering the effluent at this point in the tidal cycle. At low tides and shortly thereafter, limited mixing is expected to result in a small area in the immediate vicinity of the outfalls at pH 5.6. This pattern was attributed to the effect of the heated effluent water lifting across the rocks on the rising tide. The extent of this impacted area has been estimated as being a radius of 50 – 100 m from the cooling water outfall structures and is skewed to the east and north-east due to the direction of the incoming tide. *In situ* surface measurements of pH taken during the trial directly by the western outfall structure recorded a minimum value of 6.56 in March 2016, demonstrating a potential instant mixing and buffering of the effluent with seawater. Hence, the area predicted to be directly affected by reduced pH may be much smaller than anticipated.

The lower shore communities exhibited clear spatial differences, as demarked by their location along the shoreline, but also in their proximity to the outfalls. Significantly fewer taxa were reported at the site closest to the outfall (EO), however, there was no change in species richness during the sampling period at this site, signifying no discernible effect of the reduced pH on the overall structure of the community. Toothed wrack (*Fucus serratus*) was often common at this site, with some coverage of the honeycomb worm *Sabellaria alveolata*, and communities here were similar to those at the neighbouring site LE. 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 seaweed species, while the densities of barnacles and dog whelks were also reduced. The opportunistic species *U. lactuca* was recorded at EO, but was not as dominant on the shore compared to coverage recorded from the western site LW and at the reference site NP. Rockpools were avoided during the field assessment, and these features often supported the erect *Corralina* sp and therefore, will be under represented in the community data set presented here. However, red algae were observed to be present across the shore in the shallow rock pools along the bedrock ledges of the lower and mid shore areas. If historically, and during the present study, the reduced pH conditions were of significance to communities within the vicinity of the outfalls, then calcareous algae such as *Corralina* sp. would be likely absent as calctic species have been shown to decrease in terms of coverage along a decreasing pH gradient (Porzio *et al.,* 2011).

Different marine algal species have a wide range of tolerances, with different optima for different physiological or reproductive processes; hence not all species will be equally affected by a change in environmental conditions. At low pH, the increased free CO_2/bicarbonate ratio may favour some species, but hinder growth/reproduction in others (UK Marine SAC, 2015). Several species show reduced calcification as pH is reduced towards 6. The macroalgae species commonly recorded adjacent to the outfall (site EO) during the study was the brown fucoid algae *F. serratus*. During periods of low water exchange (e.g. during low water), members of the fucoid brown algal group *Fucaceae* have been shown to increase the pH of the water in rock pools up to 9.7 (Axelsson and Uustalo, 1988). Any local decreases in pH in the vicinity of the outfall may be potentially offset at a small scale by the phytosynthetic utilisation of HCO_3^- by macroalgae, even in elevated CO_2 concentrations (review by Gao and McKinley, 1994).

A notable spatial difference across the low shore of Limpert Bay was lower coverage of *S. alveolata* in the vicinity of the outfall, with a higher coverage to the west with an associated increase in the cover by the seaweed *Cladostephus spongiosus*; a species also common on the low shore reference site (*S alveolata* to be discussed further in 6.4 below). Temporal differences in the coverage of *S. alveolata* were recorded at EO, however, as there was no unidirectional trend in the abundance (e.g. fluctuations were apparent), which was indicative of the naturally low and patchy coverage of the tubes at this site. EO is situated in the vicinity of the upper area of *S. alveolata* bed number 3, an area less developed than its lower littoral populations. Under laboratory conditions *C. spongiosus* has been shown to be confined to acidic conditions (Porzio *et al.,* 2011) and its distribution in the western areas of Aberthaw is likely to be driven primarily by natural factors and not artificial ones.

6.2.2 Mid shore

The modelling has indicated that an area of the intertidal ledges to the east and north-east of the outfall will be subject to the cooling water plume on a rising tide. As such, if the plume migrates in a north east direction there may be expected to be some influence of the plume on the mid shore communities at sites EO and LE. However, the model has also shown that the area influenced by the plume will be similar to that under the current discharge conditions, and as such no difference is predicted to be evident beyond a distance of 350 m from the outfalls. Consequently, any impacts associated with changes to the pH of the discharge will be limited to this area.

The community analysis of the mid shore communities were not as distinct from one another at such a spatial scale as the low shore communities. The mid shore was characterised by fucoid algae, gastropods and barnacles. Analysis of the data showed that the mid shore zone at the reference site did not reflect the community recorded at Limpert Bay, with barnacles dominant and a virtual absence of fucoids. This difference is likely to be associated with a natural pattern of increased exposure at NP. Aside from this, communities across the mid shore at Limpert Bay did not indicate an obvious spatial pattern, but only a broad increase of taxa richness from east to the west, and with no significant reduction at EO, by the outfall. Community level changes at EO during the trial included a reduction in juvenile littorinids, which is likely to be a natural progression of shifting demographic patterns with a maturing population across the shore. This species can breed all year around, but their development mechanism is primarily planktotrophic, so any influences of the outfall on the community may be difficult to elude with recruitment potentially sourced from areas remote to Aberthaw. As such, there was no indication of temporal variability occurring as a result of the reduced pH conditions during the trial.

The invasive brown seaweed *Sargassum multicum*, native to the North-western Pacific was observed in the shallow rock pools along the mid to low shore levels to the east of the outfall structures during the spring and summer surveys, with an observed localised increase in coverage during this time. This species was not observed by Bamber in 1997 suggesting a relatively recent establishment in the area. Large increases in the occurrence of this species have been recorded further north and in the Irish Sea since its introduction to the UK in the 1970's (Yesson et al, 2015; Bunker *et al.,* 2012), and as such its appearance is not to be unexpected. Its growth is positively correlated with summer temperatures and its localised distribution by the relatively warmer waters of the outfall is not at all surprising. The congeneric species, *Sargassum vulgare* has been shown under artificial conditions to be abundant at lower acidities of 6.7 compared to higher experimental thresholds of 7.8 and 8.1 (Porzo *et al,* 2011), and it may be that *S. multicum* is equally tolerant to such environmental conditions.

6.2.3 Upper shore

Across the upper shore, there were no detectable temporal community changes during the pre-trial, trial and post-trial period that could be related to the pH variation at the station. The upper shore was commonly inhabited by fucoid algae and gastropods, and by the sand mason worm *Lanice conchilega* where areas of sand naturally promoted colonisation, notably at the upper shore site EO. Spatial differences were detected between the reference site and sites at Limpert Bay. At Nash Point algal cover was lower and the rocky platforms were dominated by barnacles and limpets. This is likely to be attributed to differences in exposure where such organisms can withstand the increased periods of wind and wave exposed emmersion. Lower species richness was recorded at EO but only during the pre-trial period in November 2015, and post-trial in August 2016.

The distribution patterns of mobile crustacean fauna such as amphipods (e.g. *Gammarus* spp.), prawns (*Palaemon spp.)* and crabs (e.g. *Carcinus maenas*) at Aberthaw are difficult to determine. Quantitative data from the field assessments of recordings of these fauna in the quadrats across all shore levels may not necessarily be indicative of any true spatial ranges, in contrast to their neighbouring sessile biota. Some crustaceans survive at well below pH 6.0, but others experience acute pH effects when values are in the range of 5.5-6.7 (Wolff et al., 1988). Their relatively higher motility would allow avoidance of unsuitable conditions with their combined swimming and burrowing capabilities potentially utilised.

6.2.4 Gastropod populations

The most abundant mobile invertebrate fauna common across both shores were shelled molluscs, and notably gastropods species such as limpets (*Patella vulgata)*, winkles (*Littorina* spp) and topshells (*Gibbula cineraria*). These abundant grazers are important bioengineers on the shore, controlling algal establishment and growth on the hard substratum. The distribution patterns and features of the gastropod population across Limpert Bay will be related to multiple interacting natural physical and biological factors, alongside the potential influences of power station.

Shelled molluscs are sensitive to reduced pH conditions with behaviour altered, calcification processes becoming disrupted and respiration rates influenced; potentially leading to increased mortality. Behavioural and physiological responses are utilised by molluscs to trade-off and compensate for their changing environment, increasing body burdens with responses differing between and within species (review by Gazeau *et al.,* 2013). Adverse effects are seen at pH levels greater than 8.5 and less than 7.0 (see Wolff *et al.,* 1988). *L. littorea* and *P. vulgata* have documented sub-lethal pH threshold limits of 6.6 and 5.5, respectively. The limpet (*Patella vulgata*) shows behavioural responses when exposed to seawater of pH 5.5, although once normal seawater conditions return, normal behaviour is re-established (Bibby et al., 2007); similar responses are observed in the periwinkle (*Littorina littorea*) at a pH of 6.6 (Bonner et al., 1993).

Across the low shore, populations of adult *Littorina littorea* were common but in relatively low numbers. Populations were recorded at the eastern sites where fucoid cover dominated, but were absent to the west at LW. At the reference site NP where honeycomb worm tubes encrusted the substrata at the low shore level, no temporal change in the abundance of littorinids were detected. A wider range in distribution and higher abundances of these winkles was apparent across the mid shore zones, with occurrences at all sites, in all sampling periods, although no spatial or temporal patterns were apparent. The lower tidal limit of *L. littorea* is poorly defined, and movement of local populations upwards from the lower shore may occur in warmer months (MarLin, 2016) and be limited in its upper range by physical factors. Across the upper shore where this species' tidal range may encroach, individuals were observed, but numbers low and with none recorded at HO.

Data suggests that resident populations of adult *L. littorea* naturally undergo a period of cessation in growth during the winter months, as indicated by the CI assessment of the sampled populations. At all sites (except at EO) there was a significant decrease in the CI values between the autumn and early spring, with a subsequent increase in the CI values later in the trial period. Considering this, the condition of the population in closest proximity to the cooling water discharge may potentially not have altered during the winter, suggesting a possible buffering effect of the thermal plume against the seasonal decline in sea temperature, thus stabilising growth and development.

There was no evidence from the field assessments to report any changes in the estimated health of *Patella vulgata* collected during the trial period to indicate any possible effects of the modified discharge. A high degree of variability was detected in the condition index, both between and within individual populations, which is likely to be naturally driven differences (e.g. developmental stage, sex, environmental conditions). There can be seasonal variation in growth rates of limpets, with little growth during winter months and associated lower weights recorded during this time (Blackmore, 1969). A general pattern of increased condition of the populations was reported over the monitoring programme at sites in the east of Limpert Bay; including the site adjacent to the outfall, thus supporting the assertion that the trial had no influence on the gastropod mollusc population.

The samples collected (for both species) from the reference site at Nash Point reported significantly lower CI values. It is thought that the lower values are as a consequence of the harsher, more exposed environmental conditions experienced in this area, which can influence the potential developmental patterns of organisms where impacts of wave and wind action will provide unstable conditions in which to grow. At Nash Point, barnacles had a relatively greater abundances than macroalgae and other biota, and these lower profile species are perhaps better adapted to surviving in such environments.

The dogwhelk *Nucella lapillus* was also present in the study area and was predominantly found across the lower shore areas. Bamber (1997) reported an absence of *N. lapillus* in the locality of the outfall, and this is concurrent with the quadrat assessments completed in the current study where none were recorded at all shore levels at EO and LE over the survey period. Greater populations were recorded at the most eastern site (HO), and at the far western reference site at Nash Point. Their absence in the quadrats at the sites by the outfalls may not be purely indicative of their proximity to them. *N. lapillus* and other mobile gastropods are gregarious in nature so a recorded absence may also be compounded by any smaller scale distribution patterns. During collection of this species as part of the FGD annual spring surveys for metals analysis, difficulty in sourcing and collecting suitably sized individuals across each of the four transects (HO, LE, EO and LW) at Limpert Bay has been reported (Jacobs, 2016). However, their broad distribution patterns may be also related to exposure and resource exploitation. Greater abundances were reported at the reference site and the more exposed outer areas of Limpert Bay (HO and LW), mirroring the pattern of higher abundances of barnacles in the mid shore at these sites. Barnacles are a common food source for these mobile carnivorous gastropods (Crothers, 1985).

6.2.5 *Sabellaria alveolata* beds

6.2.5.1 Distribution patterns

There are relatively extensive beds of *Sabellaria alveolata* (honeycomb worm) present across Limpert Bay, notably in the western areas. The current study identified that the beds in the west were extensive and that this unique habitat was also present immediately to the east of the outfall, albeit to lesser of an extent. This is in contrast with the NRW biotope survey where temporal comparisons of the data sets have identified some differences in the extent of the beds. The historic data reported the far western beds as hugging the lower shore, whereas in the present study it shows there to have been a landward extension of these beds. No *S. alveolata* biotopes were identified to the east of the cooling water discharge structures by NRW or to the east of the transect line HO and ascribed much of the Gallant Acre area (beds 1, 2 and 3) as having predominantly fucoid coverage. The presence of beds to the east of the outfall potentially precludes concerns that the successful establishment of this species on the shore is restricted by cooling water discharge.

The local geomorphological and hydrological conditions of Limpert Bay may provide the potential opportunity for the colonisation and horizontal extension of *S. alveolata.* This polychaete worms requires a hard substratum on which to form, coupled with strong water movements for the suspension and transport of adequate supply of sand to enable tube construction to occur (Allen *et al.,* 2002); the sand flats to the west of the outfall likely provides a localised source of sediment.

The scale of bed assessment undertaken here would exclude any fine scale observations of change occurring that may be remnant of the long term activity of the station. However, broad patterns in bed features across the shore were apparent, with upper areas of beds predominantly comprised of lower elevated structures; possibly in relation to increased wave exposure and lower relative sediment supplies in these higher shore areas. To the immediate west of the outfall *S. alveolata* was present across the terraces, and the larger bed in this area (bed number 5) encompassed these terraces, which on a smaller scale would further divide this bed.

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). The overall state of the beds present across the study area is in agreement with Innogy (2003) that reports them to be of reasonable quality with a mixture of low crusts, 'ball' formations and small reefs. To the immediate west of the western outfall, *S. alveolata* is present, but in the form of a sheet bed with low crusts under fucoids, however to the south west of this bed growth is more elevated with hummocks and a continuous low reef present. Immediately to the east of the eastern outfall (bed number 3), a similar pattern was noted and with the biotope also present by the discharge channel. The structure of the beds across the study area will not be indicative of the age of the resident polychaete population as it is a result of successive populations, and similarly variations in morphology can be due to physical and biological factors (Allen *et al.,* 2002). The abraded tubes apparent in the western areas of Limpert Bay are indicative of the increased exposure towards the outer parts of the bay and with observed relic tubes indicating that a possible local destruction event may have occurred. In the western areas during the warmer months of the study, increased areas of the beds were covered by the opportunistic macroalgae species *Ulva lactuca,* and this occurrence has been documented for other beds in the south of the UK (Boalch, 1957). Young worm colonies can remain free of epiflora, whereas older tubes provides suitable substratum for such species (Allen *et al.,* 2002), and it may be inferred that in such areas of the beds that the structures are in the later stages of their natural cycle.

6.2.5.2 Pressures

S. alveolata are sensitive to a suite of anthropogenic stressors. These may include the smothering by or starvation from sediment via changes in sedimentary regimes or from mussel cultivation and direct physical disturbances from trampling, bait digging and fishing (Plicanti *et al.,* 2016; review by Noernberg *et al.* 2010 and Allen *et al.,* 2002). Recovery rates of *S. alveolata* to some forms of physical damage have been shown to be relatively high via the rapid rebuilding of tubes by the worms, confirming it to have high resilience to such pressures (review by Gibb *et al.,* 2014).

There is insufficient information available in the current scientific literature to determine with absolute certainty the sensitivity of *S. alveolata* to changes in pH. However, various studies carried out on *S. alveolata* have, like the congeneric species *Sabellaria spinulosa* (Ross worm), indicate that these sabellarid worms are tolerant of a wide range of conditions and, provided that suitable substratum is available, can rapidly recolonise areas that have been disturbed (Jackson, 2008). Although the predominantly intertidal *S. alveolata* differs in its ecological niche from the subtidally occurring *S. spinulosa*, the worms have similar life strategies and where information is available on the sensitivity of the worms to specific physical, chemical and biological factors, they have shown comparable levels of tolerance (Jackson, 2008).

A study by Hoare and Hiscock (1974) investigating the distribution of marine organisms around the outfall from a bromide extraction plant in North Wales, recorded *S. spinulosa* closer to the outfall than any other organism. The effluent at the outfall had a pH of 4 and, among other contaminants, contained free halogens. Although caution should be applied when suggesting that this tolerance might also be true of *S. alveolata,* it is considered that, in the absence of studies specific to *S. alveolata*, some indication of its sensitivity can be derived from studies carried out on *S. spinulosa*.

Despite the limited information available on the sensitivity of either sabellarid worm to specific changes in water chemistry, there is additional evidence that suggests a reasonable level of tolerance to outfall discharges. For example, work by Bamber and Irving (1997) at the cooling water discharge at Hinkley Point found that the growth of *S. alveolata* tubes in winter was considerably greater where water temperature was raised by approximately 8-10°C, than at the control site.

As natural physical factors will also be important for the development and health of *S. alveolata*, such as with any seasonal changes in temperature and exposure, this may compound interpretation of any potential impacts of the operational activity of the power station. Biological interactions such as competition is also important and there is documented evidence of competition between the sabellarids and the blue mussel *Mytilus edulis* (Jones, 1972). Mussels were commonly observed at the reference site but only in low numbers, and as such are not considered to be of significance here. On the eastern side of the outfall at Aberthaw, the non-native *Sargassum multicum* was recorded, albiet in a localised area and possibly influenced by the warmer waters of the thermal plume. This species is known to compete for space with the intertidal populations of *S. spinulosa,* (review by Gibb *et al.,* 2014). *S. multicum* is restricted to the large rock pools of the low to mid shore across the study area and may not be able to encroach on the beds at these higher shore levels, without the protection of immersion in rockpools.

Populations of *S. alveolata* have colonised parts of the low shore in the eastern area of Limpert Bay, and within the footprint of the outfall itself, with large beds still remaining to the west of this point. As the area over which any lowered pH would be experienced is limited to the immediate vicinity of the outfalls and concentrated to the east, it appears unlikely that *S. alveolata* in consideration of its presence and establishment across the Limpert Bay and by the outfall would be significantly influenced by the proposed variation to the discharge.

6.3 Aberthaw Lagoon and saltmarshes

Lagoons are an important conservation habitat, supporting a unique community of rare plants and animals, and by nature of their size and location along the coastal fringes can be prone to degradation or destruction by pollution and mismanagement (Bamber *et al.,* 1993). Benthic lagoon fauna are a specialised group of organisms, pre-adapted to fluctuating environmental conditions. Lagoon variability is, however, slow enough for evolving tolerances and genotypic changes within species. For example, organisms may exhibit reduced planktotrophic larval periods (e.g. *Cerastoderma glaucum*) or adopt direct brooding strategies (e.g. *Ecrobia* *ventrosa*). A *K*-strategy lifestyle appears typical for such species to maximise competitive ability against non-lagoonal species (Little, 2005; Bamber *et al.,* 1993), and the lagoon at Aberthaw has been reported to support such as assemblage of specialised taxa.

At Aberthaw, at the top of the shore, there is a small area of saltmarsh and creek system in front of the seawall and lagoon. The halophytes present are typical of saltmarsh habitats with sea lavender (*Limonium* spp.) and shore dock (*Rumex rupestris*) recorded as being present (Innogy, 2003). Saltmarsh habitats are important areas supporting migrating and roosting birds and potentially nursery areas for fish.

Modelling has predicted that during HW spring tides, the low pH plume will be confined to an area immediately west of the outfall. Water in the vicinity of the area in front of the lagoon and saltmarsh at the upper reaches of the shore during HW spring tides, is predicted to have a pH higher than 8. It will be under such HW spring conditions when the water exchange may occur into the saline lagoon either through the ingress of the water via the seawall, overtopping during storm events, or via the small pipeline. Innogy (2003) in discussing an earlier report by Bamber (2001) which had identified the lagoon as being of 'low salinity good quality' type with salinities mainly in the range of 10 to 15‰, stated that it was possible that any change in CW effluent composition could potentially impact upon the habitat due to its limited exchange with the sea. It is now thought that there are in fact higher and more variable salinities occurring in the lagoon, which are dependent upon seasonal inputs (Welsh Wildlife Trust *pers. comm.* September 2016).

It is considered that the current influence of the plume is limited in its extent in these upper shore areas during HW spring tidal conditions, and thus it can be considered that any variations to the discharge composition are unlikely to impact upon these important habitats.

6.4 Fish

Marine fish species have been shown to be sensitive to both low and high pH levels with LC_{50} values being reported below 5.4, and above 9.0 (LC_{50} is the lethal concentration for 50% of the population) (UK Marine SAC, 2015). Some adult fish are reported to be unaffected at pH values above 9.0, but for the larval stage affects are noticeable above 8.5, while fish larvae feeding appears to be affected at a pH below 6.0 and above 8.4 (Wolff et al., 1988).

Langford and Bamber (1984) had summarised a range of pH effects for fish, from avoidance behaviour beginning at pH 6.5 and discolouration and eye damage at around pH 6. The cumulative effects of low pH, elevated temperatures and the presence of heavy metals is more harmful than low pH alone, as a low pH can increase the toxicity of substances, including ammonia, phosphate, borate, and some metals. Fish avoidance behaviour means that they are likely to avoid harmful waters if possible and as such any harmful effects of low pH are proportional to the length of time of exposure (review by Innogy, 2003)

The shallow warm waters in the vicinity of the power station may provide suitable nursey grounds for juvenile fish such as bass *Dicentrarchus labrax.*(Pawson and Eaton, 1999). It is possible that the reduced pH discharge will cause fish to avoid waters in the locality of the outfall, however, any effects are likely to be very localised to the immediate vicinity of the discharge where pH values below 7.0 may occur. A reduced pH in the vicinity of the mouth of the River Thaw has the potential to affect the salmonid run into the river. However, salmonids have been shown to be tolerant of pH levels well below 7.0, and the modelling indicates that pH conditions in the vicinity of the River Thaw will be close to ambient.

Salmonid olfactory senses can be affected by lowered pH with reduced response to olfactory stumuli occurring at a pH of 6.6 and being lost at 4.6 (Potter and Dare, 2003). As olfactory senses are important for fish returning to their natal river there is a potential for the plume to influence the salmonid run to the River Thaw. However, this would appear unlikely as pH levels within 300m offshore of the outfalls and in the approaches to the mouth of the River Thaw are likely to be above the threshold levels which may influence olfactory response with predicted pH levels close to 8.

Overall, it is considered that the plume is unlikely to affect salmonids migrating into and out of the River Thaw.

6.5 Marine Mammals

There is limited data on marine mammals sighted within the vicinity of Aberthaw. Due to the nature of the plume and the mobile nature of marine mammals, no effects on marine mammals are anticipated.

7. Conclusions

- Predictive modelling has indicated that during the trial, an area of the intertidal to the east and north-east of the outfall may be potentially subjected to a reduced pH during low water and mid flood tide conditions. The modelling also showed that no difference in the current and trial pH regimes was predicted to be evident beyond a distance of 350 m from the outfalls. The model predicted that the area potentially subjected to reduced pH conditions would be limited to the intertidal habitats in the immediate vicinity of the outfalls.

- Taking account of the modelling output and the physico-chemical spot sampling undertaken during the trial period, it is suggested that the pH mixing zone will be much smaller than anticipated and that most of the intertidal areas predicted to be affected will be subject to near ambient pH conditions for most of the tidal cycle.

- The low shore benthic communities towards the east of Limpert Bay were characterised by relatively dense swathes of fucoid algae (*Fucus serratus*) and gastropods (limpets, periwinkles). Towards the west, beds of *Sabellaria alveolata* were more dominant, mirroring the extensive beds at the reference site at Nash Point. Mid and upper shore benthic communities did not vary spatially in terms of species assemblages, although a greater abundances of barnacles and a reduced macroalgae coverage was observed at the more exposed Nash Point reference site in comparison to the mid shore communities of Limpet Bay where *Fucus vesiculosus* was common.

- Overall, there were no apparent differences in the benthic communities that could be attributed to the trial. Those differences observed were likely as a result of natural physical and biological patterns , which are important structuring factors. The notable differences between the reference site and Limpert Bay sites can be attributed to differences in wave and wind exposure.

- The invasive non-native algae *Sargassum multicum* was recorded at Limpert Bay, but only in a local area to the east of the outfall. The presence and abundance at this locality may be being influenced by the effects of the thermal plume.

- Populations of periwinkles (*Littorina littorea*) and limpets (*Patella vulgata*) revealed some temporal changes in condition during the study, but with no suggestion that the variation was attributable to the trial. *P. vulgata* exhibited a seasonal increase in ‘health’ as the study progressed, whilst *L. littorea* showed no over-winter decline and maintained relatively high CI values adjacent to the outfall. The latter is thought to be as a consequence of the effects of the thermal plume.

- No detectable changes in the structure and size of the *Sabellaria alveolata* beds were recorded during the trial. The model output showed that only small areas of the *S. alveolata* beds would be influenced by reduced pH conditions. Spatial differences were related to physical and biology factors (e.g. shore exposure).

- Northward extensions in the *Sabellaria alveolata* beds in the western area of Limpert Bay are reported when compared with the historic biotope data recorded by NRW. In addition, *S. alveolata* beds are now present immediately to the east of the outfalls, where they had previously been recorded as absent. These changes probably reflect a period of favourable conditions and increased sand availability, allowing development of the beds into new areas.

- The lagoon and saltmarsh habitats located at the top of the shore to eastern side of Aberthaw were unlikely to be influenced by the trial due to their distance from the cooling water outfall. The model output indicated that ambient conditions would prevail at or around high water, and as such any exchange of water into the lagoon and saltmarsh areas would be unaffected.

- Highly mobile marine receptors are likely to exhibit behavioural avoidance responses away from localised stressors. The modelling showed that the extent of the plume and related pH are unlikely to affect migratory species such salmonids which utilise the River Thaw. No effects on marine mammals are anticipated.

- Overall, no effects on the marine benthic communities were reported during the trial. A number of spatial and temporal differences were identified, but were attributable to natural seasonal patterns in community development or as a result of the effects associated with the thermal discharge.

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Appendix A. Modelling data

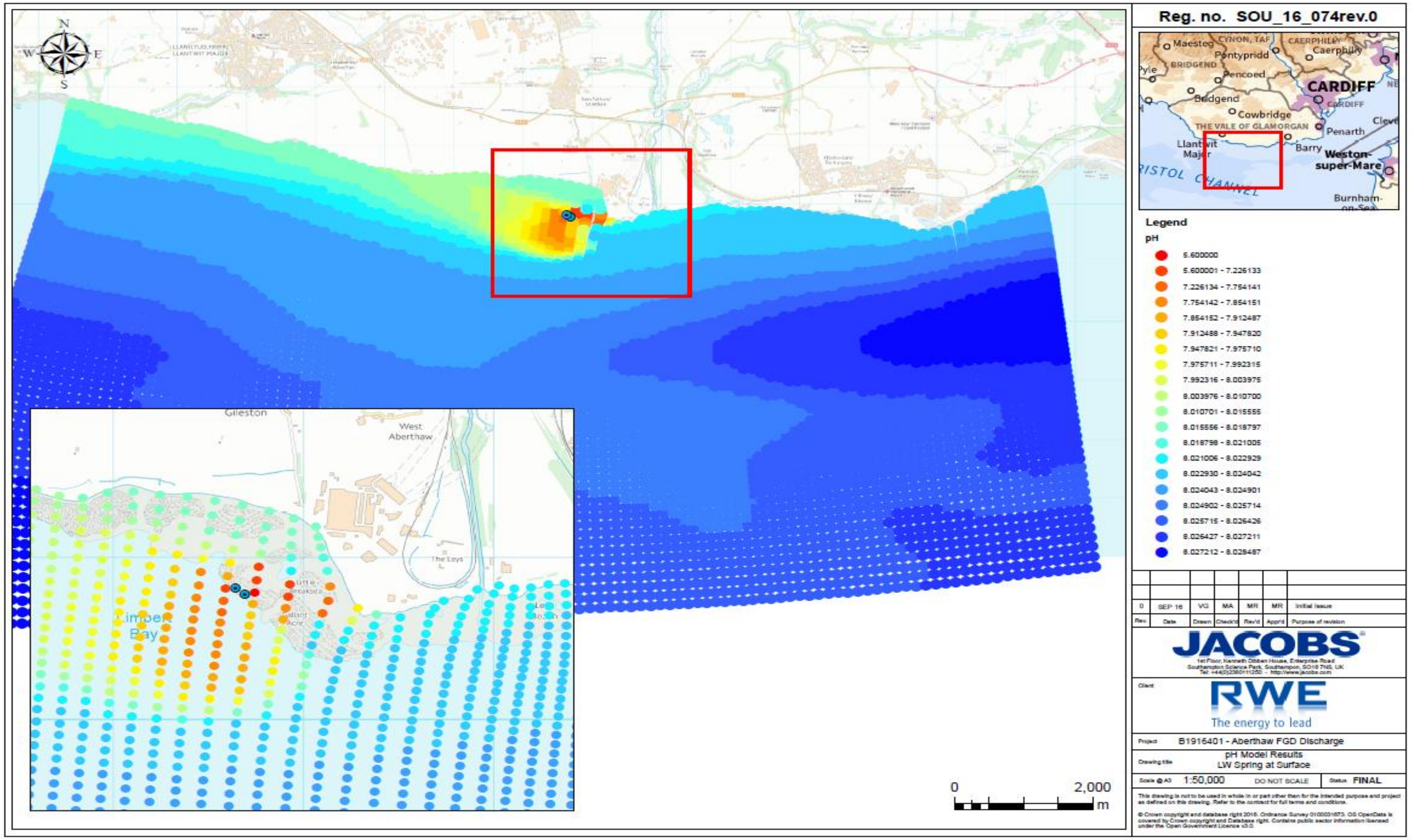

Figure A.1 : pH model results for low water (LW) spring at the surface. Minimum pH value (dark red) = 5.6

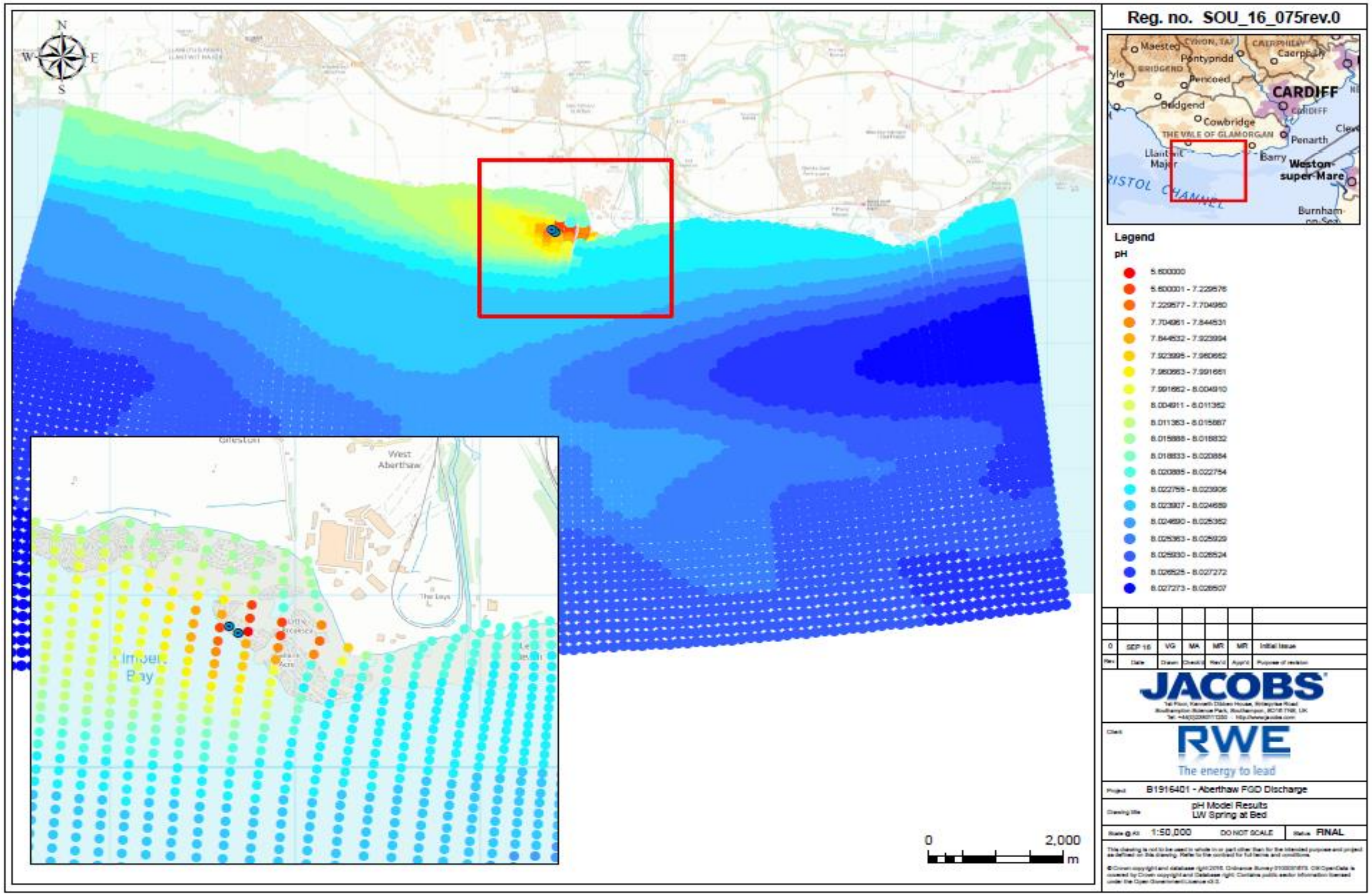

Figure A.2 : pH model results for low water (LW) spring at the bed. Minimum pH value (dark red) = 5.6.

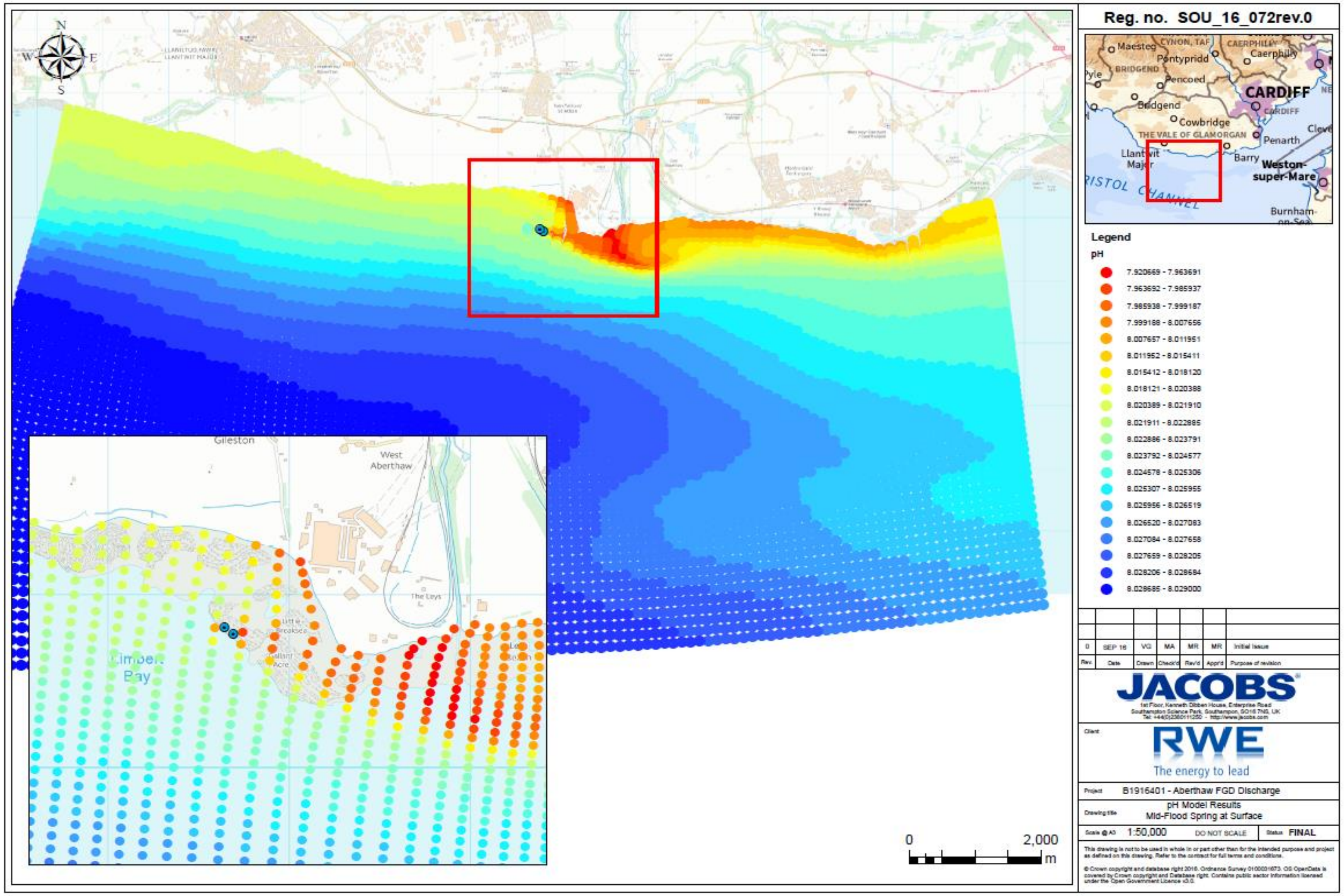

Figure A.3 : pH model results for mid flood spring at the surface. Minimum pH value (dark red) = 7.92 - 7.96.

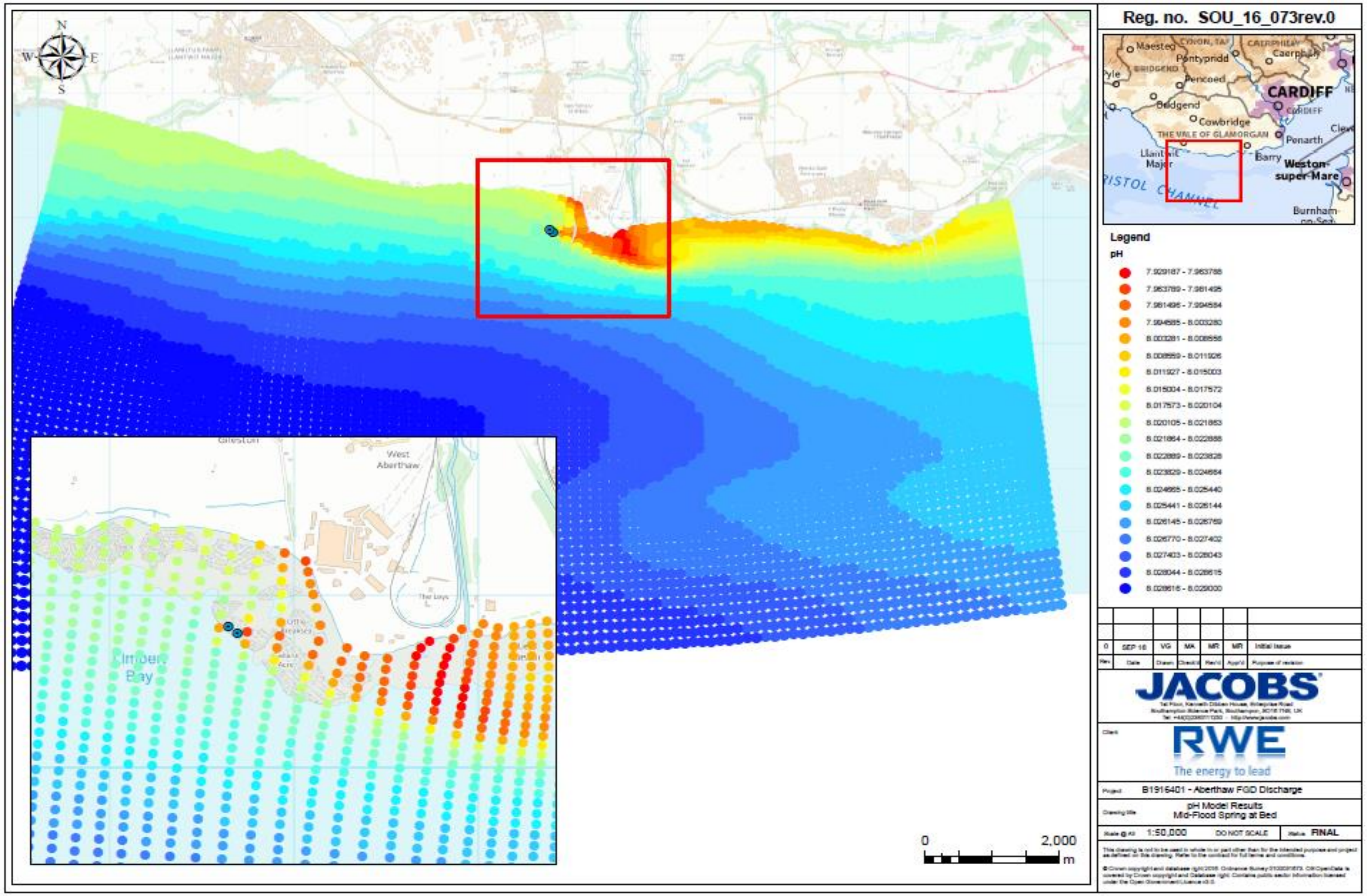

Figure A.4: pH model results for mid flood spring at the bed. Minimum pH value (dark red) = 7.92 - 7.96.

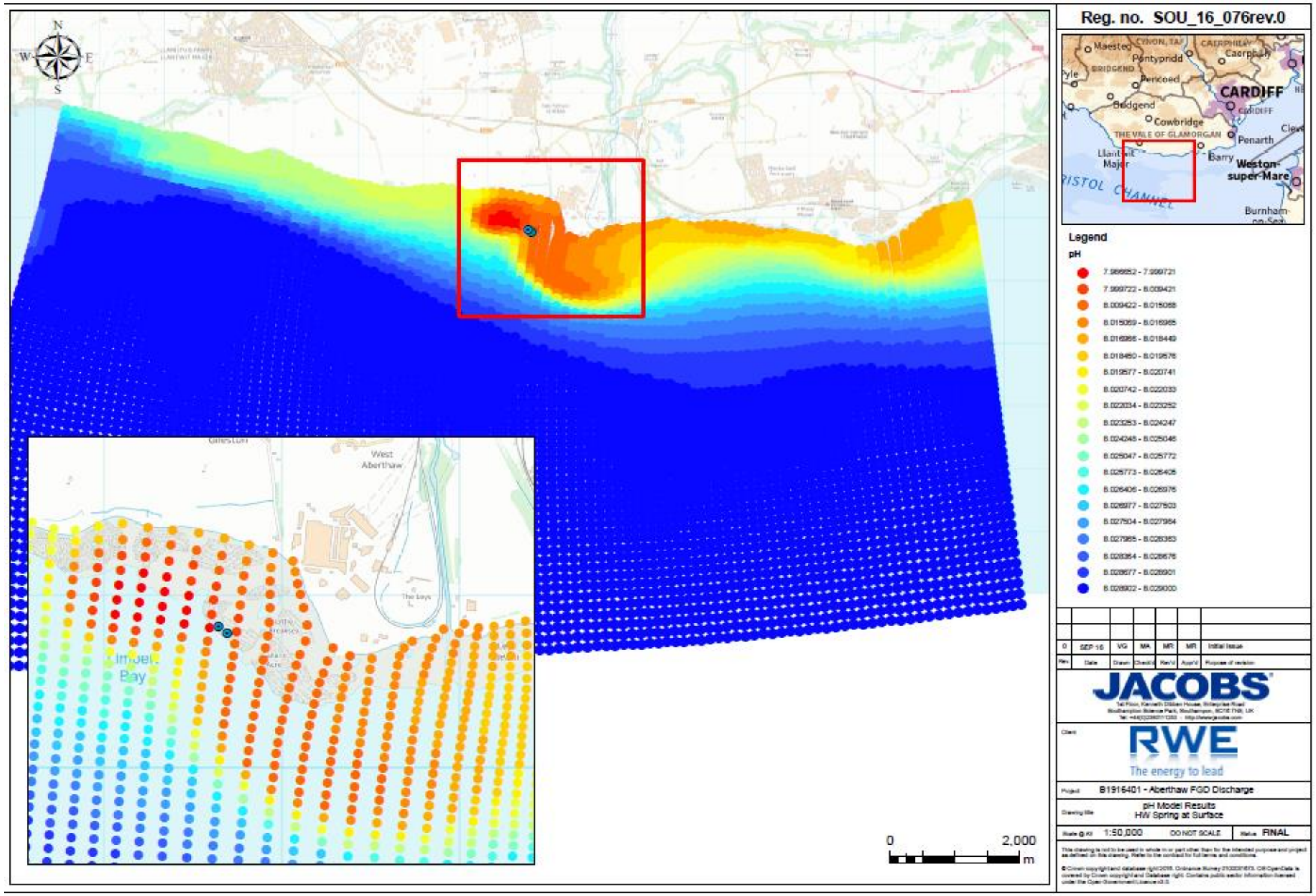

Figure A.5 : pH model results for high water (HW) spring at the surface. Minimum pH value (dark red) = 7.98 - 7.99.

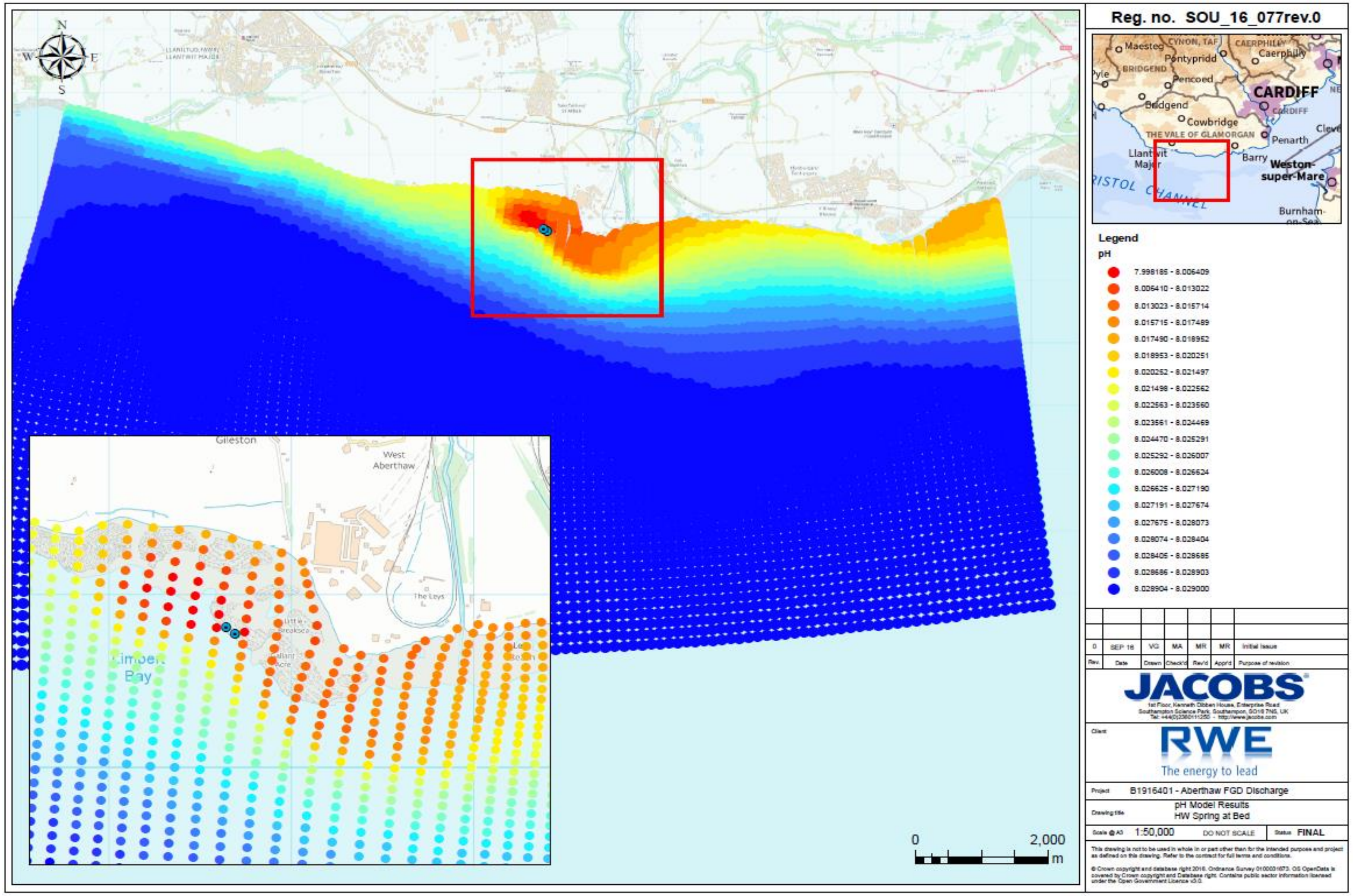

Figure A.6 : pH model results for mid flood spring at the bed. Minimum pH value (dark red) = 7.99 – 8.00.

Appendix B. Target Transect Positions

Table B.1 : Target Transect Positions sampled between November 2015 and August 2016

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. Statistical Glossary

C.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 (C.1.1 to C.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.

C.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, fourth Root transformation was selected for the multivariate analysis of the infaunal community data.

C.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.

C.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

C.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.

C.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.

C.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.

C.2 Univariate statistical analysis in MINITAB v14

The following tests (C.2.1 to C.2.5) were performed using the statistical tools within the statistical software programme Minitab v14 to reveal any statistically significant spatial and temporal differences between the means (or medians) of selected indices e.g. abundance, biomass and number of taxa.

C.2.1 Transformation of data in MINITAB

As a priori to the ANOVA test (see below) the data set is checked for normal distribution (Anderson-Darling test) and equality of variances (Barlett’s and Levene’s). If the data is not approximately normal (e.g. p = <0.05) and with un-equal variances (p = <0.05) then transformation is required and the data is Natural Log (Ln) transformed. If post-transformation, the data has normal distribution and equality of variances then the ANOVA routine can be undertaken.

C.2.2 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 and months). It assumes a normal data distribution and equality of variances.

C.2.3 Tukey's Pairwise comparison test

Tukey's Pairwise comparison analysis can be used as a post hoc ANOVA test. If a significant effect is detected following ANOVA, then the Tukey's pairwise comparison test will be undertaken to reveal where there is a significant difference between pairs of samples. The means will be statistically significant from each other if the calculated confidence-interval does not include a 0. The equivalent Holm-Sidak method was also used for post hoc pairwise comparisons of the gastropod CI values.

Appendix D. Rocky Shore Taxa List

GROUP	MCS index	TAXA	Common name	Recorded as
PORIFERA	C0001	PORIFERA	Sponge	% cover
	C0632	*Halichondria* sp.	Breadcrumb sponge	% cover
CNIDARIA	D0058	HYDROZOA	Hydroid	%
	D0662	ACTINIARIA	Sea anemone	Count
	D0679	*Anemonia viridis*	Snakelock anemone	Count
ANNELIDA	P0002	POLYCHAETA indet	Segmented worm	Count
	P0114	Phyllodocidae indet.	Paddle worm	Count
	P1116	*Sabellaria alveolata*	Honeycomb worm	% cover
	P1195	*Lanice conchilega*	Sandmason worm	Count
	P1324	Serpulidae indet.	Calcarous worm	Count
	P1362	Spirorbinae indet.	Calcarous worm	Count
ARTHROPODA (LOWER)	R0014	CIRRIPEDIA	Barnacle	% cover
	R0014	CIRRIPEDIA #spat	Barnacle juvenile	% cover
	R0014	CIRRIPEDIA #cyprid	Barnacle post-settled larvae	% cover
ARTHROPODA (HIGHER)	S0097	GAMMARIDEA #tubes	Amphipod tubes	% cover
	S0098	GAMMARIDEA	Amphipod	Count
	S0790	ISOPODA	Isopod	Count
	S0934	*Idotea* sp.	Isopod	Count
	S1293	CARIDEA indet	Shrimp/prawn	Count
	S1566	*Carcinus maenas*	Shore crab	Count
	S1570	Portuninae #juv	Crab indet	Count
	S1594	*Cancer pagurus* #juv	Edible crab	Count
	-	*Anurida maritima*	Spring tail	Count
MOLLUSCA	W0046	POLYPLACOPHORA	Chiton	Count
	W0157	*Gibbula* #juv	Topshell	Count
	W0163	*Gibbula cineraria*	Grey topshell	Count
	W0177	*Phorcus lineatus*	Lined topshell	Count
	W0277	*Patella #juv*	Limpet	Count
	W0231	*Patella vulgata*	Limpet	Count
	W0295	*Littorina* #juv	Periwinkle	Count
	W0296	*Littorina littorea*	Common periwinkle	Count
	W0299	*Littorina fabalis*	Flat periwinkle	Count
	W0302	*Littorina obtusata*	Flat periwinkle	Count
	W0305	*Littorina saxatilis*	Rough periwinkle	Count
	W0443	*Capulus ungaricus*	Bonnet shell	Count
	W0686	*Nucella* #juv	Dogwhelk	Count
	W0687	*Nucella lapillus*	Common dogwhelk	Count
	W0745	*Nassarius reticulatus*	Netted dogwhelk	Count
	W1695	*Mytilus edulis* #juv	Blue mussel	Count
	W1695	*Mytilus edulis*	Blue mussel	Count
	W2181	*Barnea candida*	White piddock	Count
BRYOZOA	Y0078	*Electra pilosa*	Sea mat	% cover
ECHINODERMATA	ZB0100	*Asterias rubens*	Common starfish	Count
PISCES	ZG0455	Gobiidae	Goby	Count
OTHERS	-	Animalia #eggs		% cover
ALGAE- Reds	-	Fine filamentous red indet.		% cover
	ZM0053	*Porphyra* sp.	Larver	% cover

GROUP	MCS index	TAXA	Common name	Recorded as
	ZM0192	*Hildenbrandia rubra*	Encrusting red	% cover
	ZM0202	*Corallina* sp.	Coral week	% cover
	ZM0224	Lithophyllum	Encrusting red	% cover
	ZM0303	*Catenella caespitosa*	Creeping chain weed	% cover
	ZM0332	*Dumontia contorta*	Dumont's tubular weed	% cover
	ZM0345	*Chondrus crispus*	Irish moss	% cover
	ZM0405	*Mastocarpus stellatus*	Grape pip weed	% cover
	ZM0507	*Ceramium* sp.	Banded pincer weeds	% cover
	ZM0653	*Osmundea pinnatifida*	Pepper dulse	% cover
	ZM0655	*Polysiphonia* spp	Siphon weed	% cover
ALGAE- Browns	-	Brown algae mats indet.		% cover
	-	Fine brown filamentous indet		% cover
	ZR0286	*Cladostephus spongiosus*	Hairy sand weed	% cover
	ZR0375	*Ascophyllum nodosum*	Egg wrack	% cover
	ZR0376	*Fucus* sp. indet	Fucoid	% cover
	ZR0382	*Fucus serratus*	Toothed wrack	% cover
	ZR0383	*Fucus spiralis*	Spiraled wrack	% cover
	ZR0384	*Fucus vesiculosus*	Bladder wrack	% cover
	ZR0386	*Pelvetia canaliculata*	Channel wrack	% cover
ALGAE- Greens	ZS0000	Dark Green encr.	Encrusting green	% cover
	ZS0000	Filamentous Greet indet		% cover
	ZS0025	*Prasiola* sp.	Green turf	% cover
	ZS0149	*Enteromorpha* spp.	Gut weed	% cover
	ZS0179	*Ulva lactuca*	Sea lettuce	% cover
	ZS0195	*Cladophora* spp.	Green branched weed	% cover
LICHENS	-	*Verrucaria mucosa*	Lichen	% cover
	-	*Verrucaria maura*	Tar lichen	% cover

Appendix E. Interaction Plot: Number of taxa

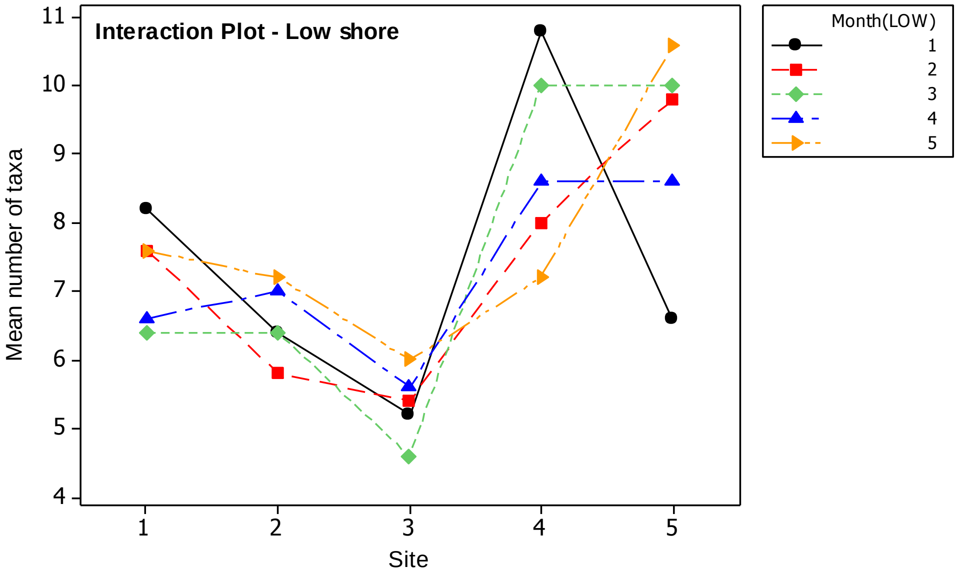

Figure E.1 : Interaction plot for mean number of taxa for the low shore communities at each of the five sites, and each of the five survey months. Site Code 1 = HO, 2 = LE, 3 = EO, 4 = LW (Limpert Bay) and 5 = NP (Nash Point). Month codes 1 = November '15, 2 = March '16, 3 = April '16, 4 = May '16 and 5 = August '16.

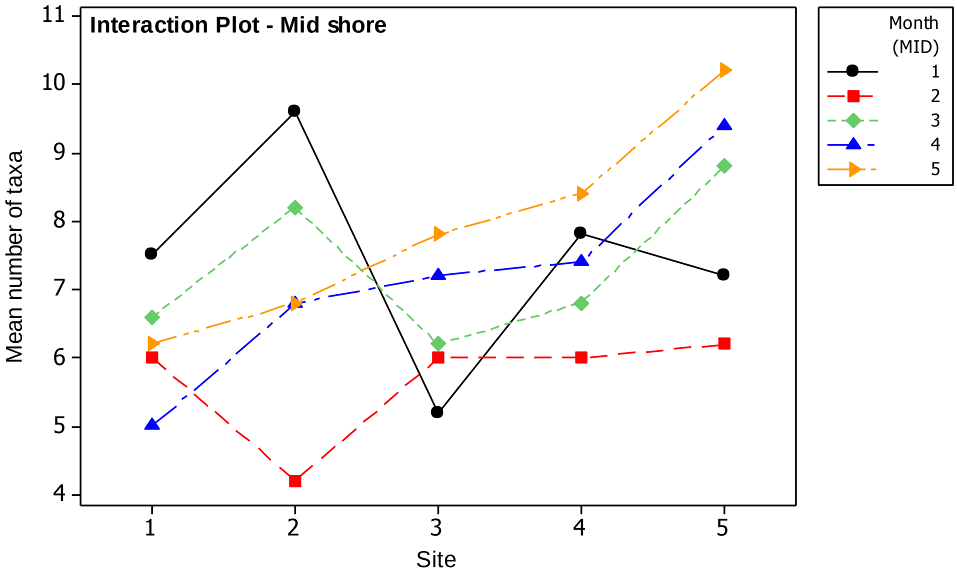

Figure E.2 : Interaction plot for mean number of taxa for the mid shore communities at each of the five sites, and each of the five survey months. Site Code 1 = HO, 2 = LE, 3 = EO, 4 = LW (Limpert Bay) and 5 = NP (Nash Point). Month codes 1 = November '15, 2 = March '16, 3 = April '16, 4 = May '16 and 5 = August '16.

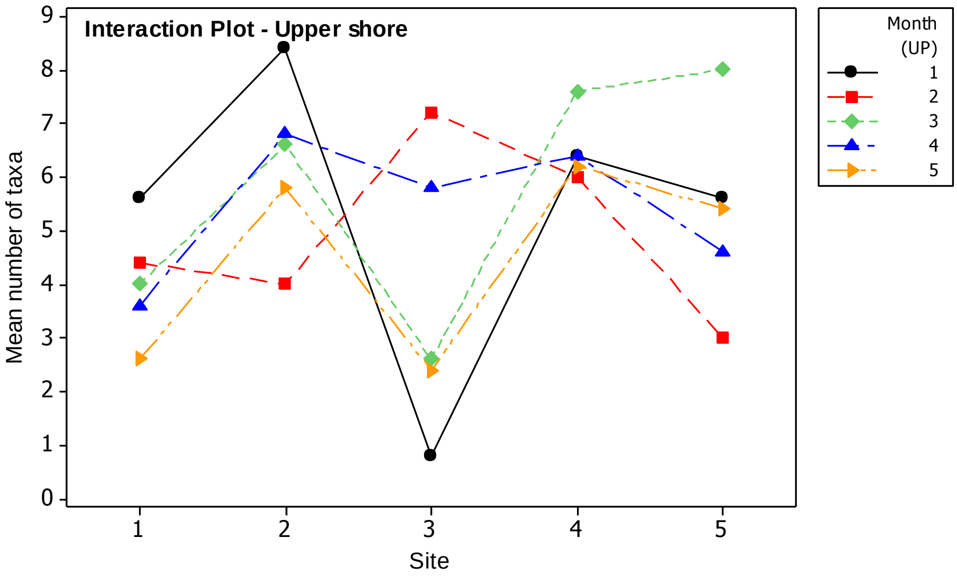

Figure E.3 : : Interaction plot for mean number of taxa for the upper shore communities at each of the five sites, and each of the five survey months. Site Code 1 = HO, 2 = LE, 3 = EO, 4 = LW (Limpert Bay) and 5 = NP (Nash Point). Month codes 1 = November '15, 2 = March '16, 3 = April '16, 4 = May '16 and 5 = August '16.

Appendix F. Low shore multivariate analysis –cluster diagrams and bubble plots

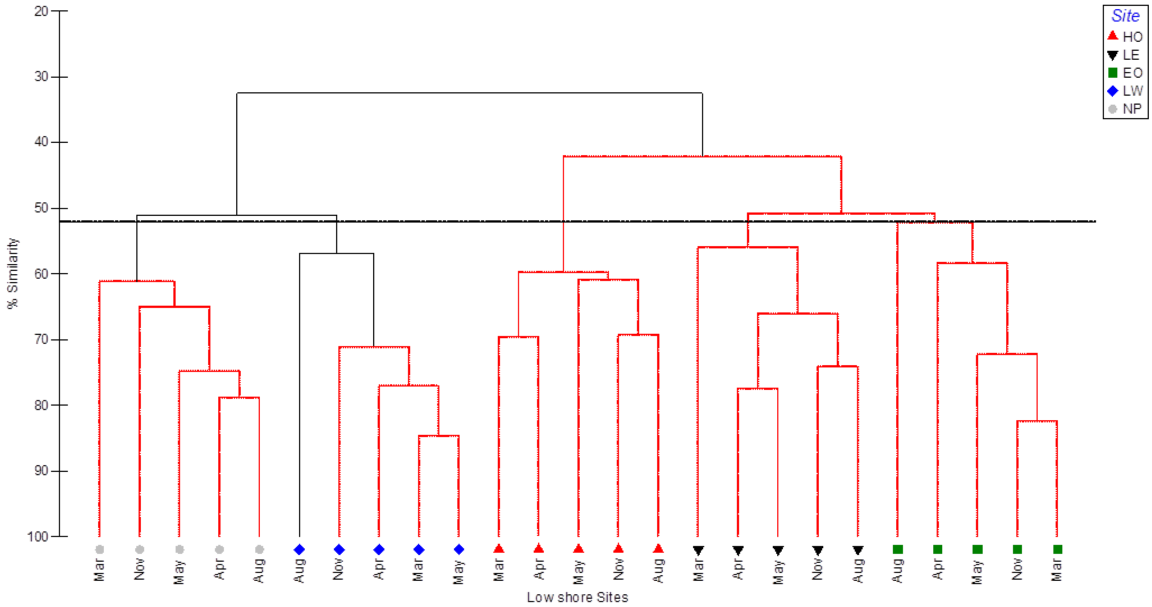

Figure F.1 : Cluster diagram based on presence/absence transformation and Bray-Curtis similarities of low shore mean community data (pooled from 5 replicate 0.25 m^{-2} quadrats) sampled between November 2015 and August 2016 across Limpert Bay (HO, LE, EO and LW) and at Nash Point (NP).

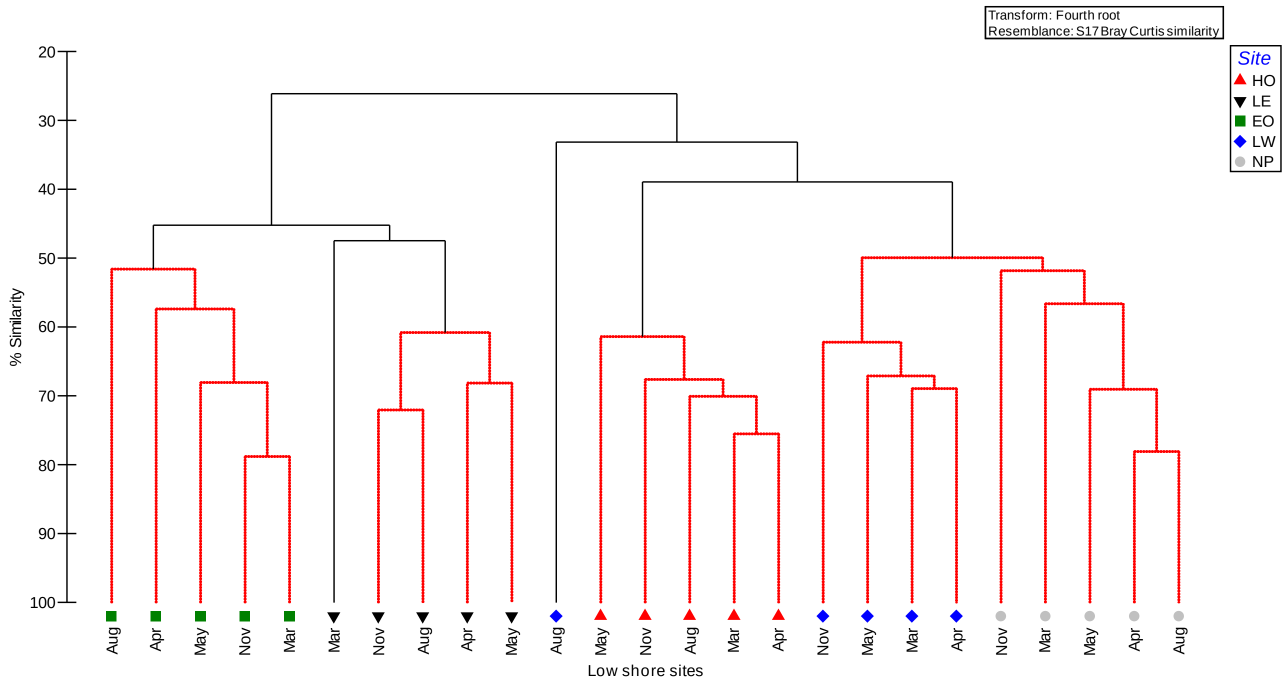

Figure F.2 : Cluster dendogram based on 4th root transformation and Bray-Curtis similarities of low shore mean community data (n=5 replicate 0.25 m-2 quadrats) sampled between November 2015 and August 2016 across Limpert Bay (HO, LE, EO and LW) and Nash Point (NP). Those clusters connected by a red line are significantly similar (p <0.05) to each other (SIMPROF analysis).

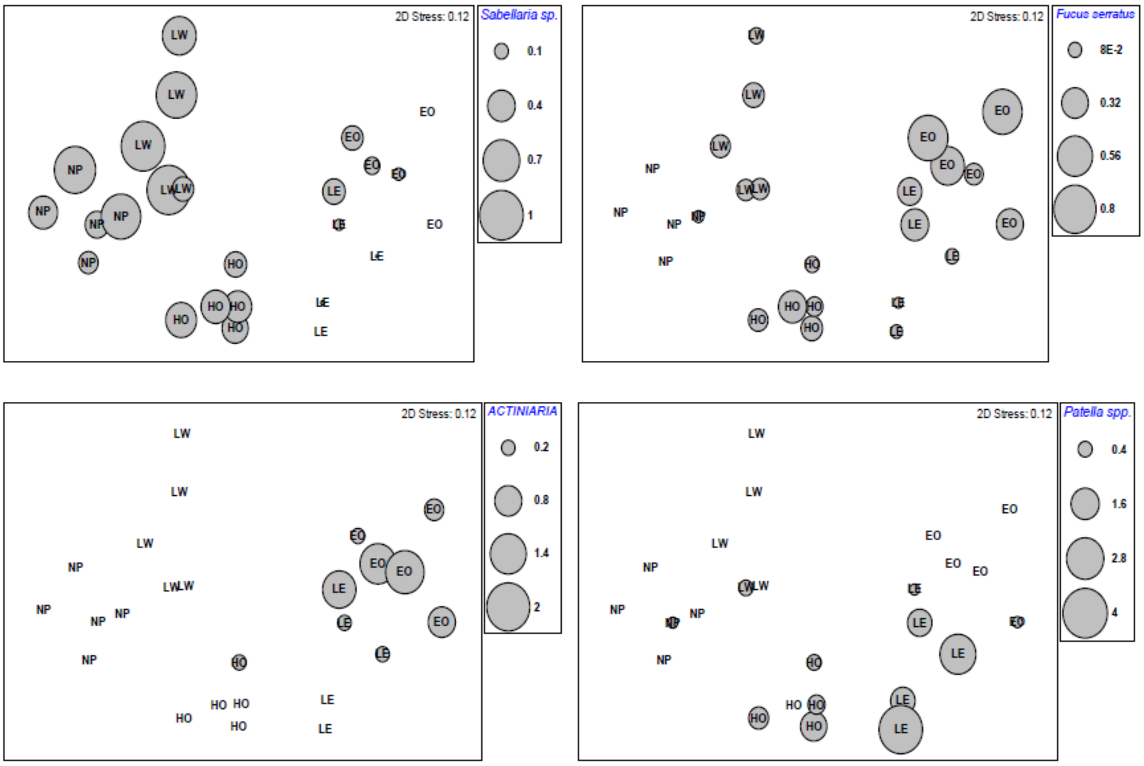

Figure F.3 : Bubble plots for key taxa recorded across the lower shore at Limpert Bay (HO, LE, EO and LW) and at Nashpoint (NP) between November 2015 and August 2016 (un-transformed abundances) overlaying the two-dimensional ordination.

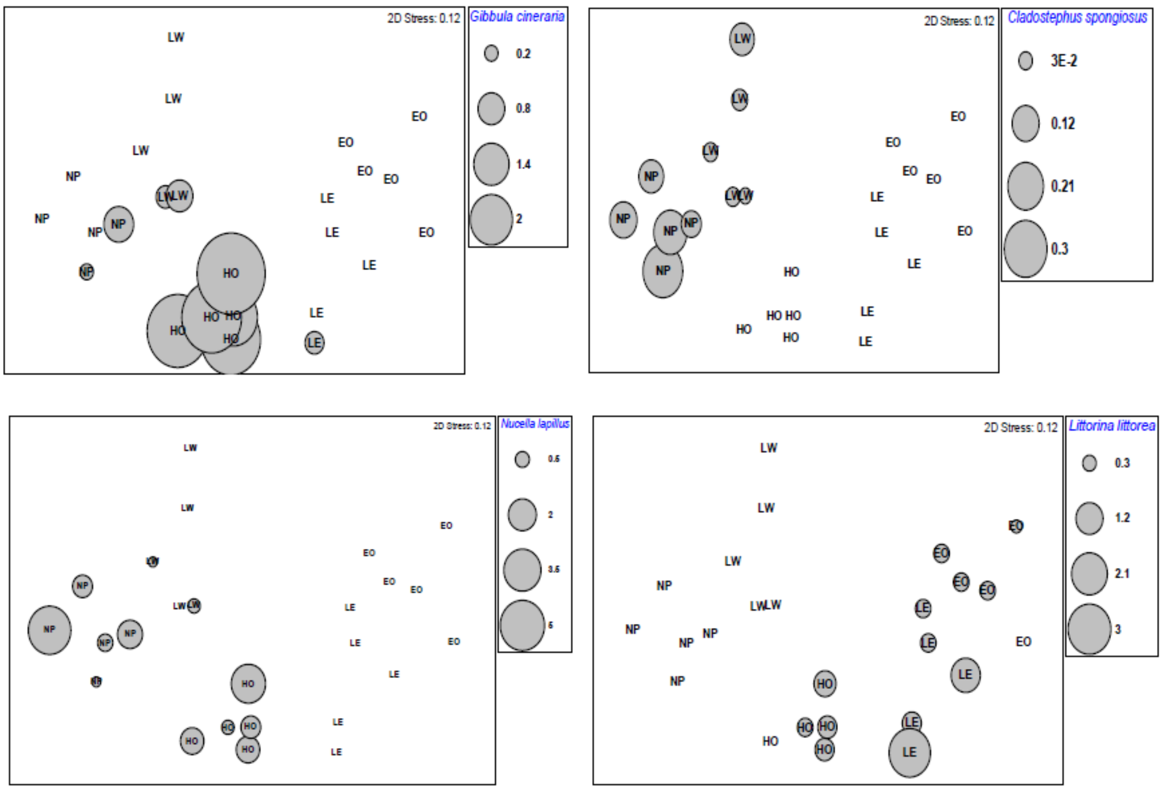

Figure F.3 :continued

Appendix G. ANOSIM and SIMPER – Low shore communities

Table G.1 : Pair-wise two-way crossed ANOSIM for low shore communities based on 4th root transformed community data and Bray-Curtis similarities.

a) Pair-wise differences between months

Pairwise tests - Month	R-statistic	*p*-value
November vs March	0.520	0.001*
November vs April	0.503	0.001*
November vs May	0.502	0.001*
November vs August	0.474	0.001*
March vs April	0.273	0.001*
March vs May	0.518	0.001*
March vs August	0.441	0.001*
April vs May	0.350	0.001*
April vs August	0.268	0.001*
April vs August	0.483	0.001*

b) Pair-wise differences between transect sites

Pairwise tests – Transect site	R-statistic	*p*-value
HO vs LE	0.784	0.001*
HO vs EO	0.982	0.001*
HO vs LW	0.922	0.001*
HO vs NP	0.938	0.001*
LE vs EO	0.709	0.001*
LE vs LW	0.812	0.001*
LE vs NP	0.962	0.001*
EO vs LW	0.974	0.001*
EO vs NP	1.000	0.001*
LW vs NP	0.762	0.001*

Table G.2 : Similarity percentage analysis (SIMPER) for low shore communities based on 4th root transformed community data.

a) Site HO – average similarity 64.03

Species	Av. Abundance	Av. Similarity	Contribution %
Gibbula cineraria	1.28	17.52	27.37
Sabellaria sp.	0.76	11.6	18.12
Fucus serratus	0.59	8.42	13.15
Nucella lapillus	0.76	6.39	9.98
Cirripedia	0.4	5.7	8.91
Spirorbinae indet.	0.22	3.89	6.07
Patella spp.	0.47	3.37	5.26
Littorina littoria	0.43	2.74	4.28

b) Site LE – average similarity 49.77

Species	Av. Abundance	Av. Similarity	Contribution %
Patella spp.	0.8	12.45	25.01
Fucus serratus	0.51	9.7	19.5
Littorina littoria	0.58	6.68	13.42
Cirripedia	0.26	4.78	9.6
Sabellaria sp.	0.24	3.61	7.25
Osmundea pinnatifida	0.22	3.07	6.16
Ulva lactuca	0.15	2.34	4.7
Fucus vesiculosus	0.19	1.85	3.72
Catenella caespitosa	0.11	1.19	2.39

c) Site EO – average similarity 59.85

Species	Av. Abundance	Av. Similarity	Contribution %
Fucus serratus	0.75	17.95	30
Catenella caespitosa	0.58	14.34	23.95
Fucus vesiculosus	0.46	8.74	14.6
Sabellaria sp.	0.31	6.51	10.87
Actiniaria	0.51	4.85	8.1
Ulva lactuca	0.11	1.62	2.7

d) Site LW – average similarity 65.90

Species	Av. Abundance	Av. Similarity	Contribution %
Sabellaria sp.	0.85	15.69	23.81
Cladostephus spongiosus	0.43	8.23	12.49
Fucus serratus	0.53	7.73	11.72
Ulva lactuca	0.36	7	10.63
Corallina sp.	0.35	6.49	9.85
Serpulidae indet.	0.38	4.63	7.03
Lithophyllum	0.27	3.72	5.65
Osmundea pinnatifida	0.23	3.32	5.04
Hildenbrandia rubra	0.19	2.74	4.16

e) Site NP – average similarity 63.42

Species	Av. Abundance	Av. Similarity	Contribution %
Sabellaria sp.	0.8	13.08	20.62
Fucus serratus	0.57	9.92	15.64
Ulva lactuca	0.42	7.01	11.05
Lithophyllum	0.39	6.49	10.23
Nucella lapillus	0.69	6.29	9.92
Serpulidae indet.	0.65	5.69	8.97
Fucus sp. Indet.	0.24	3.88	6.12
Osmundea pinnatifida	0.22	2.8	4.41
Cirripedia	0.2	2.09	3.29

f) March vs November (top 5 taxa contributing to dissimilarity) – average dissimilarity 49.34

Species	Av. Abundance Nov	Av. Abundance Mar	Av. Dissimilarity	Contribution %
Serpulidae indet.	0.08	0.48	4.19	8.5
Nucella lapillus	0.22	0.47	3.7	7.5
Littorina littorea	0.25	0.13	3.26	6.61
Sabellaria sp.	0.35	0.17	3.07	6.22
Patella spp.	0.18	0.25	2.78	5.63

Appendix H. Mid shore multivariate analysis – Cluster diagrams

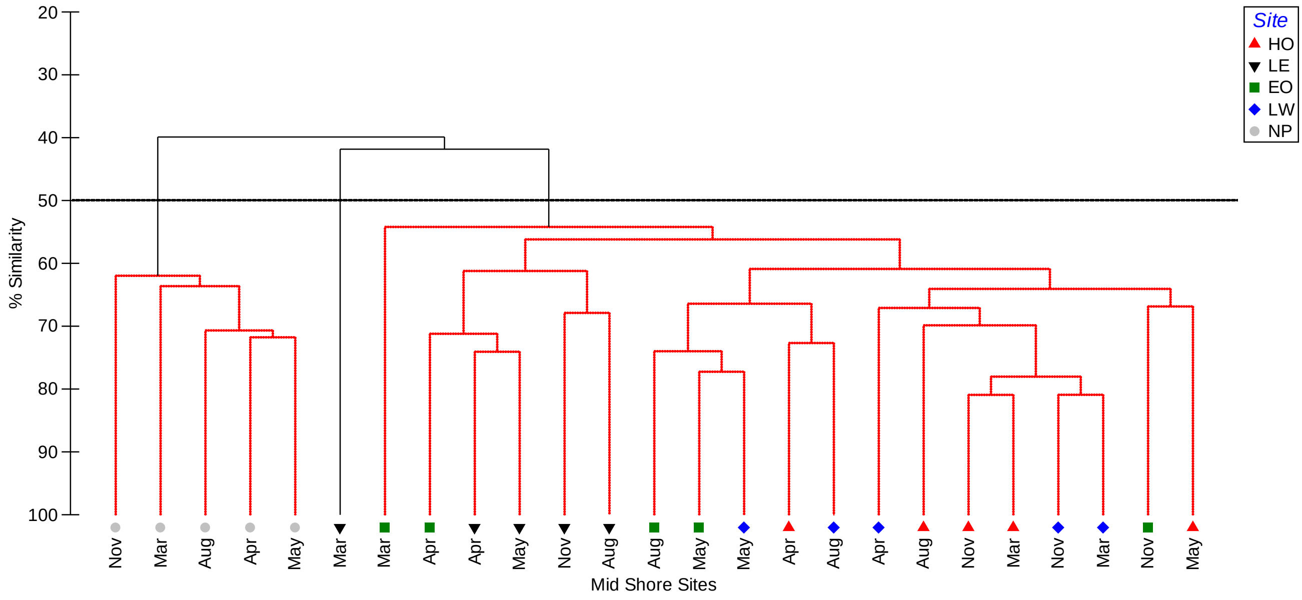

Figure H.1 : Cluster dendogram based on 4th root transformation and Bray-Curtis similarities of mid shore mean community data (n=5 replicate 0.25 m^{-2} quadrats) sampled between November 2015 and August 2016 across Limpert Bay (HO, LE, EO and LW) and Nash Point (NP) with 50% similarity marked on plot. Those clusters connected by a red line are significantly similar ($p<0.05$) to each other (SIMPROF analysis).

Appendix I. ANOSIM and SIMPER - mid shore communities

Table I.1 : Pairwise two-way crossed ANOSIM based on 4^{th} root transformed community data and Bray-Curtis similarities.

a) Differences between months

Pairwise tests - Month	R-statistic	*p*-value
November vs March	0.384	0.001*
November vs April	0.217	0.002*
November vs May	0.341	0.001*
November vs August	0.303	0.001*
March vs April	0.446	0.001*
March vs May	0.606	0.001*
March vs August	0.580	0.001*
April vs May	0.228	0.001*
April vs August	0.363	0.001*
April vs August	0.324	0.001*

b) Differences between transect sites

Pairwise tests – Transect site	R-statistic	*p*-value
HO vs LE	0.624	0.001*
HO vs EO	0.603	0.001*
HO vs LW	0.374	0.001*
HO vs NP	0.853	0.001*
LE vs EO	0.324	0.001*
LE vs LW	0.637	0.001*
LE vs NP	0.918	0.001*
EO vs LW	0.554	0.001*
EO vs NP	0.899	0.001*
LW vs NP	0.882	0.001*

Table I.2 : Similarity percentage analysis (SIMPER) for middle shore communities based on 4th root transformed community data.

a) Site NP vs Limpert Bay (top 5 taxa contributing to dissimilarity) – average dissimilarity 68.44

Species	Av. Abundance Nov	Av. Abundance Mar	Av. Dissimilarity	Contribution %
Littorina #juv	0.13	1.38	9.06	13.24
Patella spp.	1.2	0.36	6.96	10.17
Gibbula cineraria	0.7	1.35	6.46	9.43
Nucella lapillus	0.01	0.9	6.11	8.93
Fucus vesiculosus	0.66	0	4.67	6.82
Actiniaria	0.07	0.68	4.49	6.55
Cirripedia	0.33	0.78	3.66	5.34
Osmundea pinnatifida	0	0.32	2.21	3.23
Lithophyllum	0.35	0.19	2.04	2.99
Littorina obtusata	0.3	0	1.92	2.81

Appendix J. Upper shore multivariate analysis – Cluster diagrams and bubble plots

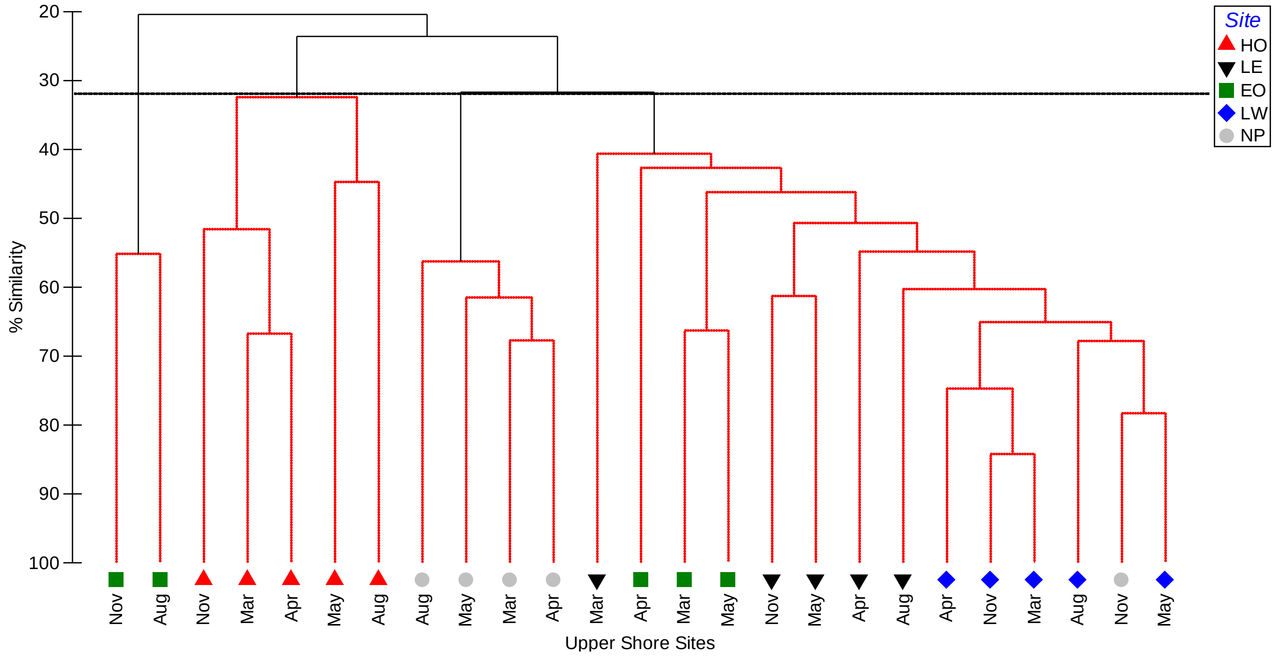

Figure J.1 : Cluster dendogram based on 4th root transformation and Bray-Curtis similarities of upper4 shore mean community data (n=5 replicate 0.25 m^{-2} quadrats) sampled between November 2015 and August 2016 across Limpert Bay (HO, LE, EO and LW) and Nash Point (NP) with 32% similarity marked on plot. Those clusters connected by a red line are significantly similar (p<0.05) to each other (SIMPROF analysis).

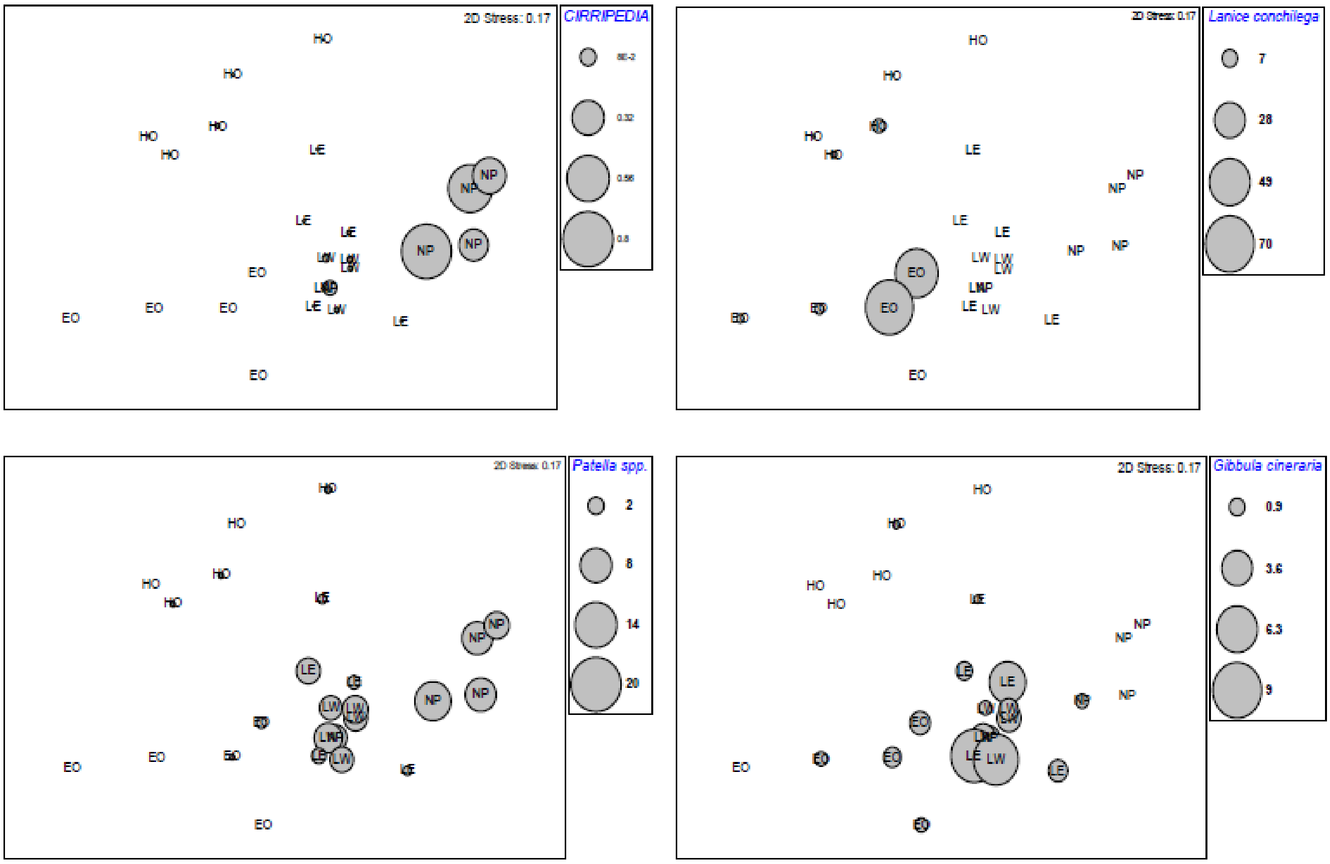

Figure J.2 : Bubble plots for key taxa recorded across the upper shore at Limpert Bay (HO, LE, EO and LW) and at Nash Point (NP) between November 2015 and August 2016.

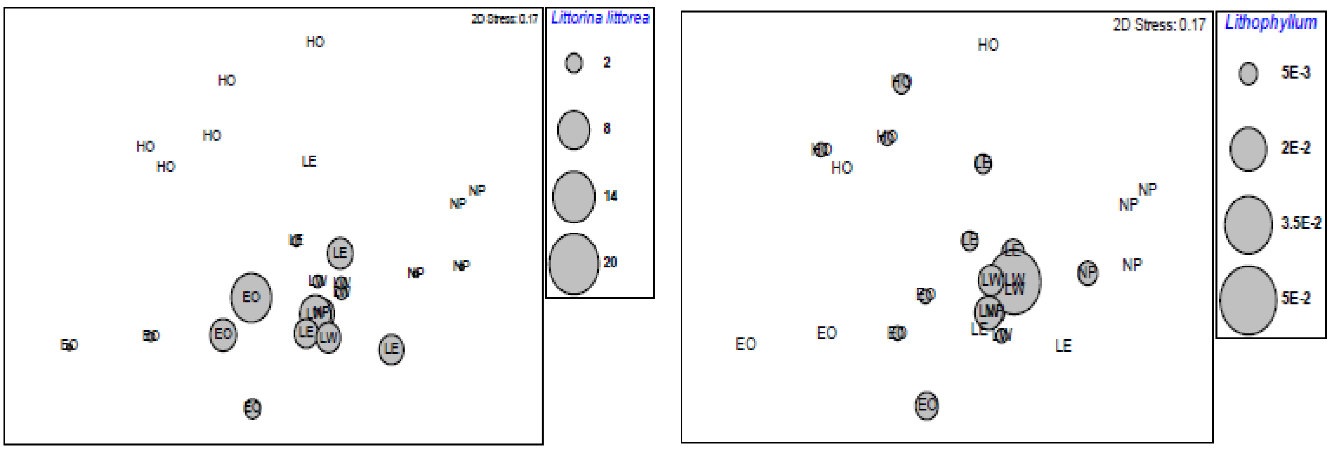

Figure J.2: continued

Appendix K. ANOSIM and SIMPER – upper shore communities

Table K.1 : Pairwise two-way crossed ANOSIM replication based on 4th root transformed community data and Bray-Curtis similarities.

a) Differences between months

Pairwise tests - Month	R-statistic	*p*-value
November vs March	0.431	0.0001*
November vs April	0.551	0.0001*
November vs May	0.471	0.0001*
November vs August	0.481	0.0001*
March vs April	0.251	0.0001*
March vs May	0.410	0.0001*
March vs August	0.556	0.0001*
April vs May	0.607	0.0001*
April vs August	0.649	0.0001*
April vs August	0.378	0.0001*

b) Differences between transect sites

Pairwise tests – Transect site	R-statistic	*p*-value
HO vs LE	0.848	0.0001*
HO vs EO	0.803	0.0001*
HO vs LW	0.972	0.0001*
HO vs NP	0.994	0.0001*
LE vs EO	0.742	0.0001*
LE vs LW	0.540	0.0001*
LE vs NP	0.816	0.0001*
EO vs LW	0.786	0.0001*
EO vs NP	0.816	0.0001*
LW vs NP	0.797	0.0001*

Table K.2 : Similarity percentage analysis (SIMPER) for upper shore communities based on 4th root transformed community data.

a) Cluster I – average similarity 22.59

Species	Av. Abundance	Av. Similarity	Contribution %
Lanice conchilega	0.78	16.6	73.46
Littorina littorea	0.3	3.24	14.35
Gibbula cineraria	0.3	2.75	12.19

b) Cluster II – average similarity 32.34

Species	Av. Abundance	Av. Similarity	Contribution %
Enteromorpha spp.	0.46	12.64	39.08
Fucus vesiculosus	0.45	8.69	26.88
Fucus spiralis	0.32	4.12	12.75
Lanice conchilega	0.4	2.63	8.14
GAMMARIDEA	0.27	1.22	3.77

c) Cluster III – average similarity 58.88

Species	Av. Abundance	Av. Similarity	Contribution %
Littorina #juv	2.2	25.23	42.85
Patella spp.	1.54	19.86	33.72
CIRRIPEDIA	0.78	10.79	18.32

d) Cluster IV – average similarity 40.67

Species	Av. Abundance	Av. Similarity	Contribution %
Littorina littorea	1.06	12.13	29.82
Patella spp.	0.95	11.49	28.25
Gibbula cineraria	0.86	8.71	21.42
CIRRIPEDIA	0.17	1.58	3.89
Lithophyllum	0.15	1.25	3.07
Corallina sp.	0.15	0.96	2.37
Fucus spiralis	0.18	0.83	2.04

Appendix L. Raw physico-chemical data

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