Cyfoeth Naturiol Cymru
Natural Resources Wales

Pembrokeshire Marine SAC intertidal rocky shore monitoring. Analysing changes and trends 2005 to 2019

Francis Bunker

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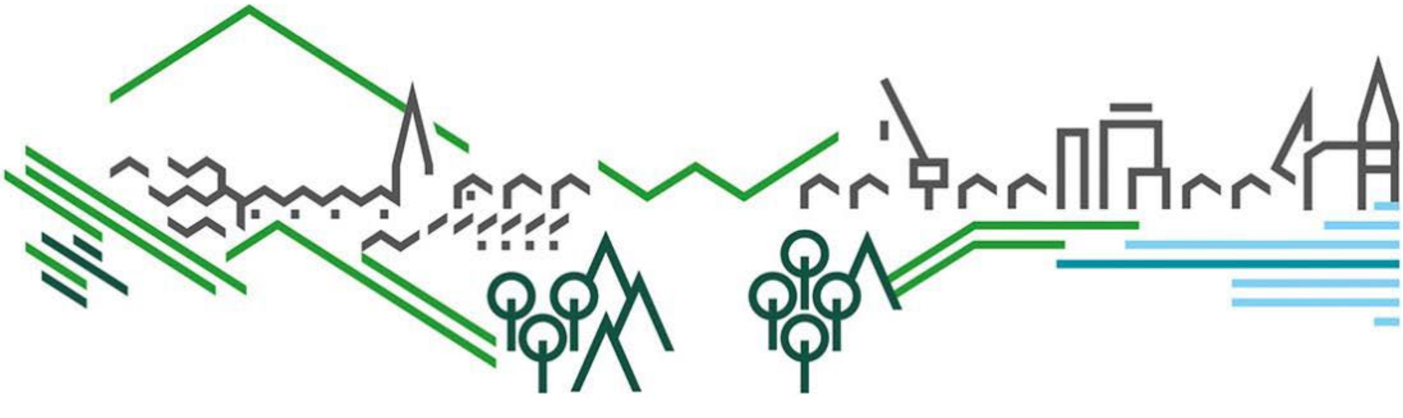

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Yn 2005, cychwynnodd Cyngor Cefn Gwlad Cymru raglen fonitro tymor hir er mwyn ymchwilio i ddosbarthiad a helaethrwydd organebau glannau creigiog fel rhan o raglen monitro rhynglanwol ACA Forol Sir Benfro. Mae *riff* yn un o'r nodweddion Atodiad I y dynodwyd yr ACA ar eu cyfer ac un o'r ardaloedd sydd o ddiddordeb yw riffiau craigwelyau rhynglanwol, yn enwedig yn Nyfrffordd Aberdaugleddau lle mae mwy o berygl o broblemau ansawdd dŵr neu broblemau eraill sy'n effeithio ar eu cyflwr.

Mae cyfres o naw safle monitro'r glannau wedi'u sefydlu. Mae chwech ohonynt yn Nyfrffordd Aberdaugleddau yng Nghei Lawrenni, Fferi Penfro, Hazelbeach, Gorsaf Bŵer Penfro, South Hook a Monk Haven. Mae un safle wrth y fynedfa i Ddyfrffordd Aberdaugleddau ym Mae West Angle. Mae dau safle ar yr arfordir agored, sef Pen-y-Holt ar arfordir deheuol Sir Benfro a Nolton Haven ym Mae Sain Ffraid, ar arfordir gorllewinol Sir Benfro. Nid oes unrhyw bedrannau sefydlog yn safle Pen-y-Holt, felly nid yw'r data o'r safle hwnnw'n rhan o'r adroddiad hwn.

Mae rhaglen o waith monitro blynyddol wedi'i chynnal yn y rhan fwyaf o'r safleoedd hyn yn y rhan fwyaf o flynyddoedd ers 2005. Mae'r adroddiad hwn yn cyflwyno data amlder 2005 i 2019 a gasglwyd o bedrannau monitro parhaol ym mhob un o safleoedd yr astudiaeth ar ffurf sy'n addas ar gyfer dadansoddiad amlamrywedd. Mae'n adeiladu ar ganlyniadau Bunker (2015). Roedd llawer o'r gwaith a wnaed i gasglu'r set ddata hon yn defnyddio cronfa ddata berthynol bwrpasol (yn MS Access) o'r enw 'Shore Survey Data'.

Dyma nodau'r adroddiad hwn, ynghyd â chrynodeb o'r canlyniadau:

- Dwyn ynghyd set ddata o 2005 i 2019 sy'n addas ar gyfer dadansoddiad amlamrywedd. Cwblhawyd y gwaith llafurus hwn, gan arwain at greu ffeil PRIMER, ac mae'r gwaith dadansoddi a wnaed arni'n darparu sylfaen yr adroddiad hwn. Mae'r ffeil hon; "Pembrokeshire Marine SAC shore quadrat data 2005 to 2019.pwk" ar gael fel atodiad electronig i'r adroddiad hwn.
- Catalogio set o ffotograffau o arolygon monitro 2005 i 2019 a chynnal dadansoddiadau gweledol. Mae'r holl ffotograffau digidol (dros 11,000 o ddelweddau) wedi'u casglu ynghyd yn Adobe Lightroom a'u labelu gydag allweddeiriau sydd wedi'n galluogi i ddidoli delweddau yn rhwydd ac yn gyflym.
- Cyflwyno'r dadansoddiadau cychwynnol ar ddata'r pedrannau a gasglwyd o 2005 i 2019 sydd â'r nod o ganfod newidiadau a thueddiadau. Mae dadansoddiadau amlamrywedd sylfaenol o'r data wedi'u cynnal yn PRIMER ac wedi'u cyflwyno. Lle mae newid ecolegol wedi'i ganfod, mae hyn wedi'i amlygu.
- Trafod canlyniadau'r dadansoddiadau o'r data o ran newid a chyflwr y safleoedd monitro. Mae'r tueddiadau a'r newidiadau a ganfuwyd yn y data (ac o ffotograffau) wedi'u trafod a, lle bu modd, wedi'u cysylltu â gwaith sydd wedi'i gyhoeddi.

Yn y pen draw, nod yr adroddiad hwn yw rhoi gwybodaeth i CNC er mwyn gallu cwblhau asesiad o gyflwr riffiau creigiog rhynglanwol ACA Forol Sir Benfro ac adrodd wrth lywodraeth y DU (Comisiwn Ewropeaidd 1994; Cyngor Cefn Gwlad Cymru 2009). Mae cwblhau'r asesiad cyflwr hwnnw y tu hwnt i gwmpas yr adroddiad hwn; yn hytrach, ei nod yw cyflwyno barn yr awdur ar statws y safleoedd monitro yn seiliedig ar y gwaith dadansoddi a wnaed. Rhoddir crynodeb o asesiad yr awdur o'r safleoedd monitro yn y tabl isod:

Tabl o bryderon am statws cadwraeth pob parth yng nglannau'r astudiaeth fonitro yn ACA Forol Sir Benfro a gwmpesir yn yr adroddiad hwn (LU = y Lan Uchaf, LG = y Lan Ganol, LI = y Lan Isaf).

Safle	Y lan uchaf	Y lan ganol	Y lan isaf	Nodiadau
Cei Lawrenni	Dim Pryder	Pryder – dirywiad o ran *Ascophyllum*	Dim Pryder	Pryder am ddirywiad *Ascophyllum nodosum* yn y lan ganol. Pryder hefyd am niferoedd uchel y rhywogaethau estron islaw pedrannau monitro'r LI.
Fferi Penfro	Dim Pryder	Dim Pryder	Dim Pryder	Mae'n debygol fod cyflwr y LG wedi newid, lle mae cregyn gwyrain a brennig yn dominyddu yn hytrach nag *Ascophyllum*
Hazelbeach	Dim Pryder	Dim Pryder	Dim Pryder	Mae'n debygol fod cyflwr y LG wedi newid, lle mae cregyn gwyrain a brennig yn dominyddu yn hytrach nag *Ascophyllum*
Gorsaf Bŵer Penfro	Pryder – dirywiad o ran *Ascophyllum*	Dim Pryder	Amherthnasol	Mae *Ascophyllum nodosum* yn diflannu o'r LU ac mae'n debygol fod cyflwr y LG wedi newid, lle mae cregyn gwyrain a brennig yn dominyddu yn hytrach nag *Ascophyllum*
South Hook Point	Dim Pryder	Dim Pryder	Wedi'i sgwrio	Pryderon posib am ddirywiad o ran *Pelvetia canaliculata* yn y LU. Mae'r lan isaf yn gynefin sydd wedi'i sgwrio'n naturiol felly mae'n anodd pennu ei statws ond bu dirywiad o ran rhywogaethau a gorchudd dros amser
Monk Haven	Dim Pryder	Dim Pryder	Wedi'i sgwrio	Pryderon posib am ddirywiad o ran *Pelvetia canaliculata* yn y LU. Mae pedrannau monitro presennol y LI yn rhy uchel ar y lan i gynrychioli cymuned y LI yn ddigonol ac mae sgwrfa clogfeini'n effeithio ar yr ardal
Bae West Angle	Dim Pryder	Dim Pryder	Dim Pryder	Mae pedrannau monitro presennol y LI yn rhy uchel ar y lan i gynrychioli cymunedau'r safle ar y LI sy'n llawn algâu
Nolton Haven	Dim Pryder	Dim Pryder	Dim Pryder	Sgwrfa tywod yn y LI ond mae hon yn nodwedd naturiol yn y gymuned

Executive Summary

In 2005, the Countryside Council for Wales implemented a long-term monitoring programme to investigate the distribution and abundance of rocky shore organisms as part of the Pembrokeshire Marine SAC intertidal monitoring programme. *Reef* is one of the Annex I features for which the SAC is designated and a specific area of interest are the intertidal bedrock reefs, particularly in the Milford Haven where there is a greater risk of water quality or other disturbance issues.

A series of nine shore monitoring sites have been established. Six are in the Milford Haven waterway at Lawrenny Quay, Pembroke Ferry, Hazelbeach, Pembroke Power Station, South Hook and Monk Haven. One site it at the entrance to Milford Haven at West Angle Bay. Two sites are on the open coast, at Pen-y-Holt on the south coast of Pembrokeshire and at Nolton Haven in St Bride's Bay, on the west coast of Pembrokeshire. There are no fixed quadrats at Pen-y-Holt so the data from that site do not form part of this report.

A program of annual monitoring has been carried out at most of these sites in most years since 2005. This report presents the 2005 to 2019 frequency data collected from permanently established monitoring quadrats at each of the study sites in a form suitable for multivariant analysis. It builds on the results from Bunker (2015). Much of the work undertaken to collate this dataset used a bespoke relational database (in MS Access) called 'Shore Survey Data'.

The aims of this report, together with a summary of outcomes are:

- To collate a 2005 to 2019 dataset suitable for multivariant analysis. This time consuming work was completed, resulting in a PRIMER file, the analysis of which provides the basis of this report. This file; "Pembrokeshire Marine SAC shore quadrat data 2005 to 2019.pwk" is available as an electronic appendix to this report.
- To catalogue a set of photographs from the monitoring surveys of 2005 to 2019 and undertake visual analyses. All the digital photographs (over 11,000 images) have been collated into Adobe Lightroom and labelled with keywords which have enabled easy and rapid sorting of images.
- To present initial analyses of the quadrat data obtained from 2005 to 2019 designed to identify change and trends. Basic multivariate analyses of the data have been carried out in PRIMER and are presented. Where ecological change has been detected, this has been highlighted.
- To discuss the results of the data analyses in terms of change and condition of the monitoring sites. The trends and changes detected in the data (and from photographs) have been discussed and where possible related to published work.

Ultimately this report aims to provide NRW with information to enable completion of a condition assessment of intertidal rocky reefs the Pembrokeshire Marine SAC and report to the UK government (European Commision, 1994; Countryside Council for Wales, 2009). It is beyond the scope of this report to complete that condition assessment but rather to put forward the author's opinions on the status of the monitoring sites based on the analyses carried out. A summary of the author's assessment of the monitoring sites is given in the table below:

Table of concerns about the conservation status of each zone of the monitoring study shores in Pembrokeshire Marine SAC covered in this report (US = Upper shore, MS = Mid shore, LS = Lower shore).

Site	Upper shore	Mid shore	Lower shore	Notes
Lawrenny Quay	No Concern	Of concern - decline in *Ascophyllum*	No Concern	Concern about decline of *Ascophyllum nodosum* in the middle shore. Also concern about prevalence of non-native species below the LS monitoring quadrats
Pembroke Ferry	No Concern	No Concern	No Concern	MS is probably in an altered state of being barnacle limpet dominated rather than *Ascophyllum* dominated
Hazelbeach	No Concern	No Concern	No Concern	MS is probably in an altered state of being barnacle limpet dominated rather than *Ascophyllum* dominated
Pembroke Power Station	Of concern - decline in *Ascophyllum*	No Concern	Not applicable	*Ascophyllum nodosum* is disappearing from the US and the MS is probably in an altered state of being barnacle limpet dominated rather than *Ascophyllum* dominated
South Hook Point	No Concern	No Concern	Scoured	Possible concerns about decline in *Pelvetia canaliculata* in the US. Lower shore is a naturally scoured habitat so status is difficult to determine but there has been a decline in species and cover over time
Monk Haven	No Concern	No Concern	Scoured	Possible concerns about decline in *Pelvetia canaliculata* in the US. Current LS monitoring quadrats are two high on the shore to adequately represent the LS community and the area is affected by boulder scour
West Angle Bay	No Concern	No Concern	No Concern	Current LS monitoring quadrats are two high on the shore to adequately represent the algae rich LS communities of the site

Site	Upper shore	Mid shore	Lower shore	Notes
Nolton Haven	No Concern	No Concern	No Concern	Sand scour in the LS but this is a natural feature of the community

1. Introduction

In 2005, the Countryside Council for Wales (CCW, now Natural Resources Wales) implemented a long term programme to monitor the condition of the intertidal features of the Pembrokeshire Marine Special Area of Conservation (SAC). The aim of the monitoring is to provide data for regular reporting on the condition of the Habitats Directive features within the Pembrokeshire Marine SAC (European Commision 1994; Countryside Council for Wales 2009).

A series of fixed quadrats across six rocky shore sites were established within the Milford Haven waterway in July 2005 (Hull *et al.* 2006). The sites were as follows:

- Lawrenny Quay
- Pembroke Ferry
- Hazelbeach
- Monk Haven
- South Hook Point
- West Angle Bay

Two open coast sites were added in 2007 for comparison with those in Milford Haven (Mercer & Brazier 2008):

- Nolton Haven in St Brides Bay (fixed quadrats)
- Pen-Y-Holt on the south coast of Pembrokeshire (rock pool studies and limpet and barnacle populations)

In 2011, a further Milford Haven site was added:

- Pembroke Power Station (adjacent to a cooling water outfall following the commissioning of Pembroke Power Station in 2010 (Bunker & Brazier 2013).

The study of intertidal *Zostera* in Angle Bay was also added in August 2009.

The sites selected were chosen primarily because they represented an environmental gradient along the Milford Haven in terms of salinity and wave exposure and also because they were adjacent to a series of sites surveyed by the Milford Haven Waterway Environmental Surveillance Group (MHWESG). Site selection was limited by the need to have sites with suitable bedrock for permanent marking, reliable and reasonable access and suitable habitat throughout the shore.

The monitoring study sites are listed in Table 1, together with abbreviations used throughout the report. Figure 1 shows the location of the monitoring shores. Monitoring data have been collected each year since sites were established with the exception of 2006 where there was no monitoring and at Monk Haven in 2010 where the site wasn't visited. A table showing years at which monitoring has taken place at the different sites is given in Appendix 1.

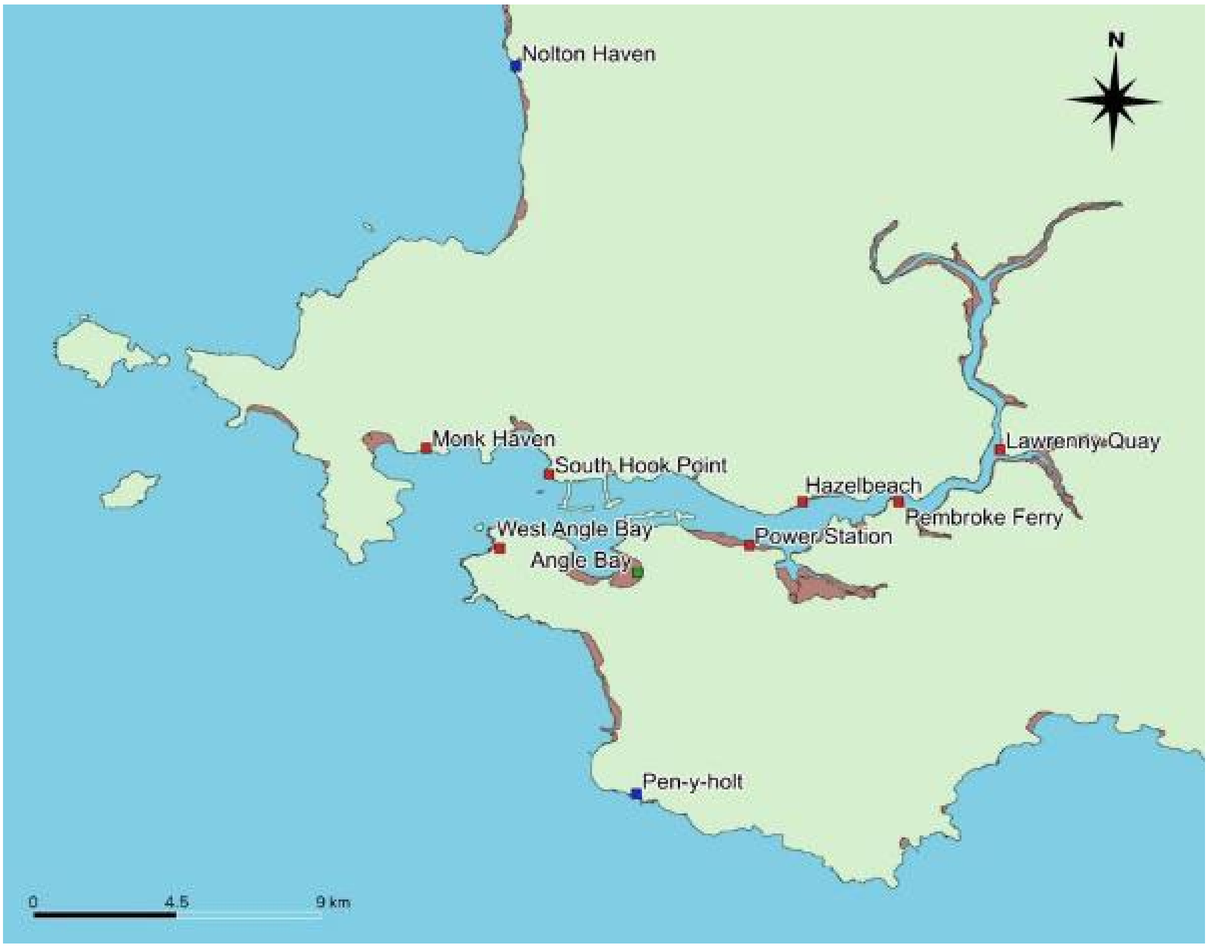
Table 1. A list of some of the main abbreviations used in the text of this report.

Site	Abbreviation
Lawrenny Quay,	LQ
Pembroke Ferry	PF
Hazelbeach	HB
Pembroke Power Station	PS
South Hook Point	SH
Monk Haven	MH
West Angle Bay	WB
Nolton Haven	NH
Pen-y-holt	PH

Term	Abbreviation
Upper shore	US
Middle shore	MS
Lower shore	LS
Above Chart Datum	ACD
Special Area of Conservation	SAC
Multidimensional Scaling	MDS
Analysis of similarity percentages	SIMPER

The locations of these sites are also shown in . .

Figure 1. Locations of intertidal features surveyed in Pembrokeshire Marine SAC. The rocky shore sites in Milford Haven are marked by red squares, the open coast sites by yellow squares and the *Zostera noltei* monitoring and sediment coring site by a green square.



A number of techniques used within the monitoring program (limpet population data and abundance and photographic identification of barnacle species) follow the same methodology as currently used within the MarClim monitoring programme

(Mieszkowska 2014) and therefore these data are comparable to data from other sites around the Welsh coastline.

1.1. Report aims

The aims of this report are as follows:

- To collate a 2005 to 2019 data set suitable for multivariant analysis.
- To catalogue a set of photographs from the monitoring surveys of 2005 to 2019 and undertake visual analyses.
- To present initial analyses of the quadrat data obtained from 2005 to 2019, designed to identify change and trends.
- To discuss the results of the data analyses in terms of change and condition of the monitoring sites.

2. Methods

The survey methodology employed is based upon recommendations provided by CCW to The Institute of Estuarine and Coastal Studies (IECS) in 2005 (Hull *et al.* 2006). Refinements to the methodology given in (Bunker & Brazier 2013) and (Bunker 2015) have subsequently been adopted and recording protocols have been honed over the years in order to assist with consistency. Site specific relocation sheets (Appendix 2), protocols (Appendix 3) and recording forms (Appendix 4) have been developed for each shore, examples of which are given in the Appendices.

At each of the eight monitoring sites, four fixed quadrat positions have been marked in each of three zones: Upper Shore (US), Middle Shore (MS) and Lower Shore (LS). The exception being Pembroke Power Station where rock descends to soft mud in the LS so the fixed quadrats are only in the US and MS. The shore heights are defined as follows:

- Upper shore (US): Quadrats located at the top of the barnacle zone or the *Pelvetia canaliculata* zone (equivalent to 6.0m ACD (above chart datum) on wave exposed shores).
- Middle shore (MS): Quadrats located in the middle of the barnacle zone or *Ascophyllum nodosum* zone (equivalent to 4.2m ACD on wave exposed shores).
- Lower shore (LS): Quadrats located at the lower edge of barnacle zone or middle of the *Fucus serratus* zone (equivalent to 1.8m ACD on wave exposed shores).

In each zone, four 1m x 1m squared quadrats are located at the same height in homogeneous areas of inclined rock, where possible avoiding rock pools and large fissures. These quadrats are marked using screws and (where appropriate) plastic discs in at least two corners. The plastic discs sometimes are lost overtime and not always replaced, especially at sites where they would be conspicuous to the public. Quadrats are placed over the markers and recording of organisms present and abundances are taken *in situ*. Photographs are taken of all quadrats within each zone.

An example of a site relocation sheet showing quadrat positions is illustrated in Appendix 2.

2.1. The survey team, briefings and data collection

At the beginning of each survey, the survey leader shows the team a PowerPoint presentation outlining the common shore species, common identification problems, and reports on new non-native species which may be encountered. The basic methodology is also explained.

Field surveys are ideally carried out by teams of three persons per site; two with identification expertise and one recorder. Exceptions to this are Lawrenny Quay and Monk Haven, where there is too much work for one team to complete in one visit.

Prior to each field outing the teams are given a briefing on the sites to be surveyed (including things that are unique to each site) and protocols for recording at those sites are discussed (see Appendix 3).

Personnel in teams should be familiar with the sites, the species and the methods used. A core team of marine biologists has undertaken this monitoring program and this has been a great asset to helping achieve recording consistency. The familiarity of the sites and development of protocols by the team over the years has all helped in this regard. A list of survey personnel is given in Appendix 9.

2.2. Site relocation

Detailed site relocation sheets have been prepared for each site. These include photographs and diagrams illustrating the location of the quadrats and bolts drilled into the rock on which they are placed. An example of one of these site relocation sheets is given in Appendix 2. All relocation sheets are in Mercer & Brazier (2009).

2.3. Quadrat recording

Data are recorded onto prepared recording sheets which are bespoke for every zone on each shore (see example in Appendix 4). Recording protocols have also been produced for each shore and are taken into the field as a reminder for recorders (see example in Appendix 3).

1 m^2 quadrats are placed over the rock markers prior to recording and the quadrat is photographed. The quadrats are gridded into 25 cells (each 20 cm x 20 cm) and frequency scores (out of 25) are recorded for most species. Where an organism cannot reliably be identified to species it is identified to genus or a higher taxonomy. Examples of this include Corallinaceae (crusts) and *Patella*. In some cases (like *Patella*) individual species may be recognised and where this is so, a record is made of the species being 'present' in the whole 1 m^2 quadrat.

Barnacles are counted as Cirripedia (apart from the large *Perforatus perforatus*) as it has proved very difficult (and time consuming) to look for the presence of each species in each of the twenty-five 20 x 20 cm squares (Bunker 2015). Instead, individual barnacle species are recorded as being 'present' in the whole 1 m^2. The proportion of the different species is calculated from a series of (at least 5) randomly placed 5 x 5 cm photographic quadrats in each zone, which are analysed after the fieldwork. (This has been done for some priority sites by NRW and by other consultants, but the results are not available for this report). The methodology for doing this is outlined in Appendix 7.

Some other species have proved problematical to count consistently for different reasons. One example are small snails living in crevices and empty barnacle shells. These including rough periwinkles (*Littorina saxatilis* and related species), *Melarhaphe neritoides* and other small or juvenile snails. More often than not, the frequency of each species present proves difficult if not impossible to count with accuracy, so they have been recorded as the group 'small Gastropods in crevices'. Records of the individual species are recorded as 'present'. Other species recorded as 'present' include highly mobile species such as gammarids, amphipods and crabs.

Only algae whose holdfasts are within the quadrat are counted. Epiphytes on macroalgae are recorded to be from the quadrat cells where the macroalgae they are epiphytic on is attached. are is taken to minimize disturbance of mobile invertebrates when macroalgal species are moved.

2.4. Photography

Photographs of each quadrat are taken together with general 'contextual' shots of the shore and each zone. These photographs are an essential visual record to supplement the presence / absence data records from the quadrats. The photographs are labelled and catalogued during each survey and a set is held by NRW.

2.5. Limpet counts

Limpet abundance (all species aggregated) is recorded from 5 random 20cm x 20cm cells within each quadrat to allow the estimation of mean limpet abundance for all zones at each monitoring site. The recording form for limpet counts is given in Appendix 5. The limpet data are not considered in this report.

2.6. Limpet measurements

Approximately 200 limpets (minimum 100) are selected at random within the middle zone at each site. The longest shell length at the base is measured in millimetres using Vernier callipers. Recorders are instructed to record limpets within the same zone and habitat as the fixed monitoring quadrats (but not necessarily within the quadrats). The recorders work systematically measuring all the limpets of different sizes within an area. Once measured, the limpet shells are marked with chalk to prevent repeated measuring of the same limpet. The data collected are used to construct population profiles for each site. The recording form for limpet measurements is given in Appendix 5. The limpet data are not considered in this report.

2.7. Cirripedia (barnacle) abundance

Percentage cover of barnacles (all species aggregated) are recorded from 5 random 20 cm x 20 cm cells within each quadrat to allow the estimation of mean barnacle abundance for all zones at each survey site. The recording form for barnacle abundance is given in Appendix 5. The barnacle abundance data are not considered in this report.

Calculating the proportion of the different barnacle species is described in section 2.3.

2.8. *Ascophyllum nodosum* age structure study

As part of the monitoring program, a study of the age structure of the fucoid *Ascophyllum nodosum* in the middle shore at Lawrenny Quay has been undertaken. The air bladders are counted to give an indication of age. The recording form for this study is given in Appendix 6. The results of this study are not considered in this report (Mercer in prep).

2.9. Other contextual information

In 2013 a scheme was introduced to record contextual information on cover of common shore species in each zone on each shore together with records of non-native species encountered which were present (e.g. in the lower shore) but not necessarily in the quadrats. An example of the recording form is given in Appendix 8. The information from these forms, as well as photographs has been used to help interpret the data analysed in this report.

2.10. Data management and analysis

2.10.1 Compiling the data

Up to 2014, the year's field data were compiled into individual spreadsheets which then had to be collated manually in order to produce a data set for analysis. This proved very time consuming and was problematical. Many factors including inconsistencies in field recording, errors in the way surveyors entered data into spreadsheets and taxonomic changes all added to the problems. In 2014 ASML commissioned Exegesis Spatial Data Management to produce a database based on the World Register of Marine Species taxonomic database (WoRMS) in which to enter and store the data. The database is a bespoke Microsoft Access relational database called Shore Survey Data which allows for flexible manipulation of the data, querying and export for further analysis. The structure of this database is outlined in Appendix 10.

Since 2014 the database has been used for data entry and storage and all the survey data from 2005 to 2013 has now been entered from the original data sheets.

Following data export, a certain amount of 'data cleaning' is required in order to sort out inconsistencies. Inconsistencies are corrected in the database and the 'cleaned' data are then re-exported ready for analysis. Now all the historic data are in good order, it is relatively simple to sort out inconsistencies in new data inputs.

2.10.2 Quality assurance and quality control

Inconsistencies in recording are minimised by a series of quality assurance (QA) procedures. The Standard Operating Procedures (SOPs) for each site (Appendix 3) and bespoke recording sheets for each shore (Appendix 4) are a great help in ensuring that species are recorded consistently. (Prior to 2009 the same recording sheet was used for every shore and SOPs had not been developed leading to many inconsistencies).

QA procedures continue with data entry. The field surveyors of particular sites enter their data directly into the database. The entered data are then checked by another field team against the recording sheets and inconsistencies are resolved with the recorders.

Quality control (QC) is carried out on the data set when it is exported at the end of the survey. Inconsistencies at this stage are sorted out (by Francis Bunker) before the data goes forward for analysis or entering into Marine Recorder. All original field data sheets are kept in case further reference to them is needed in subsequent years.

Following export of multiple data years from Short Survey Data for the purposes of analysis and reporting, further QC is undertaken. Changes in taxonomy and the way in which species or species groups have been recorded between years are resolved before analysis.

2.10.3 Data structure

A diagram showing the relationships between fields in the database design is given in Appendix 10.

The database table of recorded taxa (*entities*) is carefully managed to provide a level of standardisation appropriate for long-term monitoring. Each *entity* is defined as a taxon (using the agreed taxonomic nomenclature provided by the WoRMS database) and any qualifiers (e.g. encrusting, juvenile, orange) that are typically recorded. A few new entities are routinely added to the table after each survey, but only if they are clearly different from those already on the list. Attribute data linked to each entity includes the 'Aphia id', taxonomic authority and classification details available from the WoRMS database.

2.10.4 Analysis of data

This report focuses on the analysis of the quantitative frequency data collected at each site and each zone. Those species for which only presence / absence data are recorded from whole quadrats are not considered here.

Tabulated data in Excel formats were exported from the Shore Survey Data in a form ready for import into Marine Recorder (Marine Recorder is a Microsoft Access database used by the Countryside Agencies and JNCC to store survey data).and PRIMER 7 (Clarke *et al.* 2014; Clarke & Gorley 2015) where multivariate analyses were carried out. Within PRIMER 7, the data were handled as follows:

Prior to analysis, the frequency data were square root transformed

Resemblance matrices were created by employing Bray-Curtis similarity

MDS - non-metric Multi-Dimensional Scaling was carried out

Where data required further analysis to explain trends, a SIMPER analysis was undertaken.

In some cases (e.g. where a species has been seen to increase or decrease dramatically) graphs have been compiled to show changes in the frequency data over time.

2.10.5 Analysis of photographs

The photographic archive is in excess of 7,000 digital images. These have been catalogued in Adobe Lightroom and can be searched using keywords allotted to each image.

Sets of images for each site, zone and individual quadrat have been prepared and examined to look for visual changes over time. Observations from the sets of photographs are described in the results and related (where possible) to the data analyses.

2.10.6 Data storage

Details of data storage and archiving are given in Appendix 11.

3. Results

The PRIMER file "Pembrokeshire Marine SAC shore quadrat data 2005 to 2019.pwk" showing details of the analyses is given as an electronic appendix to this report.

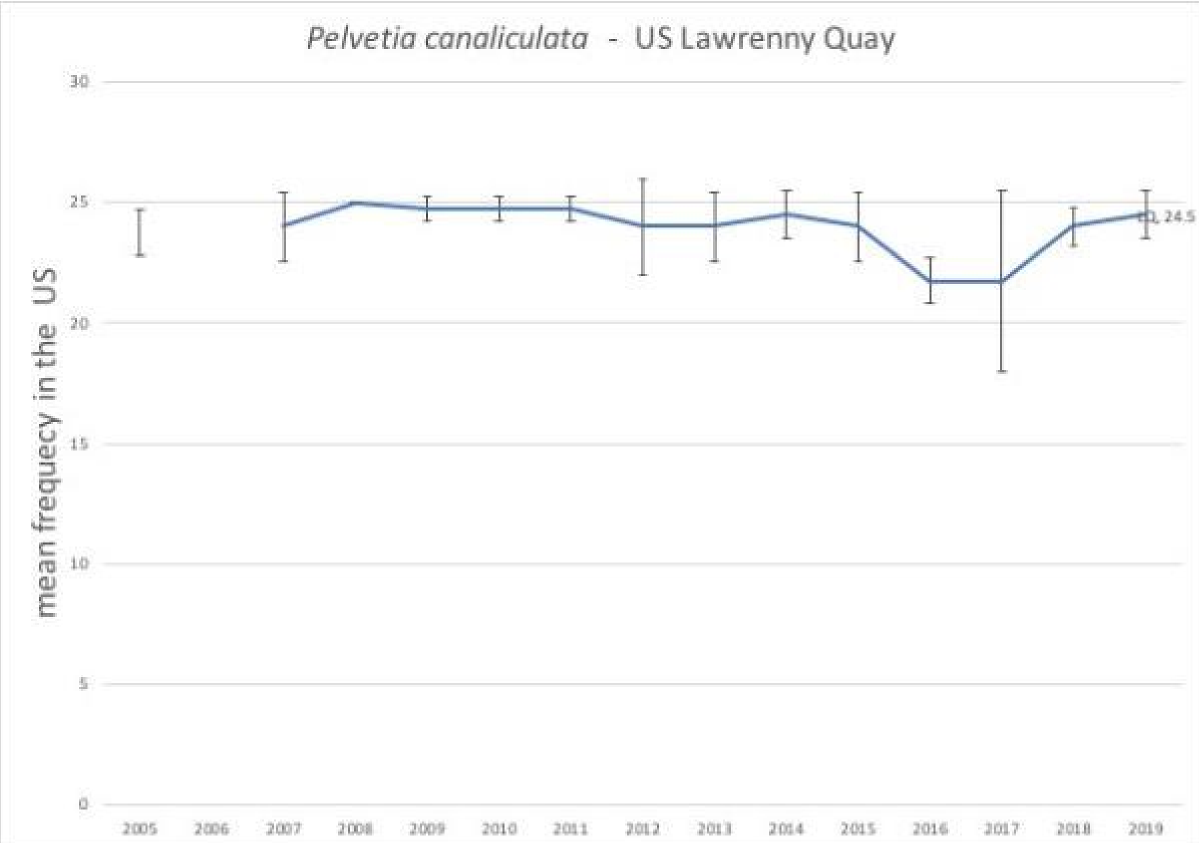
3.1. Lawrenny Quay US

The results of data analyses for Lawrenny Quay US are summarised below.

3.1.1 Visual Change

The frequency data for the dominant species in the US, *Pelvetia canaliculata,* (averaged from all quadrats) was plotted over time in Figure 2. The frequency data shows little in terms of significant change, apart from a decrease in 2016.

Figure 2. Graph to show the mean abundance (frequency) of *Pelvetia canaliculata* in the US of Lawrenny Quay fixed monitoring quadrats, with standard deviation bars



A better idea of cover is shown in the photographs of the Lawrenny Quay US quadrats. Between 2005 and 2019 there are some obvious changes in cover of *Pelvetia canaliculata*. Figure 3 presents photographs of quadrat 1 selected to illustrate changes of *P. canaliculata* cover over time. There is a decline in cover of *P. canaliculata* between 2005 and 2007 after which cover increases to 2015 and then declines again to 2017 and then increases again to 2019.

Figure 3. US Q1 at Lawrenny Quay showing the cyclical decline and increase in fucoid cover (mainly *Pelvetia canaliculata*) between 2005 and 2019. (Years selected to illustrate the major trend).

US Q1 2005

US Q1 2007

US Q1 2011

US Q1 2015

US Q1 2017

US Q1 2019

3.1.2 Multidimensional scaling (MDS)

MDS plots presenting the data for all taxa recorded in the US quadrats are shown in Figure 4 and Figure 5. The stress is low (below 0.2) suggesting there is a good fit of the data to the two-dimensional plot generated. There is a general pattern for all the quadrats for particular years to be grouped together (Figure 4). The MDS plots also show a division between the data recorded between 2005 and 2010 in comparison to that recorded between 2011 and 2019 (Figure 5).

Figure 4. Non-metric MDS plot showing the data for all taxa (for which frequency was recorded) in all quadrats in Lawrenny Quay US between 2005 and 2019

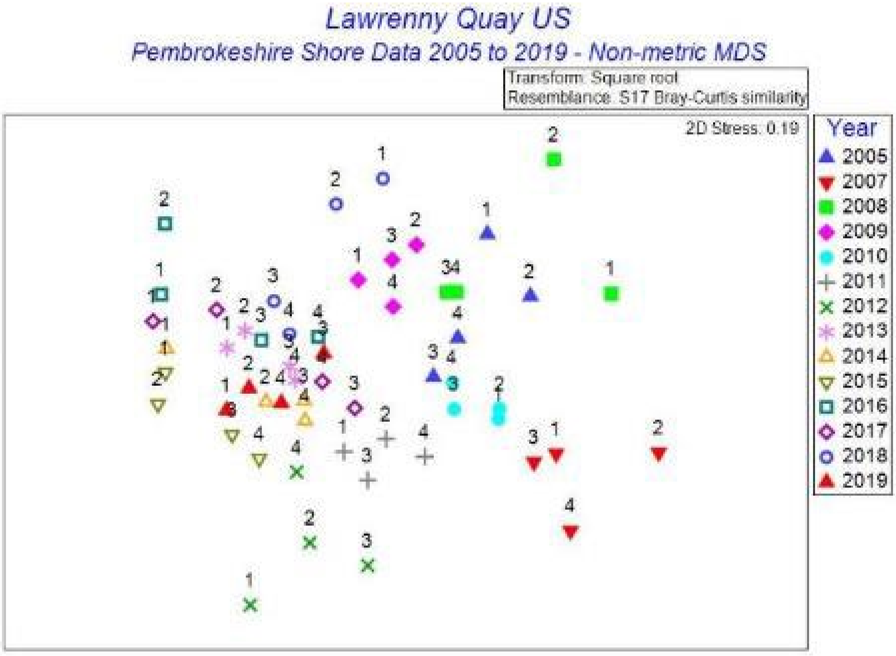
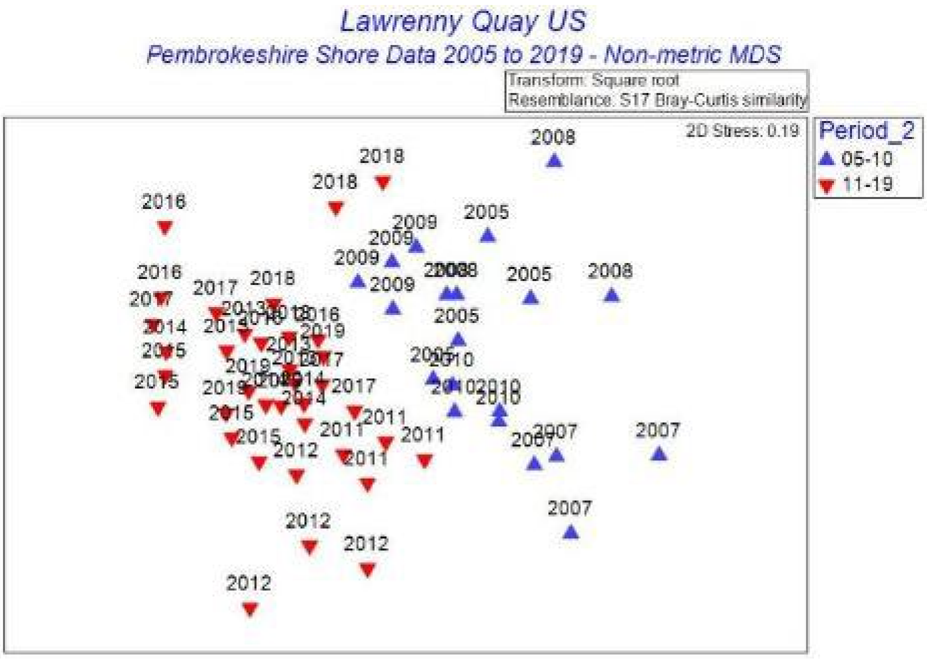


Figure 5. Non-metric MDS plot (the same one as in Fig. 4) showing the data for all taxa (for which frequency was recorded) in all quadrats in Lawrenny Quay US between 2005 and 2019, with symbols showing two periods: 2005 to 2010 and 2011 to 2019



It is considered that differences between the recording periods shown in Figure 5 are most likely to be due to changes in recording forms and protocols employed (see section 3.1.3).

3.1.3 Analysis of similarity percentages (SIMPER)

A SIMPER analysis of the US Lawrenny Quay quadrat data was undertaken, with the factor groups being sample (i.e. quadrat and year) and period (i.e. 2005 to 2010 and 2011 to 2019). The dissimilarity between these periods is not very high but Table 2 highlights the species recorded that account for the main dissimilarity. These were Chlorophyta film, fuzz or threads, *Ulva* tubular, *Fucus* sporelings, *Hildenbrandia* (all species) and *Fucus spiralis*. The differences between periods was most likely due to difference in recording. In 2011 new recording forms were developed to encourage surveyors to look for particular species which were characteristic of each site and zone. Prior to 2011, surveyors would often miss out recording particular species.

Table 2. Results of SIMPER analysis of Lawrenny Quay US data. The data from 2005 and 2010 is compared with that from 2011 to 2019.

Group 05-10 Average similarity: 73.56

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Pelvetia canaliculata	4.94	22.58	9.12	30.69	30.69
Bostrychia scorpioides	3.69	14.01	4.29	19.04	49.73
Verrucariaceae	3.22	12.61	5.95	17.14	66.88
Catenella caespitosa	2.64	9.56	2.46	13	79.87

Group 11-19 Average similarity: 74.93

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Pelvetia canaliculata	4.86	15.91	9.95	21.24	21.24
Catenella caespitosa	3.68	11.13	5.96	14.86	36.09
Hildenbrandia all species	3.47	9.39	2.97	12.52	48.62
Bostrychia scorpioides	3.46	9.2	2.36	12.28	60.9
Verrucariaceae	3.45	8.93	1.92	11.92	72.82

Groups 05-10 & 11-19 Average dissimilarity: 34.31

Species	Group 05-10 Av.Abund	Group 11-19 Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Chlorophyta film, fuzz or threads	0	2.24	4.22	1.62	12.31	12.31
Ulva tubular	1.78	0.35	3.5	0.92	10.19	22.5
Fucus sporelings	0.05	1.81	3.45	1.42	10.05	32.54
Hildenbrandia all species	2.43	3.47	3.38	1.27	9.85	42.39
Fucus spiralis	1.5	2.8	2.76	1.47	8.06	50.45
Bostrychia scorpioides	3.69	3.46	2.44	1.28	7.12	57.56
Verrucariaceae	3.22	3.45	2.43	1.23	7.08	64.64
Catenella caespitosa	2.64	3.68	2.34	1.21	6.83	71.47

3.2. Lawrenny Quay MS

Lawrenny Quay MS is dominated by *Ascophyllum nodosum*. The results of data analyses for are summarised below.

3.2.1 Visual Change

The frequency data for the dominant fucoid in the MS, *Ascophyllum nodosum,* (averaged from all quadrats) was plotted over time in Figure 6. The frequency data doesn't show significant change but examination of the quadrat photographs (Figure 7 and Figure 8) shows that *A. nodosum* has more or less disappeared from MS Q1.

Figure 6. Graph to show the mean abundance (frequency) of *Ascophyllum nodosum* in the MS of Lawrenny Quay fixed monitoring quadrats, with standard deviation bars

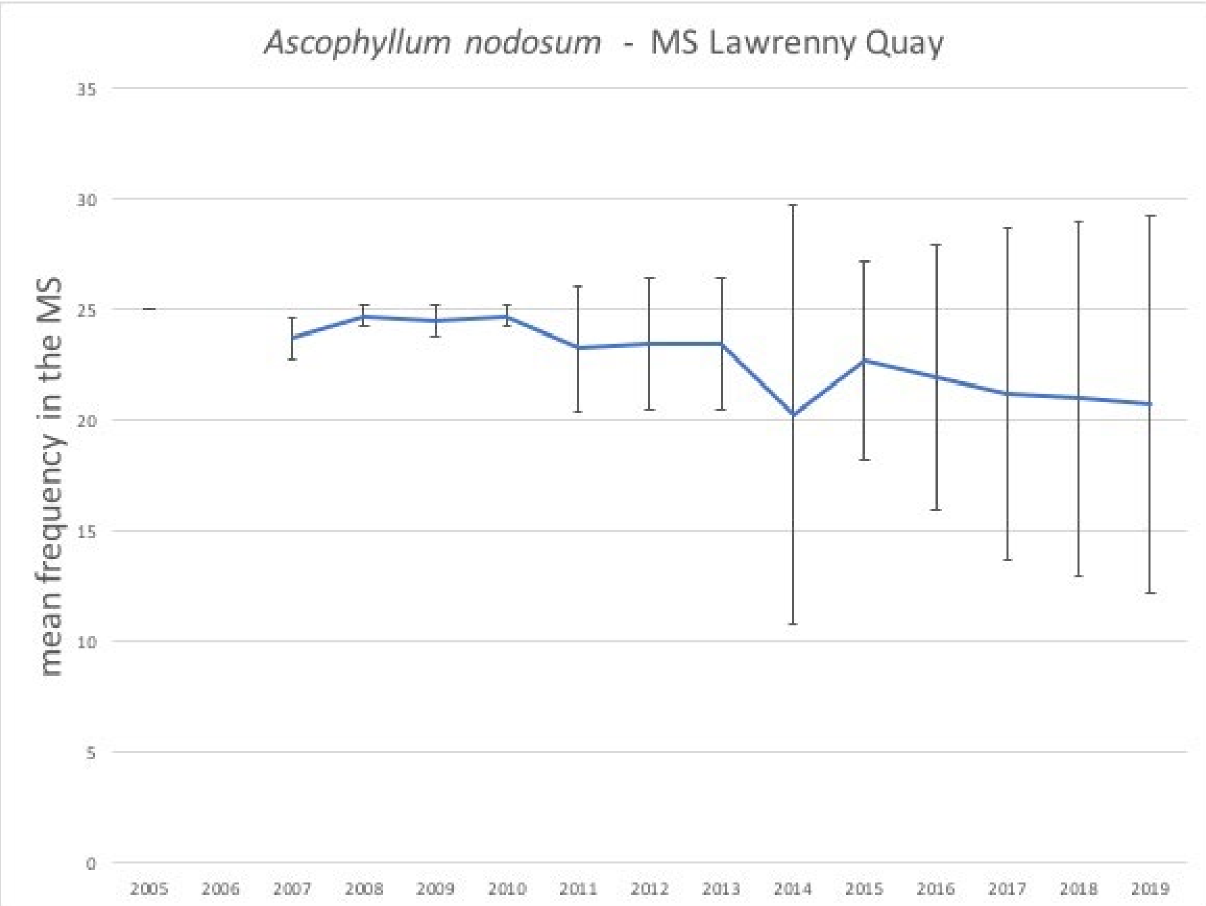


Figure 7. Selected photographs of MS Q1 at Lawrenny Quay, showing a decline in *Ascophyllum nodosum* since 2009.

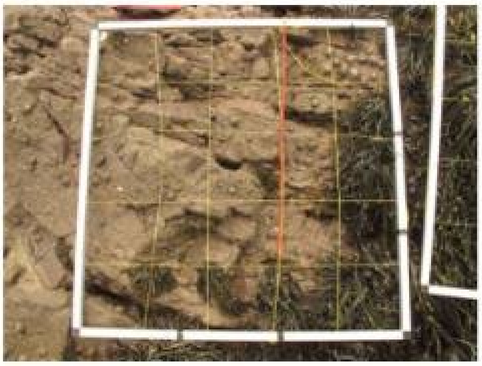
MS Q1 2005

MS Q1 2009

MS Q1 2011

MS Q1 2013

MS Q1 2017



MS Q1 2019

Figure 8. Lawrenny Quay MS monitoring area in 2005 and 2016 to illustrate decrease of *Ascophyllum nodosum* in the area of MS Q1

MS quadrat area 2005

MS quadrat area 2016

3.2.2 Multidimensional scaling (MDS)

An MDS plot presenting the data for all taxa recorded in the MS quadrats are shown in Figure 9 and Figure 10. The stress is low (below 0.2) suggesting there is a good fit of the data to the two-dimensional plot generated. There is a general pattern for all the quadrats for particular years to be group together (Figure 9). The MDS plot also shows a division between the data recorded between 2005 and 2010 in comparison to that recorded between 2011 and 2019 (Figure 10).

Figure 9. Non-metric MDS plot showing the data for all taxa (for which frequency was recorded) in all quadrats in Lawrenny Quay MS between 2005 and 2019

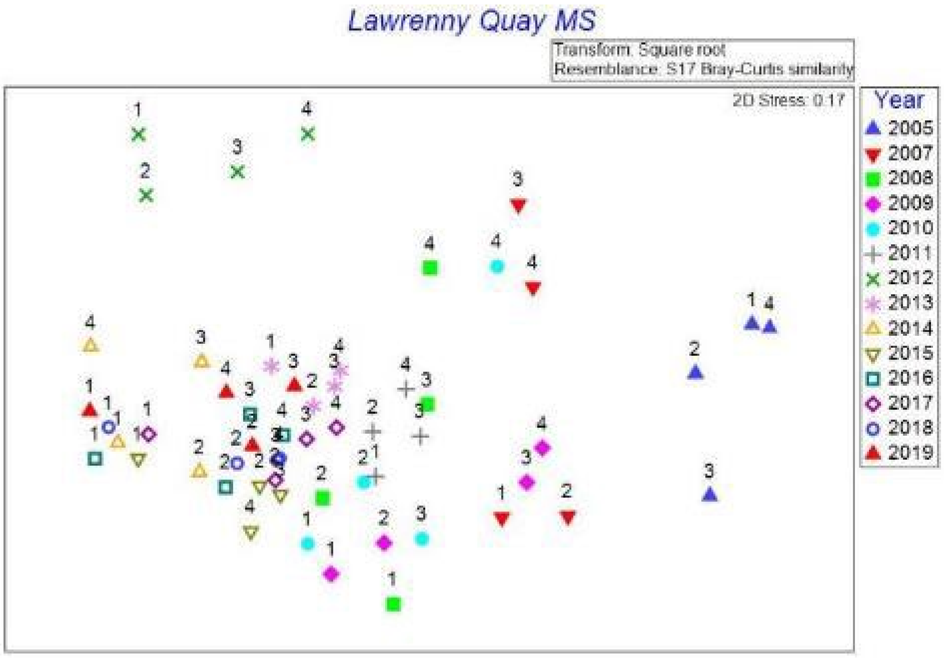
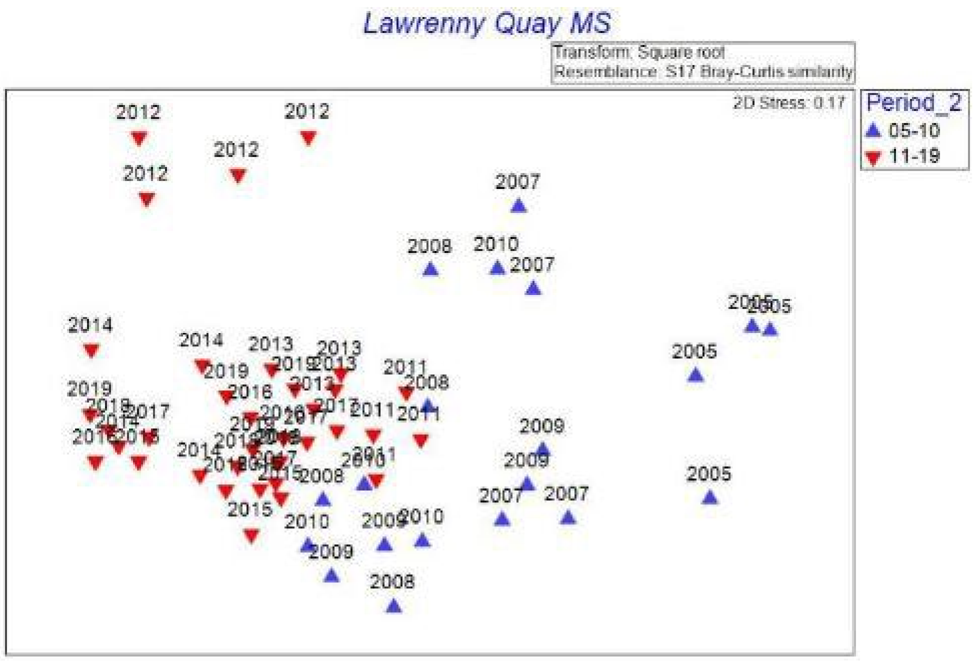


Figure 10. Non-metric MDS plot showing the data for all taxa (for which frequency was recorded) in all quadrats in Lawrenny Quay MS between 2005 and 2019, with symbols showing two periods; 2005 to 2010 and 2011 to 2019.



3.2.3 Analysis of similarity percentages (SIMPER)

A SIMPER analysis of the Lawrenny Quay MS quadrat data was undertaken to determine which species were responsible for 2012 data separating from the rest of the 2011 to 2019 data in the MDS plot (Figure 10). The results of the SIMPER analysis are summarised in Table 3.

The average dissimilarity between the two year-groups was 45.6%. Several common MS species were either not recorded in 2012 or (in most cases) recorded in a lower abundance compared to the rest of the 2011 to 2019 group. The species are ranked with those contributing the most to the dissimilarity at the top of the list. Reasons for the differences seen are unclear.

Table 3 Results of SIMPER test to show a calculation of the dissimilarity of the species abundance (frequency) data from Lawrenny Quay MS between the two factor groups 2011 to 2019 and 2012

Group 2011-2019 (minus 2012) Average similarity: 70.51

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Cirripedia all except *P. perforatus*	4.87	8.14	8.36	11.54	11.54
Ascophyllum nodosum	4.61	7.34	4.29	10.41	21.95
Hildenbrandia all species	4.03	5.89	4.02	8.35	30.3
Vertebrata lanosa	3.57	5.27	4.54	7.48	37.78
Littorina obtusata / fabalis	3.3	4.72	5.02	6.69	44.47
Fucus sporelings	3.37	4.6	2.78	6.52	51
Gelidium all species	2.97	4.18	3.01	5.93	56.92
Hymeniacidon perlevis	2.67	3.75	4.1	5.32	62.24
Spirorbinae	2.68	3.06	1.23	4.34	66.58
Corallinaceae crusts	2.38	2.65	1.6	3.75	70.33

Group 2012 Average similarity: 62.42

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Ascophyllum nodosum	4.84	14.89	10.74	23.85	23.85
Cirripedia all except *P. perforatus*	4.55	13.36	6.7	21.4	45.26
Vertebrata lanosa	4.14	11.65	12.1	18.66	63.92
Hildenbrandia all species	2.99	5.82	0.9	9.32	73.24

Group 2011-2019 (minus 2012) Average similarity: Average dissimilarity = 45.60

Species	Gp 11-19 (-12) Av.Abund	Gp 12 Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Littorina obtusata / fabalis	3.3	0	3.63	4.18	7.97	7.97
Spirorbinae	2.68	0	2.99	1.71	6.55	14.52
Fucus sporelings	3.37	1.66	2.44	1.48	5.36	19.88
Dynamena pumila	2.18	0	2.44	1.48	5.35	25.23
Patella	2.09	0	2.31	1.47	5.07	30.29
Amathia imbricata	2.07	0	2.28	1.67	4.99	35.29
Ceramium all species	2.04	2.56	2.23	1.6	4.88	40.17
Corallinaceae crusts	2.38	0.71	1.96	1.55	4.31	44.48
Hildenbrandia all species	4.03	2.99	1.88	1.1	4.13	48.6
Fucus serratus	1.9	2.03	1.86	1.45	4.07	52.67
Chondrus crispus	0.88	1.59	1.79	1.13	3.93	56.6
Gelidium all species	2.97	1.81	1.67	1.26	3.67	60.27
Ulva tubular	1.46	0	1.59	1.25	3.48	63.75
Hymeniacidon perlevis	2.67	1.96	1.56	1.42	3.42	67.17
Chlorophyta film, fuzz or threads	1.37	0.35	1.37	1.17	3	70.17

3.3. Lawrenny Quay LS

The results of data analyses for Lawrenny Quay LS are summarised below.

3.3.1 Visual change

Little in the way of visual change has been noted in the LS during the time of the study. The monitoring quadrats are in an area dominated by *Fucus serratus* (see Figure 11).

Quadrats LS Q1 and LS Q2 are slightly lower in position and on a steep slope when compared with LS Q3 and LS Q4 which are slightly higher and on a more gradual slope.

Figure 11. Lower shore monitoring area at Lawrenny Quay (2nd September 2012), showing quadrat positions LS Q2 (left) and LS Q4 (right).

3.3.2 Multidimensional scaling (MDS)

MDS plots of the data for all taxa recorded in the LS quadrats are shown in Figure 12 and Figure 13. The stress is fairly low suggesting there is a reasonably good fit of the data to the two-dimensional plot generated. Two main trends can be seen in the MDS plots. In Figure 12, the 2005 quadrats are all separated from the rest of the data. When the data are presented so the quadrats are labelled with different colours, there is a general separation of MS Q1 and MS Q2 from MS Q3 and MS Q4 (see Figure 13).

Figure 12. Non-metric MDS plots showing the data for all taxa (for which frequency was recorded) in all quadrats in the Lawrenny Quay LS between 2005 and 2019.

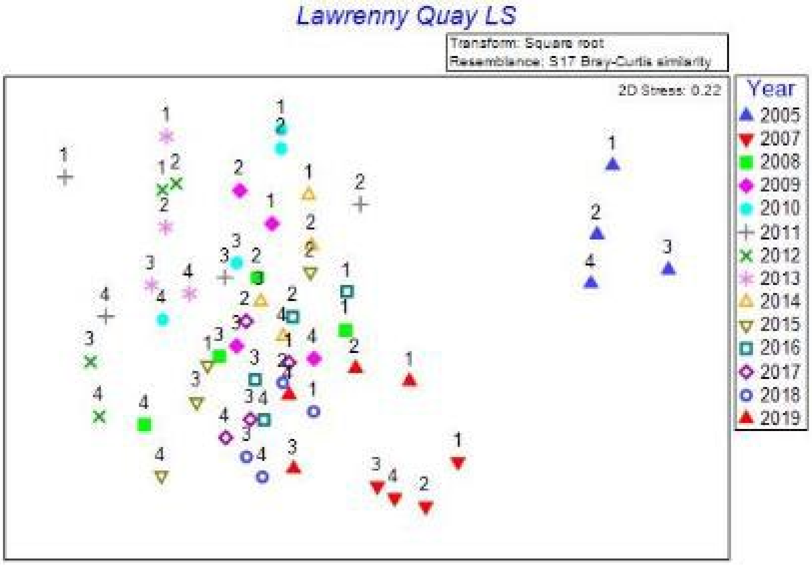
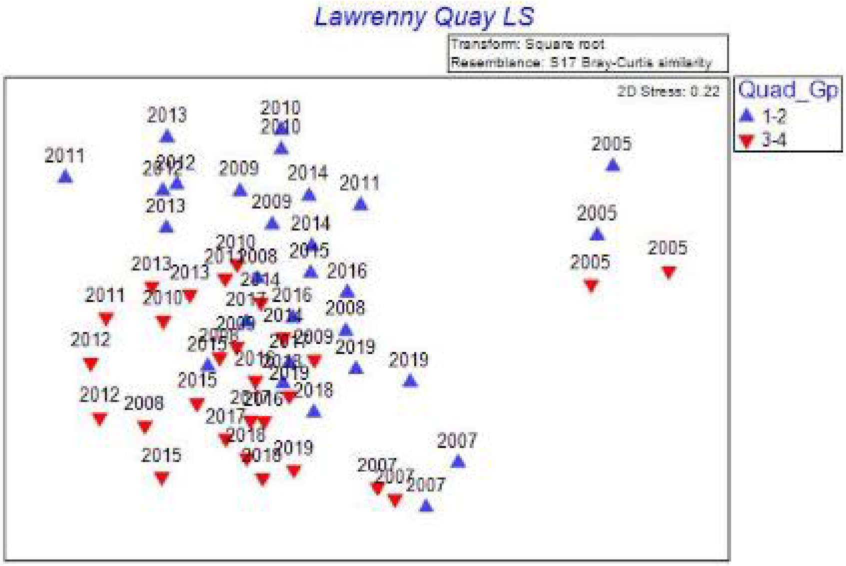


Figure 13. Non-metric MDS plots showing the data for all taxa (for which frequency was recorded) in all quadrats in Lawrenny Quay LS between 2005 and 2019, with symbols showing two quadrat groups: LS Q1 and Q2 and LS Q3 and Q4.



3.3.3 Analysis of similarity percentages (SIMPER)

A SIMPER analysis of the Lawrenny Quay LS quadrat data was undertaken to determine which species were responsible for the 2005 data separating from the 2011 to 2019 data in the MDS plot (Figure 12). The results of the SIMPER analysis are summarised in Table 4.

The average dissimilarity between the two year-groups was 49.75%. The dissimilarity is the result of many species either not being recorded at all in 2005 or (with few exceptions) in lower abundance than in the other years. The species in Table 4 are ranked with those contributing the most to the dissimilarity at the top of the list.

Table 4. Results of SIMPER test to show a calculation of the dissimilarity of the species abundance (frequency) data from Lawrenny Quay LS between the two factor groups 2005 and 2007 to 2019. Groups 2005 & 2007-2019: Average dissimilarity = 49.75

LQ LS 05 Average similarity: 70.00

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Fucus serratus	4.3	10.01	4.23	14.3	14.3
Flustrellidra hispida	4.01	9.24	6.96	13.21	27.5
Littorina obtusata / fabalis	3.31	8.21	10.45	11.73	39.23
Chondrus crispus	3.12	6.35	2.18	9.07	48.3
Ulva tubular	2.62	6.14	6.64	8.78	57.08
Alcyonidium Includes *A. gelatinosum, A. mytili* and *A. polyoum*	2.64	5.64	2.61	8.06	65.14
Ectocarpales filamentous	2.41	5.1	5.53	7.29	72.42

LQ LS 07-19 Average similarity:64.03

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Cirripedia all except *P. perforatus*	4.58	5.95	2.55	9.28	9.28
Fucus serratus	4.33	5.62	7.33	8.77	18.06
Flustrellidra hispida	4.21	5.27	3.44	8.23	26.28
Dynamena pumila	4.09	5.17	5.1	8.07	34.35
Chondrus crispus	4.14	5.03	2.37	7.86	42.22
Ulva flat	3.53	4.06	2.42	6.34	48.56
Spirorbinae	3.54	3.94	2.2	6.15	54.71
Littorina obtusata / fabalis	3.11	3.25	1.91	5.08	59.78
Dendrodoa grossularia	3.08	3.22	1.97	5.02	64.81
Alcyonidium Includes *A. gelatinosum, A. mytili* and *A. polyoum*	2.98	3.2	2.2	4.99	69.8
Amathia imbricata	2.5	2.49	1.49	3.89	73.69

LQ LS 05 &07-19 Average similarity:49.75

Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Dendrodoa grossularia	0.6	3.08	2.31	1.83	4.64	4.64
Dynamena pumila	1.66	4.09	2.3	1.44	4.62	9.26
Amathia imbricata	0	2.5	2.25	2.03	4.53	13.79
Cirripedia all except *P. perforatus*	2.47	4.58	2.2	2.59	4.43	18.22
Spirorbinae	1.64	3.54	2.12	1.44	4.26	22.48
Ectocarpales filamentous	2.41	0.59	1.78	1.93	3.58	26.06
Gelidium all species	0	1.99	1.77	1.52	3.56	29.63
Ceramium all species	0	1.84	1.61	1.19	3.24	32.87
Ulva flat	2.23	3.53	1.51	1.63	3.04	35.9
Rhodophyta indet. (non calc. crusts)	0	1.64	1.51	0.86	3.04	38.94
Ulva tubular	2.62	1.26	1.45	1.63	2.92	41.86
Gracilariaceae	1.57	0	1.44	6.98	2.9	44.76
Corallinaceae crusts	0	1.61	1.42	1.21	2.85	47.62
Chondrus crispus	3.12	4.14	1.39	1.31	2.79	50.41
Bryozoa indet crusts	1.33	0.87	1.37	1.09	2.75	53.17
Fucus sporelings	0	1.43	1.24	0.92	2.49	55.66
Littorina littorea	0.6	1.72	1.13	1.45	2.27	57.93
Vertebrata fucoides	0.79	1.06	1.02	1.1	2.06	59.99
Alcyonidium Includes *A. gelatinosum, A. mytili* and *A. polyoum*	2.64	2.98	1.02	1.3	2.06	62.05
Mastocarpus stellatus	0	1.08	0.98	1.05	1.98	64.03

Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Littorina obtusata / fabalis	3.31	3.11	0.97	1.03	1.94	65.97
Hildenbrandia all species	0	1.09	0.94	0.69	1.89	67.87
Mytilus edulis	0.85	1	0.91	1.22	1.83	69.7
Halichondria (Halichondria) panicea	0	0.93	0.85	1.27	1.7	71.4

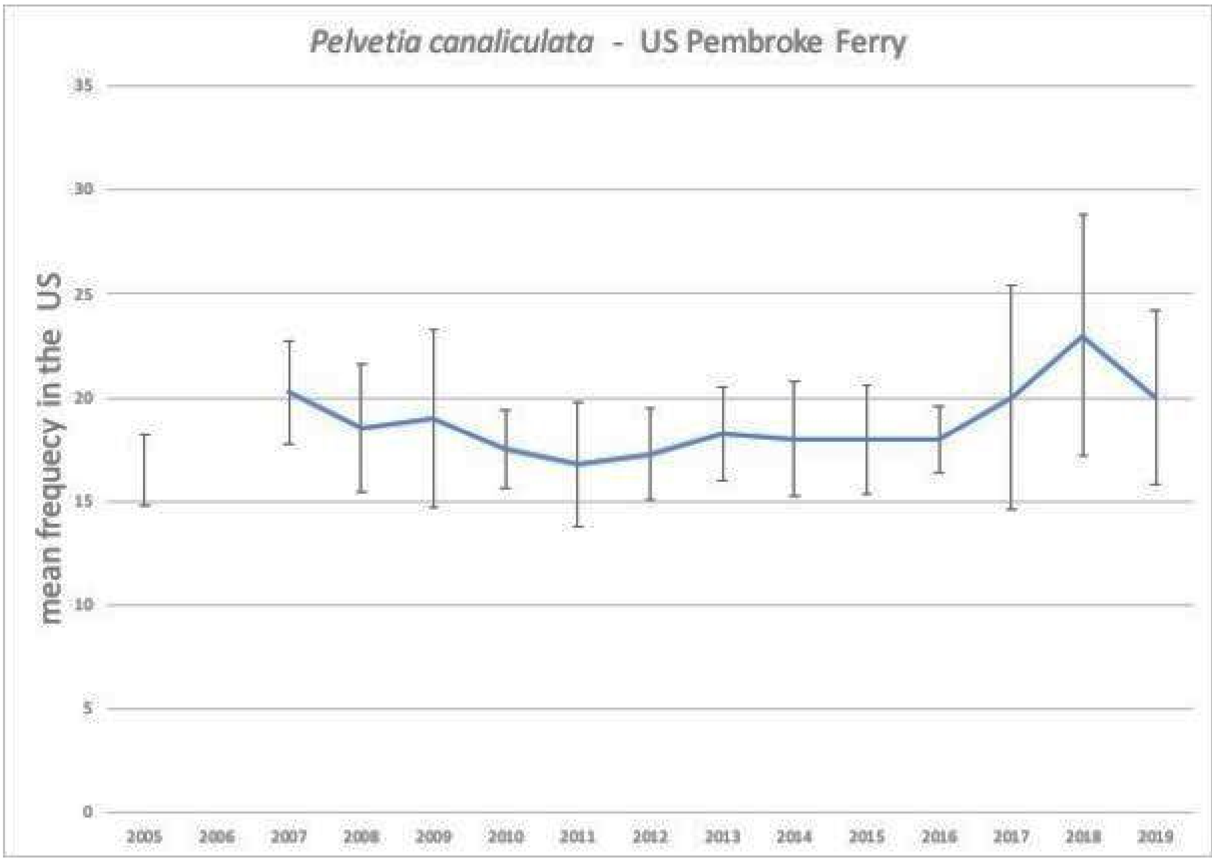
3.4. Pembroke Ferry US

The results of data analyses for Pembroke Ferry US are summarised below.

3.4.1 Visual Change

The frequency data for a fucoid in the US, *Pelvetia canaliculata* (averaged from all quadrats), was plotted over time in Figure 14. The frequency data shows ups and downs but no significant change.

Figure 14. Graph to show the mean abundance (frequency) of *Pelvetia canaliculata* in the US of Pembroke Ferry fixed monitoring quadrats, with standard deviation bars



A series of photographs of the Pembroke Ferry US quadrats between 2005 and 2019 shows some obvious changes in cover of algae. Figure 15 presents photographs of Q4 selected to illustrate changes in the community of algae cover over time. Increases and decreases of cover of different species can be seen. Within the time series, fucoid cover was greatest in 2016 but has since declined. Whereas other species have fluctuated in abundance, *Ascophyllum nodosum* cover has stayed almost constant over the years. The 'frequency of occurrence' method of recording seaweeds does not take into account the size of individual seaweeds/biomass, so the photographs are a useful addition to the frequency data.

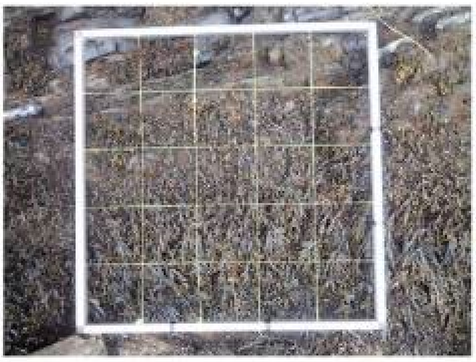
Figure 15. US Q4 at Pembroke Ferry showing the cyclical decline and increase in algal cover between 2007 and 2019. (Years selected to illustrate the major trend).

US Q4 2007

US Q4 2009

US Q4 2011

US Q4 2013



US Q4 2016

US Q4 2019

3.4.2 Multidimensional Scaling (MDS)

MDS plots presenting the data for all taxa recorded in the US quadrats are shown in Figure 16 and Figure 17. The stress is fairly low suggesting there is a reasonably good fit of the data to the two-dimensional plot generated. There is a general pattern of all the quadrats for particular years grouping together (Figure 16). The 2005 data separates from the other years. Despite this, the 2005 data shows some separation from the rest. In general, the early year data tends to separate from the later year data.

Figure 16. Non-metric MDS plot showing the data for all taxa (for which frequency was recorded) in all quadrats in Pembroke Ferry US between 2005 and 2019

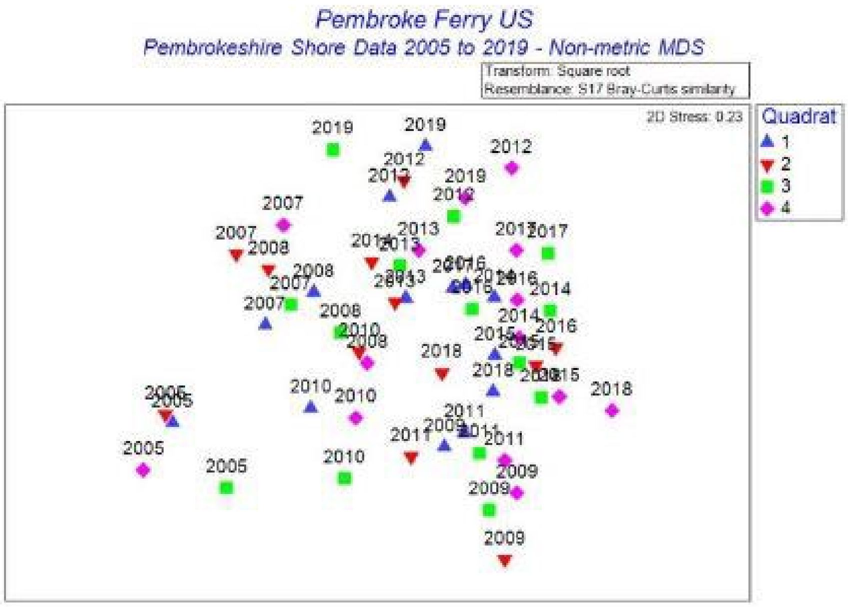
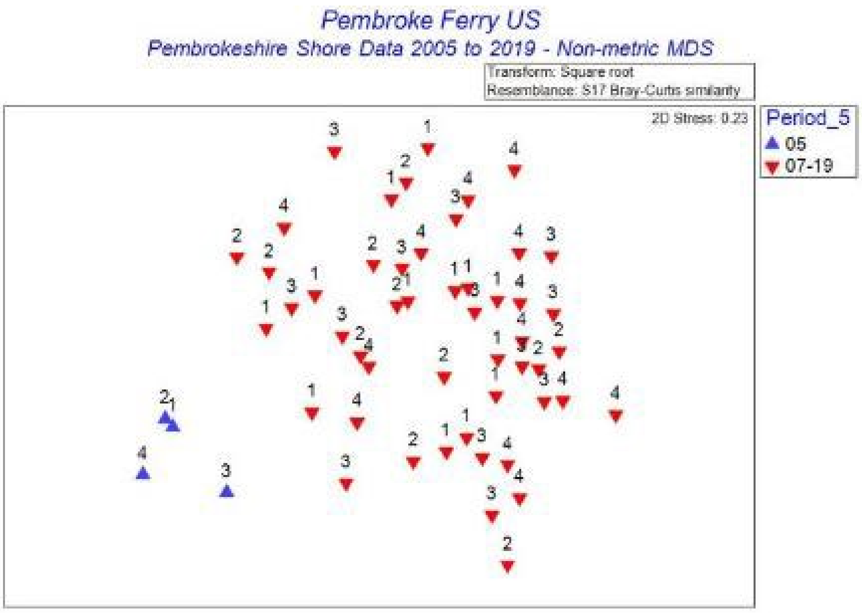


Figure 17. Non-metric MDS plots showing the data for all taxa (for which frequency was recorded) in all quadrats in Pembroke Ferry US between 2005 and 2019, with symbols showing two periods; 2005 and 2011 to 2019



3.4.3 Analysis of similarity percentages (SIMPER)

A SIMPER analysis of the Pembroke Ferry US quadrat data was undertaken to determine which species were responsible for the 2005 data separating from the 2007 to 2019 data in the MDS plot (Figure 17). The results of the SIMPER analysis are summarised in Table 5.

The average dissimilarity between the two year-groups was 33.75%. The species in Table 5 are listed in ranked with those contributing the most to the dissimilarity at the top of the list. The dissimilarity is largely the result of several species recorded from 2007 and 2019 not being recorded in 2005.

Table 5. Results of SIMPER test to show a calculation of the dissimilarity of the species abundance (frequency) data from Pembroke Ferry US between the two factor groups 2005 and 2007 to 2019. Groups 05 & 07-19 Average dissimilarity = 33.75%

PF US 05 Average similarity: 86.31

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Catenella caespitosa	4.06	11.94	26.56	13.84	13.84
Pelvetia canaliculata	4.06	11.86	19.26	13.74	27.58
Bostrychia scorpioides	4	11.61	26.67	13.45	41.03
Fucus spiralis	3.59	10.2	6.85	11.82	52.85
Fucus vesiculosus	3.49	10.08	25.46	11.68	64.53
Chlorophyta film, fuzz or threads	3.42	9.69	29.13	11.23	75.76

PF US 07-19 Average similarity: 75.95

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Catenella caespitosa	4.87	10.64	10.85	14.01	14.01
Bostrychia scorpioides	4.35	9.18	9.23	12.09	26.1
Pelvetia canaliculata	4.15	8.77	8.22	11.54	37.64
Hildenbrandia all species	4.22	8.37	5.3	11.03	48.67
Fucus vesiculosus	4.02	8.37	6.28	11.01	59.68
Verrucariaceae	3.48	6.81	5.49	8.97	68.66
Fucus spiralis	2.95	5.29	2.86	6.96	75.62

PF US 05 & 07-19 Average dissimilarity: 33.75

Species	PF US 05 Av.Abund	PF US 07-19 Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Hildenbrandia all species	0	4.22	5.37	6.25	15.91	15.91
Chlorophyta film, fuzz or threads	3.42	1.27	3.18	1.94	9.43	25.33
Rhodothamniella floridula	0	2.4	3.04	1.82	9	34.33
Fucus sporelings	0	2.16	2.67	1.11	7.91	42.24
Rhizoclonium riparium	0	1.76	2.3	0.86	6.82	49.06
Ulva tubular	0	1.8	2.3	1.02	6.8	55.86
Cirripedia all except *P. perforatus*	0.86	1.33	1.53	1.34	4.54	60.4
Fucus spiralis	3.59	2.95	1.29	1.31	3.82	64.22
Ulva flat	0.68	0.85	1.26	1.04	3.72	67.94
Cladophora rupestris	0.5	0.86	1.17	1.23	3.47	71.4

3.5. Pembroke Ferry MS

The results of data analyses for Pembroke Ferry MS are summarised below.

3.5.1 Visual Change

Not much visual change has occurred in the middle shore of Pembroke Ferry (see Figure 18).

Figure 18. Pembroke Ferry middle shore illustrating its steep barnacle and limpet dominated nature which has not changed much over the course of monitoring. The red seaweed

Aglaothamnion hookeri is common in rock crevices (but it is too small to be seen in whole quadrat photographs).

MS Q3 2007

MS Q3 2018

MS contextural view

Surveying the MS

Aglaothamnion hookeri

3.5.2 Multidimensional scaling (MDS)

MDS plots presenting the data for all taxa recorded in the MS quadrats are shown in Figure 19 and Figure 20. The stress is fairly low suggesting there is a reasonably good fit of the data to the two-dimensional plot generated. Despite the similarities within the data set, the MDS plots do show patterns.

Figure 19 shows a general pattern for all the quadrats for particular years to be grouped together. This suggests that there is some change over time, with all four quadrats undergoing the same change.

Figure 20 shows a division between the data recorded between 2005 and 2014 in comparison to that recorded between 2015 and 2019 (Figure 20).

Figure 19. Non-metric MDS plot showing the data for all taxa (for which frequency was recorded) in all quadrats in Pembroke Ferry MS between 2005 and 2019

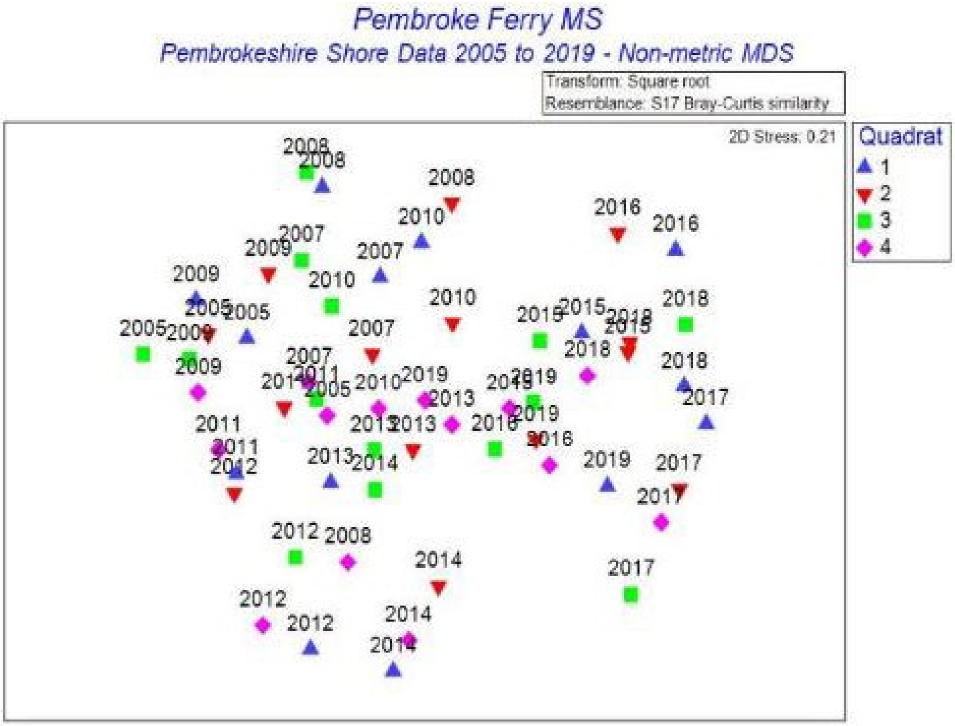
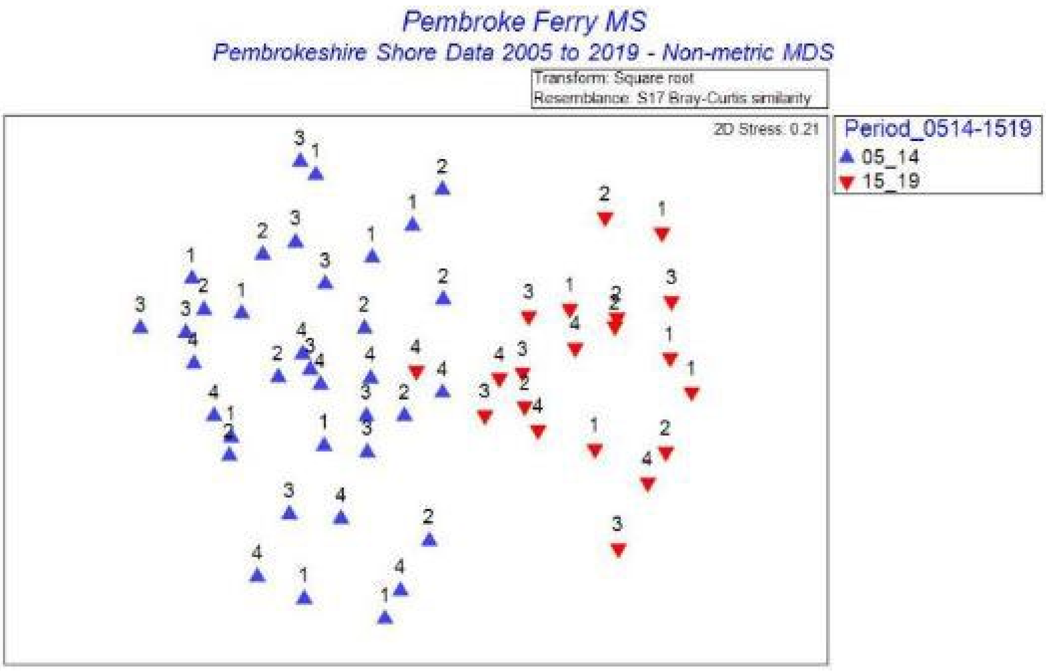


Figure 20. Non-metric MDS plot showing the data for all taxa (for which frequency was recorded) in all quadrats in Pembroke Ferry MS between 2005 and 2019, with symbols showing two periods; 2005 to 2014 and 2015 to 2019



3.5.3 Analysis of similarity percentages (SIMPER)

A SIMPER analysis of the Pembroke Ferry MS quadrat data was undertaken to determine which species were responsible for the 2005 to 2014 data separating from the 2015 to 2019 data in the MDS plot (Figure 20). The results of the SIMPER analysis are summarised in Table 6.

The average dissimilarity between the two year-groups was 33.75%. The species in Table 6 are listed in ranked with those contributing the most to the dissimilarity at the top of the list. The dissimilarity is largely the result of an increase in algae, particularly *Ulva* spp and diatom film. There is also a decrease in *Mytilus edulis* from the 2005 to 2014 year-grouping to the 2007 to 2019 year-grouping.

Table 6. Results of SIMPER test to show a calculation of the dissimilarity of the species abundance (frequency) data from Pembroke Ferry MS between the two factor groups 2005 to 2014 and 2015 to 2019. Groups 05-14 & 05-19 Average dissimilarity = 33.65%

PF MS 2005 to 2014 Average similarity: 73.44

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Patella	5	21.07	9.32	28.68	28.68
Cirripedia all except *P. perforatus*	4.99	21.02	9.34	28.62	57.3
Gastropoda small in crevices	3.95	14.81	4.95	20.16	77.47

PF MS 2015 to 2019 Average similarity: 76.53

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Cirripedia all except *P. perforatus*	5	14.23	10.27	18.59	18.59
Patella	5	14.23	10.27	18.59	37.19
Gastropoda small in crevices	4.71	12.75	8.66	16.67	53.85
Ulva tubular	3.52	8.13	3.05	10.63	64.48
Ulva flat	3.17	7.73	4.21	10.1	74.58

PF MS 2005 to 2014 & 2015 to 2019 Average dissimilarity : 33.65

Species	2005 to 2014 Av. Abund	2015 to 2019 Av. Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Ulva flat	0.76	3.17	4.15	2.14	12.34	12.34
Ulva tubular	1.54	3.52	3.82	1.61	11.34	23.68
Bacillariophyceae diatom film	0.56	1.73	2.99	1.4	8.89	32.57
Polychaeta Spongy worm holes, *Polydora*?	0.15	1.43	2.3	1.49	6.84	39.41
Mytilus edulis	1.05	0.1	1.73	1.08	5.14	44.55
Corallinaceae crusts	2.41	2.65	1.73	1.18	5.13	49.68
Aglaothamnion hookeri	0.62	1.29	1.59	1.38	4.74	54.42
Gastropoda small in crevices	3.95	4.71	1.55	1.35	4.6	59.02
Diadumene lineata	0.42	0.81	1.37	1.08	4.09	63.11

Species	2005 to 2014 Av. Abund	2015 to 2019 Av. Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Hildenbrandia all species	0.17	0.78	1.36	0.81	4.04	67.15
Verrucariaceae	0.27	0.72	1.33	0.74	3.95	71.1

3.6. Pembroke Ferry LS

The results of data analyses for Pembroke Ferry LS are summarised below.

3.6.1 Visual change

Visually, the quadrats in the lower shore of Pembroke Ferry have stayed remarkably similar over the monitoring period (see Figure 21).

Figure 21. LS at Pembroke Ferry showing little obvious change in two quadrats over the monitoring time frame and a contextual photo of the zone.

LS Q2 2005

LS Q2 2019

LS Q4 2005

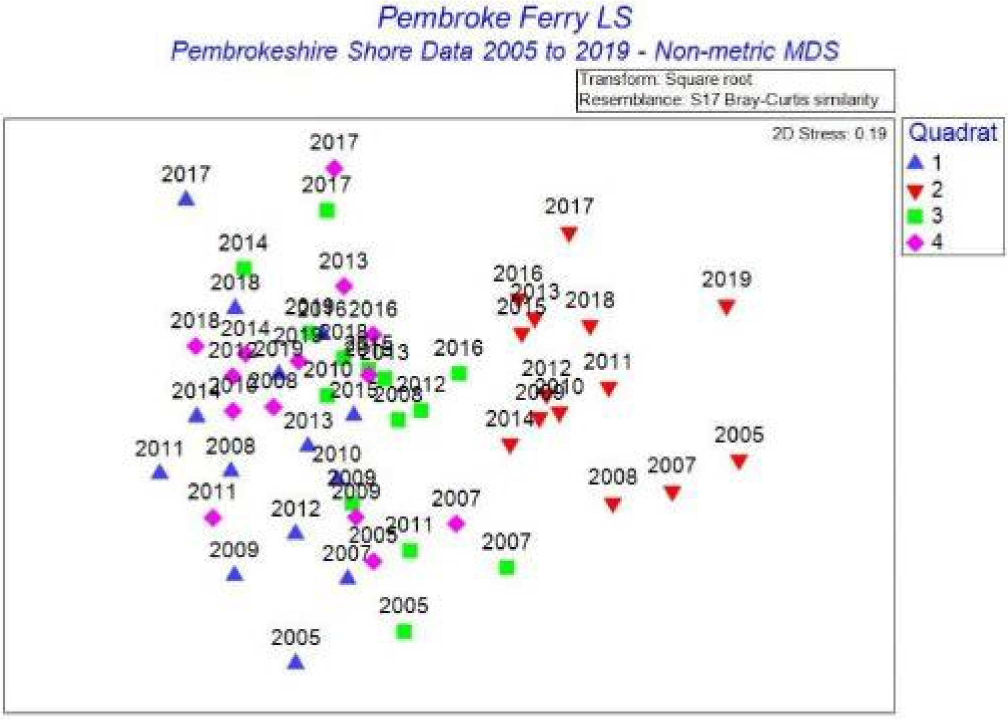
LS Q4 2019

Surveying Pembroke Ferry LS in 2016

3.6.2 Multidimensional scaling (MDS)

An MDS plot presenting the data for all taxa recorded in the MS quadrats are shown in Figure 22. The stress is low (below 0.2) suggesting there is a good fit of the data to the two-dimensional plot generated. There is no obvious pattern of separation between years but more of a separation of LS Q2 from the other quadrats.

Figure 22. Non-metric MDS plots showing the data for all taxa (for which frequency was recorded) in all quadrats in Pembroke Ferry LS between 2005 and 2019



3.6.3 Analysis of similarity percentages (SIMPER)

A SIMPER analysis of the Pembroke Ferry LS quadrat data was undertaken to determine which species were responsible for the differences between data from LS Q2 compared to the other LS quadrats seen in the MDS plot (Figure 22). The results of the SIMPER analysis are summarised in Table 7.

The average dissimilarity between the two groups was 38.8%. The species in Table 7 are listed in ranked order with those contributing the most to the dissimilarity at the top of the list. The dissimilarity results from a greater abundance of larger algae and epiphytes in LS Q2 compared to the other quadrats.

Table 7. Results of SIMPER test to show a calculation of the dissimilarity of the species abundance (frequency) data from Pembroke Ferry LS between the two factor groups LS Q1, Q3 and Q4 and LS Q2.

Q1, Q3, Q4 & Q2 Average dissimilarity: 38.80

Species	Q1, Q3, & Q4 Av.Abund	Q2 Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Palmaria palmata	0.94	2.96	1.55	1.94	4	4
Fucus serratus	1.44	3.27	1.46	2.1	3.75	7.75
Chondrus crispus	1.27	3.26	1.45	2.1	3.75	11.5
Flustrellidra hispida	1.23	3.24	1.45	2.17	3.74	15.24
Bacillariophyceae diatom film	2.09	1.57	1.37	1.3	3.53	18.77
Mastocarpus stellatus	0.29	2.11	1.34	2.05	3.47	22.23
Gastropoda small in crevices	4.16	2.54	1.28	1.33	3.31	25.54
Rhodophyta indet. (non calc. crusts)	0.92	1.92	1.28	1.26	3.3	28.84
Ulva tubular	3.31	3.19	1.21	1.29	3.11	31.95
Diadumene lineata	2.36	1.09	1.16	1.38	2.99	34.94
Fucus sporelings	1.52	2.57	1.12	1.42	2.88	37.83
Aglaothamnion hookeri	1.49	0.58	1.05	1.11	2.71	40.54
Dynamena pumila	0.45	1.76	1.05	1.64	2.71	43.24
Ectocarpales filamentous	0.62	1.77	1.01	1.55	2.61	45.85
Alcyonidium Includes *A. gelatinosum*, *A. mytili* and *A. polyoum*	0.63	1.63	0.94	1.37	2.43	48.28
Ulva flat	3.48	4.07	0.89	1.05	2.28	50.56
Botryllus schlosseri	0.02	1.24	0.86	2.47	2.23	52.79
Ceramium all species	1.62	2.32	0.86	1.38	2.21	55
Spirobranchus	0.36	1.33	0.82	1.38	2.11	57.11
Gelidium all species	0.76	1.45	0.8	1.33	2.06	59.17
Steromphala cineraria	1.15	2.19	0.8	1.58	2.06	61.23
Hymeniacidon perlevis	2.56	3.58	0.76	1.69	1.96	63.19
Hildenbrandia all species	0.51	0.85	0.76	0.84	1.95	65.14
Spirorbinae	2.38	3.32	0.73	1.18	1.89	67.03
Halichondria (Halichondria) panicea	1.47	0.69	0.73	1.41	1.89	68.92
Osmundea hybrida	1.27	0.78	0.72	1.27	1.85	70.77

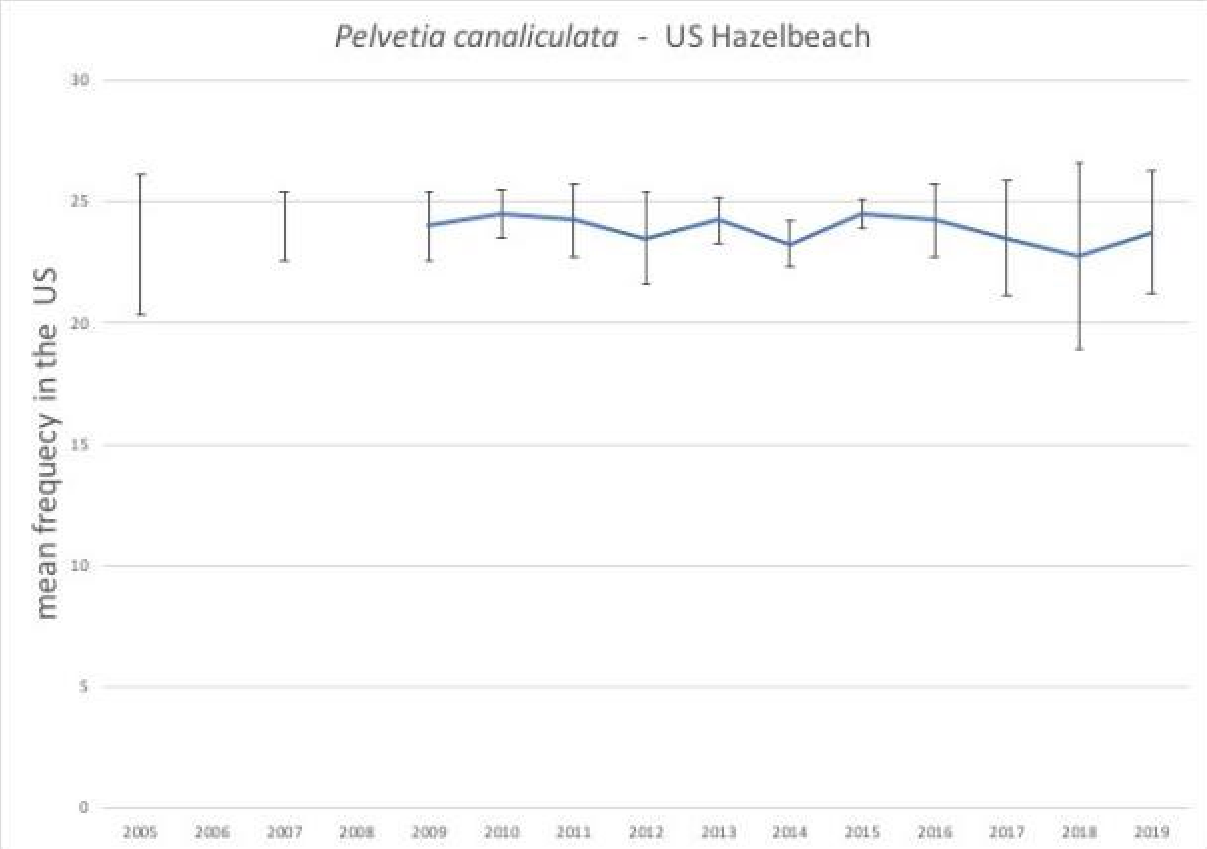
3.7. Hazelbeach US

The results of data analyses for Hazelbeach US are summarised below.

3.7.1 Visual change

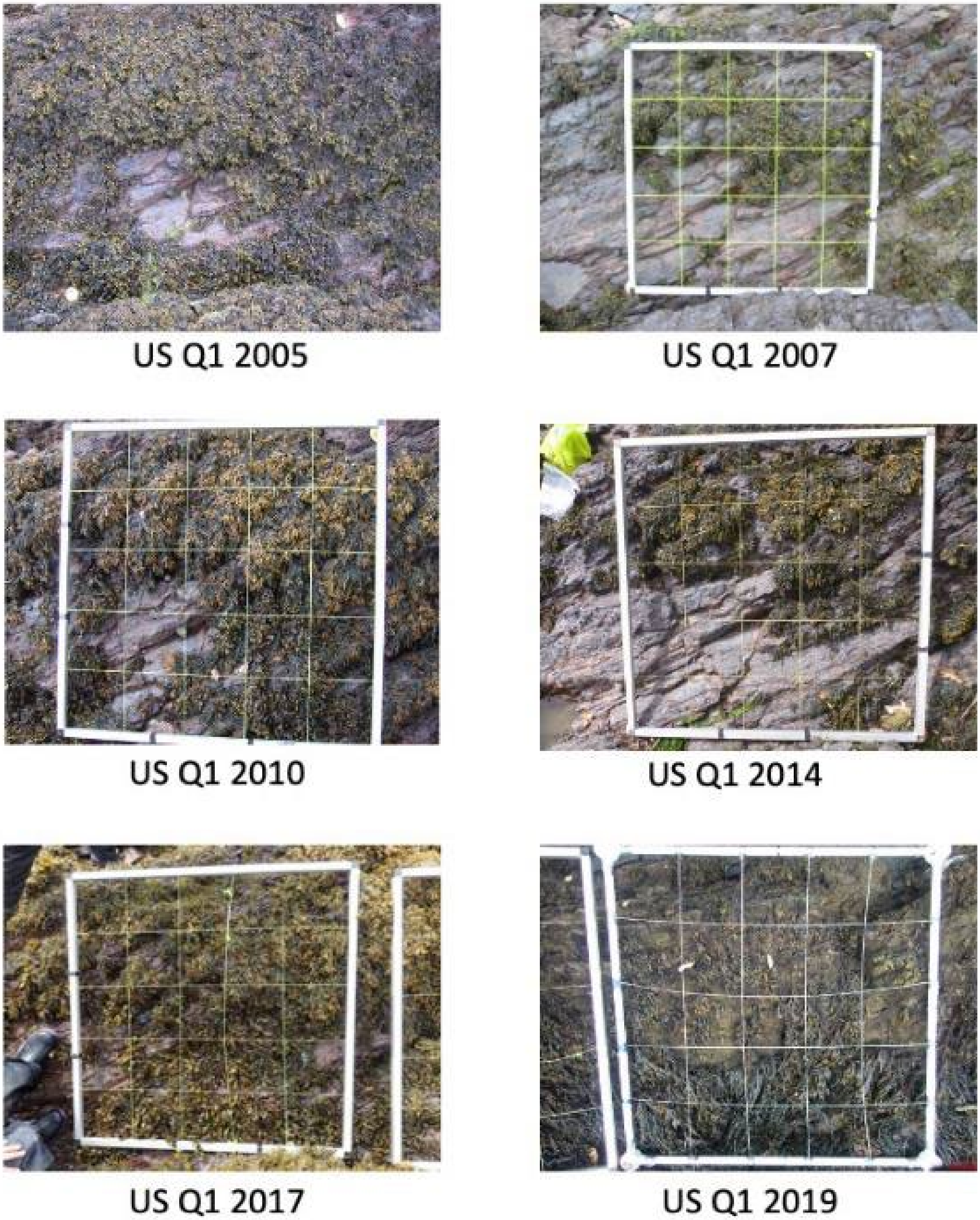
The frequency data for a fucoid in the US, *Pelvetia canaliculata* (averaged from all quadrats), was plotted over time in Figure 23. The frequency data shows ups and downs but little in the way of significant change.

Figure 23. Graph to show the mean abundance (frequency) of *Pelvetia canaliculata* in the US of Hazelbeach fixed monitoring quadrats, with standard deviation bars



A series of photographs of the Hazelbeach US quadrats between 2005 and 2019 shows some obvious changes in cover of algae over time (Figure 24). Increases and decreases of cover (mainly of *Pelvetia canaliculata*) can be seen. Within the time series, fucoid cover was greatest in 2017.

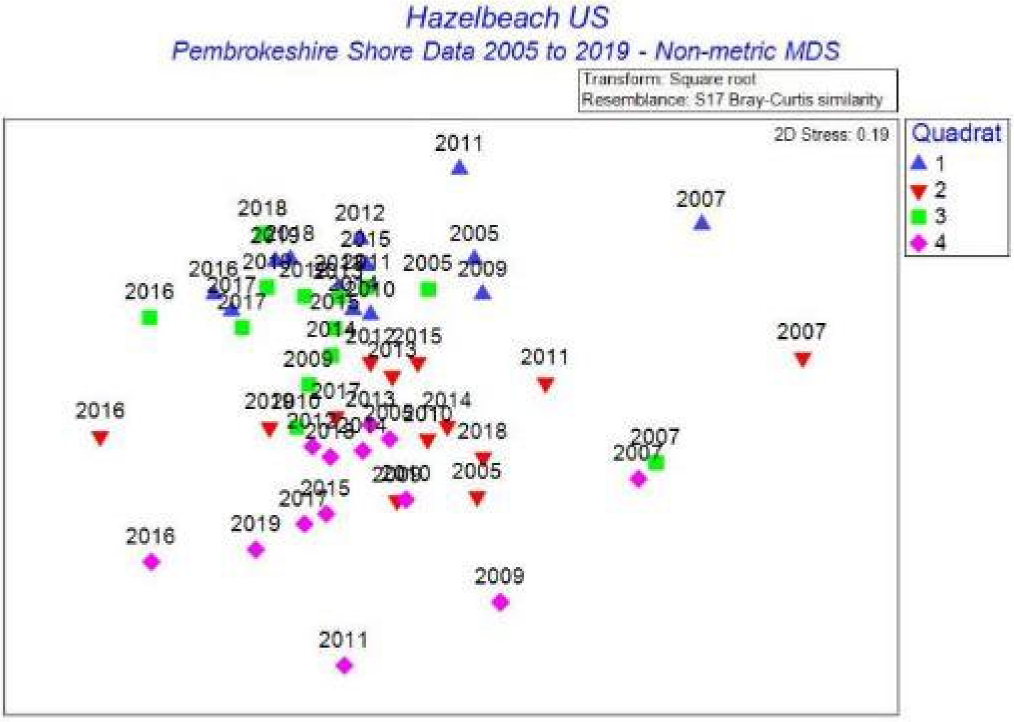
Figure 24. US Q1 at Hazelbeach showing a cyclical decline and increase in fucoid cover (mainly *Pelvetia canaliculata*) between 2005 and 2019. (Years selected to illustrate the major trend)



3.7.2 Multidimensional scaling (MDS)

An MDS plot presenting the data for all taxa recorded in the US quadrats are shown in Figure 25. The stress is low (below 0.2) suggesting there is a good fit of the data to the two-dimensional plot generated. The general pattern is for individual quadrats to group together across the years e.g. all of the USQ1 together, all of the US Q2s together and so on.

Figure 25. Non-metric MDS plot showing the data for all taxa (for which frequency was recorded) in all quadrats on Hazelbeach US between 2005 and 2019



3.7.3 Analysis of similarity percentages (SIMPER)

A SIMPER analysis of the Hazelbeach US quadrat data was undertaken to determine similarities and differences between species frequency records in each quadrat over time. As would be expected from the results of the MDS analysis (Figure 25), each of the four quadrats studied had a high degree of similarity (see Table 8) across the years. (The differences between quadrats has not been included here as it is small but it can be seen in the PRIMER file “Pembrokeshire Marine SAC shore quadrat data 2005 to 2019.pwk”).

Table 8. Results of SIMPER test calculating the similarity of species frequency records in each of the four US quadrats studied between 2005 and 2019

US Q1 Average similarity: 82.76

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Verrucariaceae	4.92	14.59	16.83	17.63	17.63
Cirripedia all except *P. perforatus*	4.75	13.81	7.61	16.69	34.32
Pelvetia canaliculata	4.63	13.61	10.89	16.45	50.77
Fucus spiralis	3.68	10.21	8.32	12.34	63.11
Hildenbrandia all species	4	9.65	1.96	11.66	74.76

US Q2 Average similarity: 80.45

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Pelvetia canaliculata	4.98	17.59	16.9	21.86	21.86
Verrucariaceae	4.94	17.31	13.73	21.52	43.38
Hildenbrandia all species	4.02	11.66	2.06	14.49	57.87
Catenella caespitosa	3.4	10.89	6.2	13.54	71.4

US Q3 Average similarity: 82.17

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Pelvetia canaliculata	4.95	15.12	11.13	18.4	18.4
Verrucariaceae	4.88	14.68	12.12	17.86	36.26
Cirripedia all except *P. perforatus*	4.53	13.07	7.56	15.91	52.17
Hildenbrandia all species	4.49	12.56	6.34	15.29	67.46
Fucus spiralis	2.99	7.17	1.95	8.72	76.18

US Q4 Average similarity: 82.11

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Pelvetia canaliculata	4.96	19.91	11.96	24.25	24.25
Verrucariaceae	4.66	17.28	3.56	21.05	45.3
Hildenbrandia all species	4.54	16.99	6.79	20.69	65.99
Cirripedia all except *P. perforatus*	3.14	9.54	1.88	11.61	77.6

3.8. Hazelbeach MS

The results of data analyses for Hazelbeach MS are summarised below.

3.8.1 Visual change

Little in the way of visual change was seen in the Hazelbeach MS, although barnacle cover fluctuates over time (see Figure 26).

Figure 26. Photographs of MS Q2 at Hazelbeach to illustrate that there has been little obvious change in the MS quadrats over time (2005 to 2019) apart from barnacle cover.

MS Q2 2005

MS Q2 2012

MS Q2 2018

3.8.2 Multidimensional scaling (MDS)

MDS plots presenting the data for all taxa recorded in the MS quadrats are shown in Figure 27 and Figure 28Figure 34. The stress is low suggesting there is a good fit of the data to the two-dimensional plot generated. The MDS plots show some separation between the data recorded between 2005 and 2011 in comparison to that recorded between 2012 and 2019. This can be seen clearly in Figure 28Figure 34. The reasons for this division are explored using SIMPER analysis in Section 3.8.3.

Figure 27 Non-metric MDS plot showing the data for all taxa (for which frequency was recorded) in all quadrats in Hazelbeach MS between 2005 and 2019.

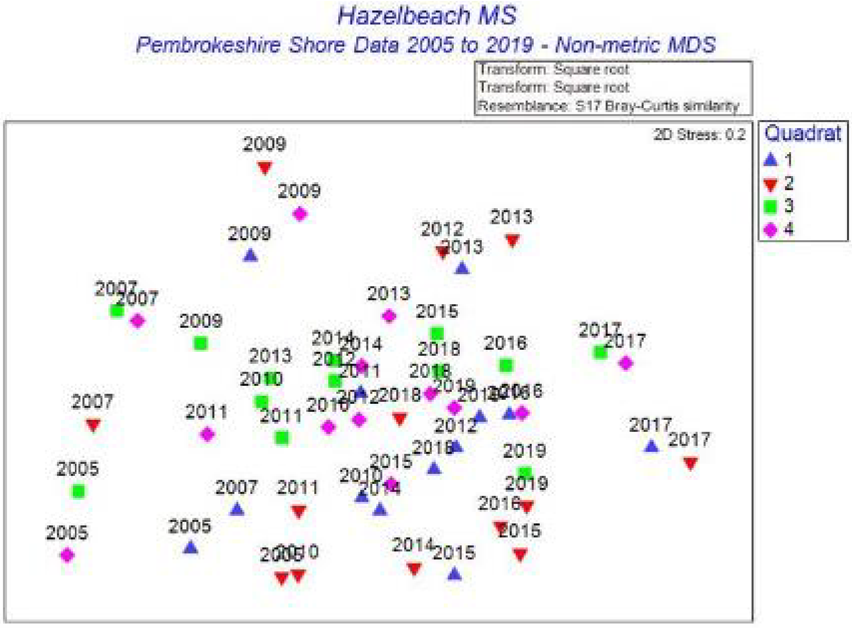
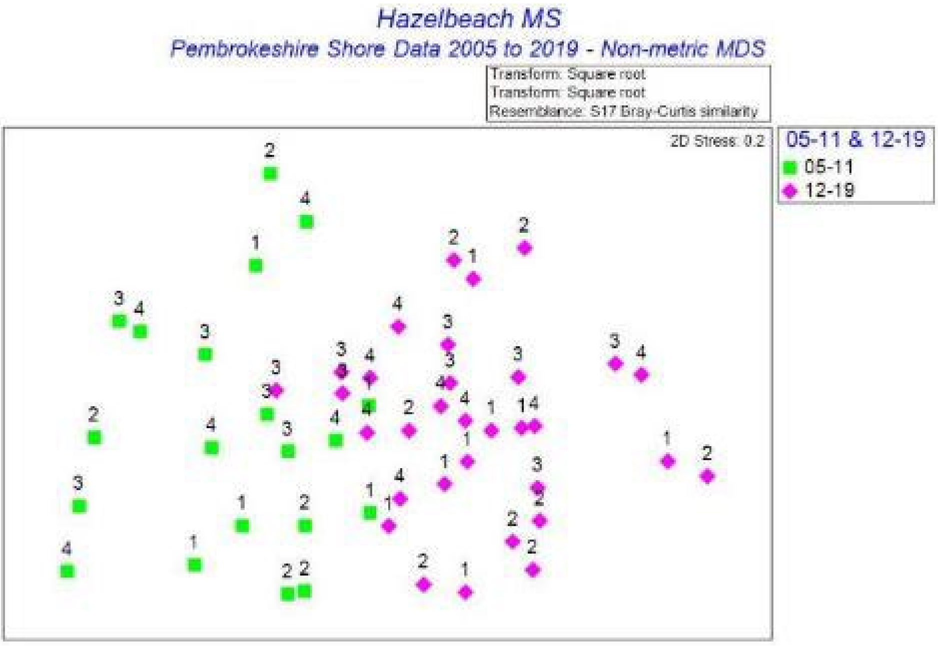


Figure 28. Non-metric MDS plot showing the data for all taxa (for which frequency was recorded) in all quadrats in Hazelbeach MS between 2005 and 2019, with symbols showing two periods; 2005 to 2011 and 2012 to 2019



3.8.3 Analysis of similarity percentages (SIMPER)

A SIMPER analysis of the Hazelbeach MS quadrat data was undertaken to determine which species were responsible for the 2005 to 2011 data separating from the 2012 to 2019 data in the MDS plot (Figure 27). The results of the SIMPER analysis are summarised in Table 9.

The average dissimilarity between the two year-groups was low at 32.33%. The species in Table 9 are listed in ranked with those contributing the most to the dissimilarity at the top of the list. The dissimilarity is the result of change in abundance of common species. Of note (and top of the list) is a decrease in the abundance of *Mytilus edulis* from the period 2005 to 2011 and 2012 to 2019.

Table 9. Results of SIMPER test to show a calculation of the dissimilarity of the species abundance (frequency) data from Hazelbeach MS between the two factor groups: 2005 to 2011 and 2012 to 2019.

Group 05-11 Average similarity: 72.86

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Cirripedia all except *P. perforatus*	2.24	12.86	8.88	17.65	17.65
Patella	2.23	12.76	8.99	17.52	35.17
Gastropoda small in crevices	2.18	12.25	9.22	16.81	51.98
Mytilus edulis	1.78	9.28	3.79	12.73	64.7
Steromphala umbilicalis	1.53	7.53	4.64	10.34	75.04

Group 12-19 Average similarity: 75.75

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Cirripedia all except *P. perforatus*	2.24	10.69	7.87	14.11	14.11
Patella	2.21	10.5	7.87	13.86	27.97
Gastropoda small in crevices	2.2	10.41	7.63	13.74	41.71
Steromphala umbilicalis	1.77	7.91	6.6	10.45	52.16
Corallinaceae crusts	1.76	7.47	5.39	9.87	62.02
Phorcus lineatus	1.61	7.26	6.74	9.58	71.61

Groups 05-11 & 12-19 Average dissimilarity = 32.33

Species	Av.Abund Group 05-11	Av Abund Group 12-19	Av.Diss	Diss/SD	Contrib%	Cum.%
Mytilus edulis	1.78	0.35	3.77	2.2	11.65	11.65
Verrucariaceae	0.52	0.73	2.14	1.07	6.63	18.28
Ralfsia verrucosa	0.44	1	2.13	1.36	6.6	24.88
Littorina littorea	0.77	1.46	2.04	1.21	6.3	31.18
Osmundea pinnatifida	0.28	0.81	1.86	1.27	5.76	36.94
Corallinaceae crusts	1.22	1.76	1.82	1.06	5.64	42.58
Ulva flat	0.42	0.68	1.7	1.13	5.24	47.82
Hymeniacidon perlevis	0.66	0.8	1.67	1.11	5.18	53
Actinia equina	0.4	0.67	1.48	1.1	4.58	57.57
Nucella lapillus	0.05	0.57	1.44	1.04	4.44	62.02
Rhodophyta indet. (non calc. crusts)	0	0.6	1.44	0.8	4.44	66.46
Phorcus lineatus	1.18	1.61	1.24	0.99	3.83	70.29

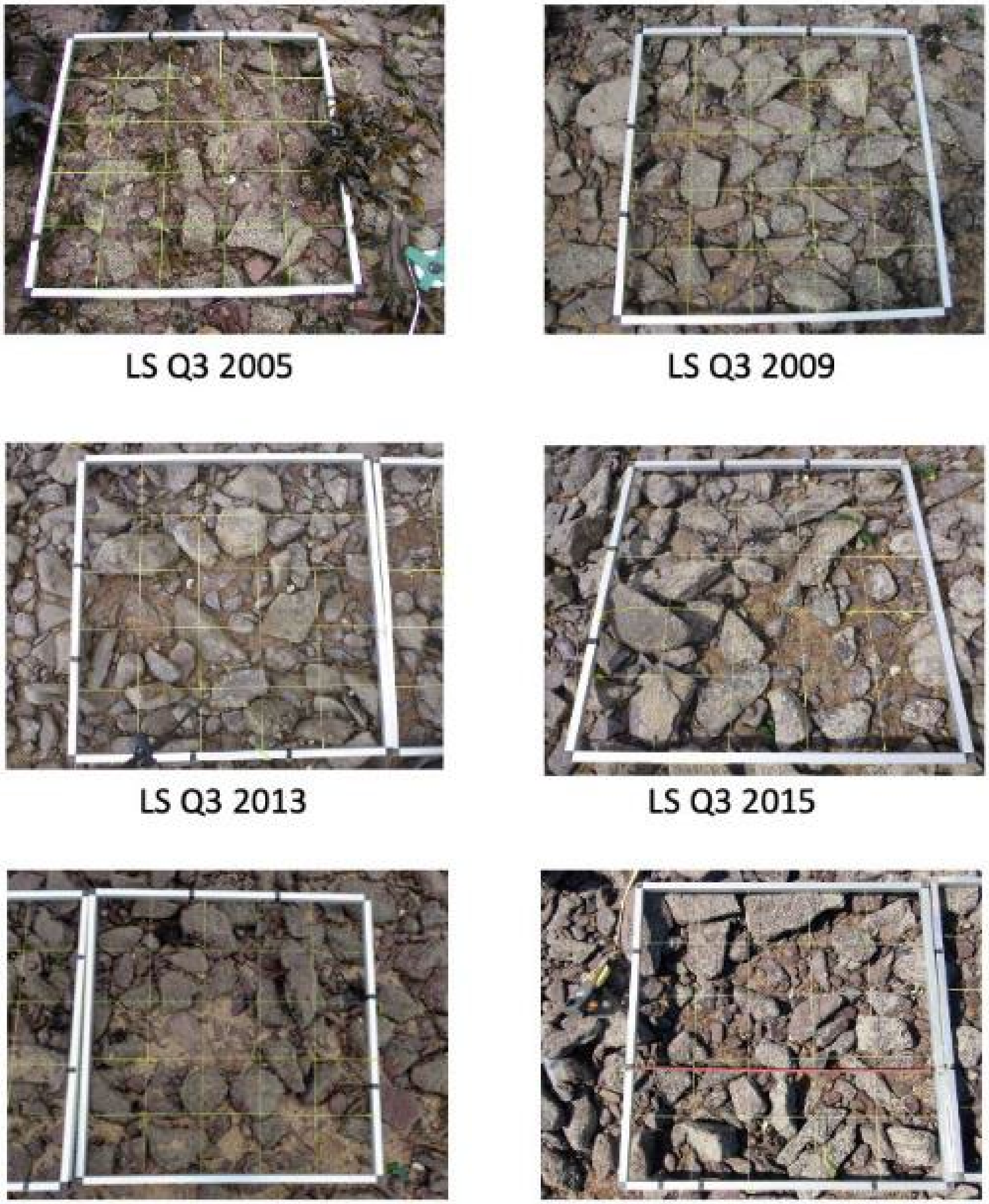
3.9. Hazelbeach LS

The results of data analyses for Hazelbeach LS are summarised below.

3.9.1 Visual change

The substrata in the LS of Hazelbeach moves almost annually. This is illustrated by photographs of the quadrats in Figure 29.

Figure 29. LS Q3 at Hazelbeach to illustrate the regular changes in the substrata between 2005 and 2019. (Years selected to illustrate the trend).



LS Q3 2005 | LS Q3 2009

LS Q3 2013 | LS Q3 2015

LS Q3 2017 | LS Q3 2019

3.9.2 Multidimensional scaling (MDS)

MDS plots presenting the data for all taxa recorded in the LS quadrats are shown in Figure 30 and Figure 31. The stress is fairly low suggesting there is a reasonably good fit of the data to the two-dimensional plot generated. In Figure 30, the following years appear as outliers: 2005, 2007, 2011 and 2019 with the other years grouping together (2009 to 2010 & 2012 to 2018). Figure 31 shows the years as they appear as groups.

Figure 30. Non-metric MDS plot showing the data for all taxa (for which frequency was recorded) in all quadrats in Hazelbeach LS between 2005 and 2019

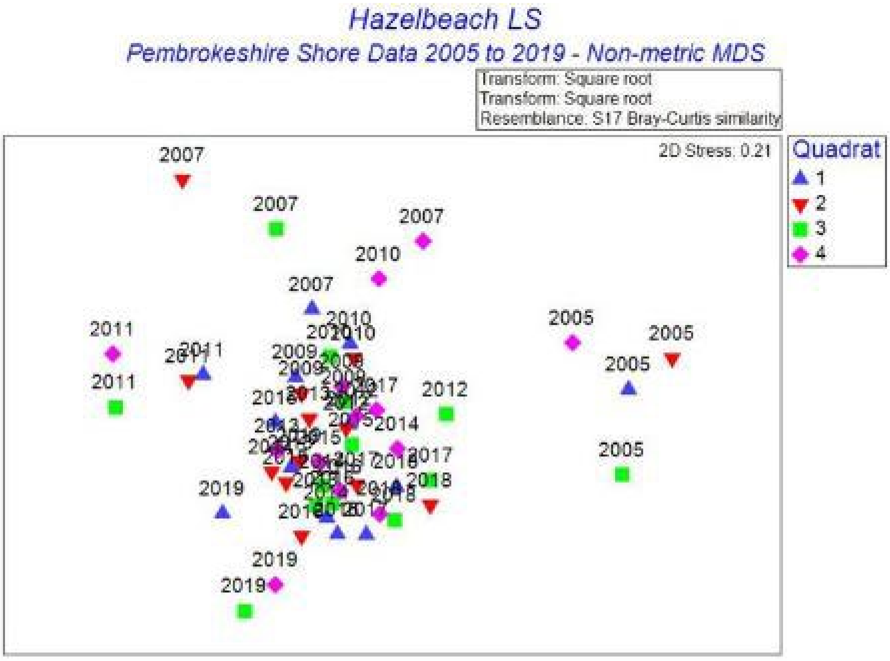
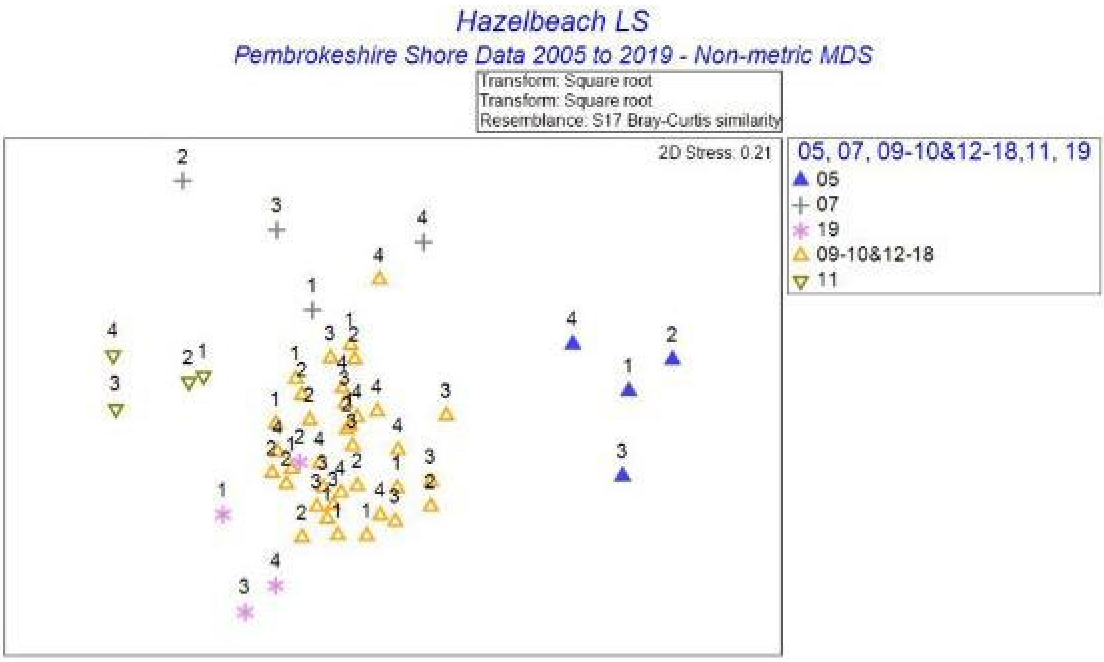


Figure 31. Non-metric MDS plot showing the data for all taxa (for which frequency was recorded) in all quadrats in Hazelbeach LS between 2005 and 2019, with symbols showing five periods; 2005, 2007, 2009 to 2010 & 2012 to 2018, 2011 and 2019.



3.9.3 Analysis of similarity percentages (SIMPER)

A SIMPER analysis of the Hazelbeach LS quadrat data was undertaken to determine which species were responsible for the differences between the year groups shown in Table 10. The results of the full analysis are included in the PRIMER analysis file: 'Pembs Marine 2005 to 2019.ppl' which is appended to this report.

Table 10. Results of SIMPER test to show a calculation of the dissimilarity of the species abundance (frequency) data from Hazelbeach LS between the factor groups: 2005, 2007, 2011 and 2019 with the other years grouping together (2009 to 2010 & 2012 to 2018)

Groups 05; Average dissimilarity = 74.13

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Cirripedia all except *P. perforatus*	2.24	9.73	12.64	13.12	13.12
Littorina littorea	1.76	7.5	9.62	10.12	23.24
Spirobranchus	1.75	7.1	12.31	9.58	32.82
Lanice conchilega	1.62	6.52	10.65	8.8	41.62
Crepidula fornicata	1.37	5.56	11.13	7.51	49.12
Littorina obtusata / fabalis	1.34	5.35	7.71	7.21	56.34
Steromphala umbilicalis	1.3	5.35	7.71	7.21	63.55
Fucus serratus	1.28	5.17	12.64	6.98	70.53

Groups 07; Average dissimilarity = 74.68

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Cirripedia all except *P. perforatus*	2.24	15.92	9.16	21.31	21.31
Littorina littorea	1.87	12.71	9.16	17.02	38.33
Lanice conchilega	1.32	8.1	4.74	10.85	49.18
Gastropoda small in crevices	1.31	8.06	9.8	10.79	59.97
Patella	1.09	7.34	8.09	9.83	69.8
Mytilus edulis	0.8	3.78	0.91	5.07	74.87

Groups 09-10&12-18; Average dissimilarity = 77.17

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Cirripedia all except *P. perforatus*	2.24	10.76	10.61	13.94	13.94
Littorina littorea	1.96	9.05	9.21	11.73	25.67
Lanice conchilega	1.88	8.52	7.16	11.04	36.71
Mastocarpus stellatus	1.68	7.53	10.24	9.75	46.46
Steromphala umbilicalis	1.66	7.37	6.54	9.55	56.01
Patella	1.61	7.34	8.27	9.51	65.52
Ralfsia verrucosa	1.42	5.71	2.56	7.39	72.91

Groups 11; Average dissimilarity = 80.46

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Cirripedia all except *P. perforatus*	2.24	11.67	20.12	14.5	14.5
Littorina littorea	2.14	10.86	18.47	13.5	28
Phaeophyceae crust	2.08	10.56	17.98	13.12	41.12
Patella	1.71	8.34	10.89	10.36	51.48
Lanice conchilega	1.73	7.99	4.23	9.93	61.41
Mastocarpus stellatus	1.56	7.61	8.94	9.46	70.86

Groups 19; Average dissimilarity = 83.20

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Cirripedia all except *P. perforatus*	2.24	17	13.62	20.44	20.44
Littorina littorea	1.96	14.34	15.87	17.24	37.68
Steromphala umbilicalis	1.66	12.13	13.46	14.58	52.26
Lanice conchilega	1.65	11.7	18.84	14.06	66.32
Nucella lapillus	1.14	8.32	8.77	10	76.32

3.10. Pembroke Power Station US

The results of data analyses for Pembroke Power Station US are summarised below.

3.10.1 Visual change

The most striking visual change in the US quadrats at Pembroke Power Station is the disappearance of much of the *Ascophyllum nodosum* since monitoring began in 2011. This trend isn't picked up from the frequency records (Figure 32) but is very apparent from photographs (Figure 33 and Figure 34).

Figure 32. Graph to show the mean abundance (frequency) of *Ascophyllum nodosum* in the US of Hazelbeach fixed monitoring quadrats, with standard deviation bars

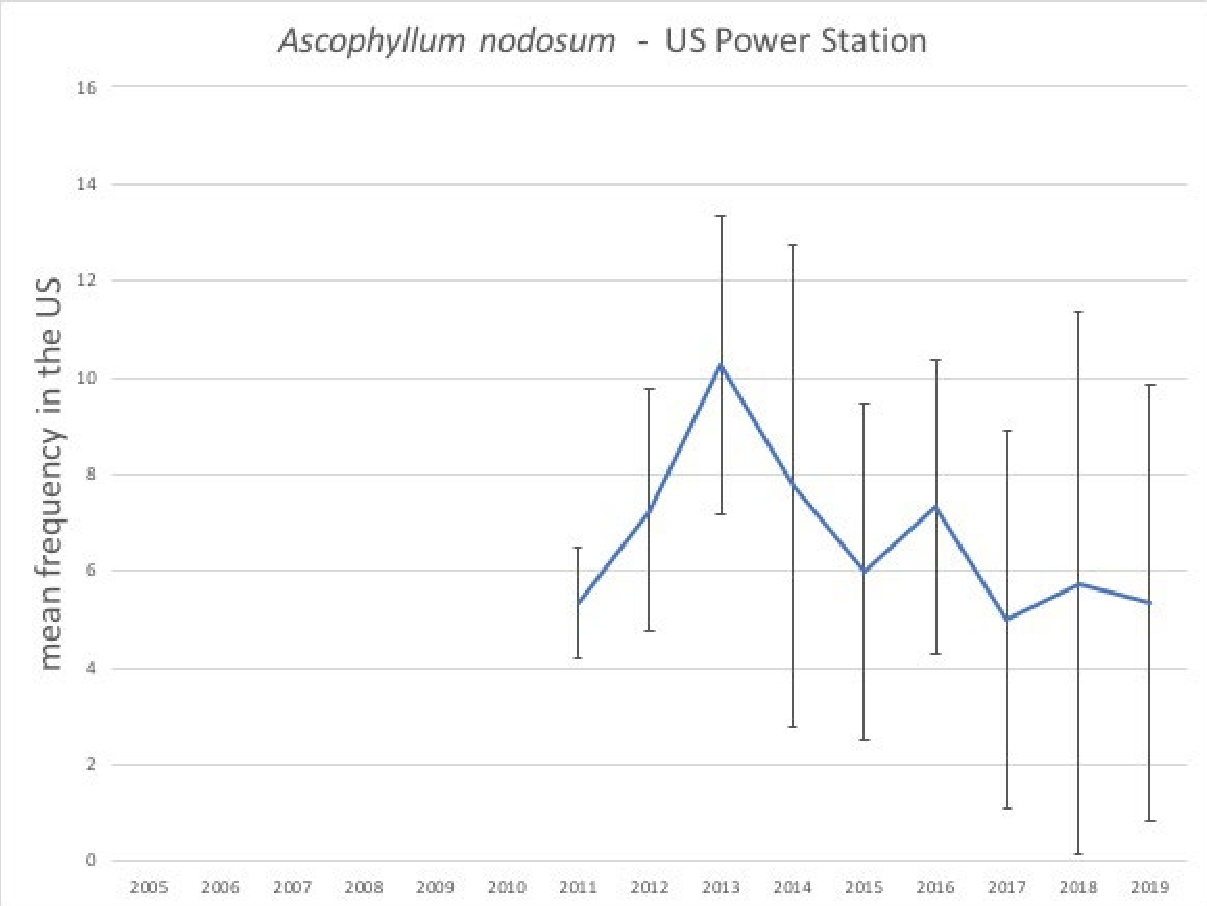
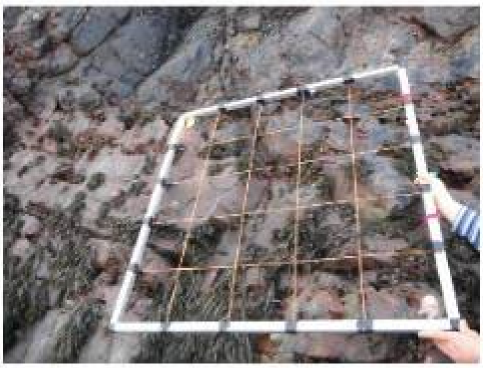


Figure 33. US Q1 at Pembroke Power Station showing a decline in *Ascophyllum nodosum* between 2011 and 2019. (Years selected to illustrate the major trend)

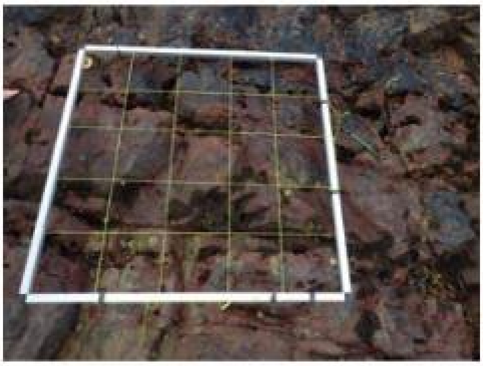


US Q1 2011

US Q1 2012

US Q1 2013

US Q1 2014



US Q1 2015

US Q1 2019

Figure 34. The upper shore monitoring area in the region of US Q3 and Q4 in 2011 and 2019. Although mainly below the fixed monitoring quadrats, a marked decline in *Ascophyllum nodosum* can be seen

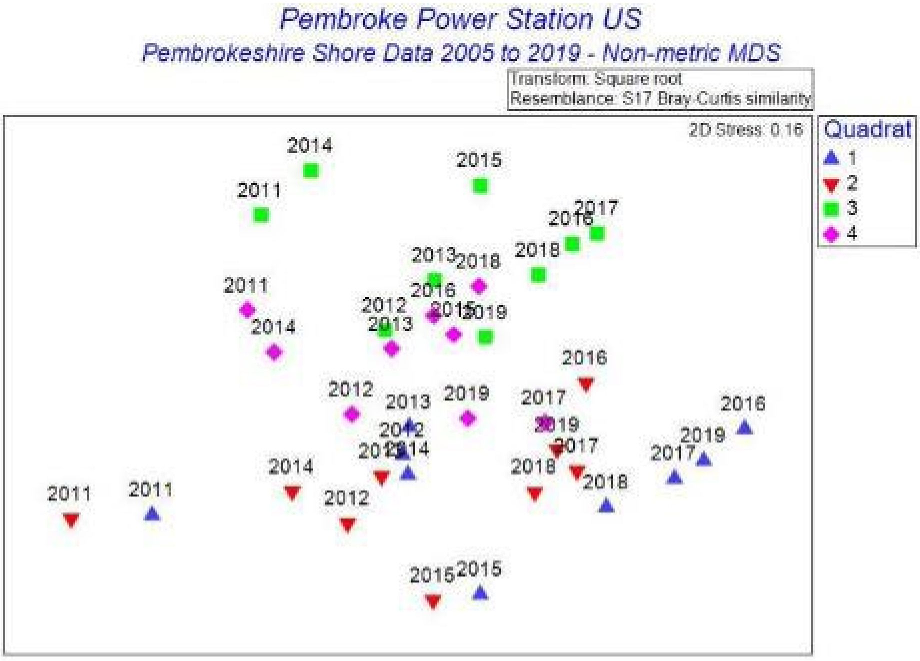
Pembroke Power Station US monitoring in region of Q3 2011

Pembroke Power Station US monitoring in region of Q3 2019

3.10.2 Multidimensional scaling (MDS)

An MDS plot presenting the data for all taxa recorded in the US quadrats are shown in Figure 35. The stress is low (below 0.2) suggesting there is a good fit of the data to the two-dimensional plot generated. The general pattern is for individual quadrats to group together across the years e.g. all of the USQ1 together, all of the US Q2s together and so on.

Figure 35. Non-metric MDS plot showing the data for all taxa (for which frequency was recorded) in all quadrats on Pembroke Power Station US between 2011 and 2019



3.10.3 Analysis of similarity percentages (SIMPER)

A SIMPER analysis of the Pembroke Power Station US quadrat data was undertaken to determine similarities and differences between species frequency records over time. As would be expected from the results of the MDS analysis (Figure 35), each of the four quadrats studied had a high degree of similarity (Table 11) across the years.

Table 11. Results of SIMPER test calculating the similarity of species frequency records in each of the four Pembroke Power Station US quadrats studied between 2011 and 2019

US Q1 Average similarity: 66.27

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Cirripedia all except *P. perforatus*	4.72	13.46	8.99	20.31	20.31
Catenella caespitosa	4.33	10.93	1.8	16.49	36.8
Gastropoda small in crevices	2.65	5.65	2.63	8.53	45.33
Patella	2.22	5.49	2.52	8.28	53.62
Littorina littorea	2.81	5.36	1.38	8.08	61.7
Fucus spiralis	2.19	4.93	3	7.44	69.14
Pelvetia canaliculata	2.09	3.64	1.38	5.5	74.64

US Q2 Average similarity: 68.86

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Cirripedia all except *P. perforatus*	4.25	11.7	9.37	17	17
Catenella caespitosa	4.34	11.09	1.83	16.1	33.1
Littorina littorea	3.71	8.89	2.53	12.92	46.02
Pelvetia canaliculata	3.23	7.83	4.79	11.37	57.38
Fucus spiralis	2.55	6.44	3.48	9.35	66.73
Gastropoda small in crevices	2.51	5.35	1.49	7.77	74.5

US Q3 Average similarity: 72.89

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Cirripedia all except *P. perforatus*	4.29	10.85	8.79	14.88	14.88
Catenella caespitosa	3.74	9.94	14.34	13.63	28.51
Fucus spiralis	3.18	7.82	5.46	10.73	39.25
Littorina littorea	3.1	7.73	4.03	10.61	49.85
Ascophyllum nodosum	2.89	6.81	1.79	9.34	59.19
Patella	2.06	5.02	5.01	6.89	66.08
Rhodothamniella floridula	1.93	3.89	1.53	5.34	71.42

US Q4 Average similarity: 74.41

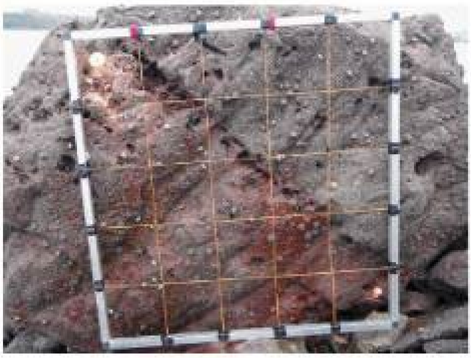
Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Cirripedia all except *P. perforatus*	4.34	11.93	6.8	16.03	16.03
Catenella caespitosa	3.83	11.07	10.37	14.88	30.91
Ascophyllum nodosum	2.85	7.91	8.56	10.64	41.54
Fucus spiralis	3.05	7.83	4.3	10.52	52.06
Littorina littorea	2.91	7.46	4.39	10.02	62.08
Pelvetia canaliculata	2.61	6.79	6.39	9.13	71.21

3.11. Pembroke Power Station MS

The results of data analyses for Pembroke Power Station MS are summarised below.

3.11.1 Visual change

Figure 36. MS Q3 at Pembroke Power Station at time intervals between 2011 and 2019 to illustrate that there has been little obvious change in the MS quadrats apart from barnacle cover and a decline in numbers of *Nucella lapillus* over time (Figure 37)



MS Q3 2011

MS Q3 2012

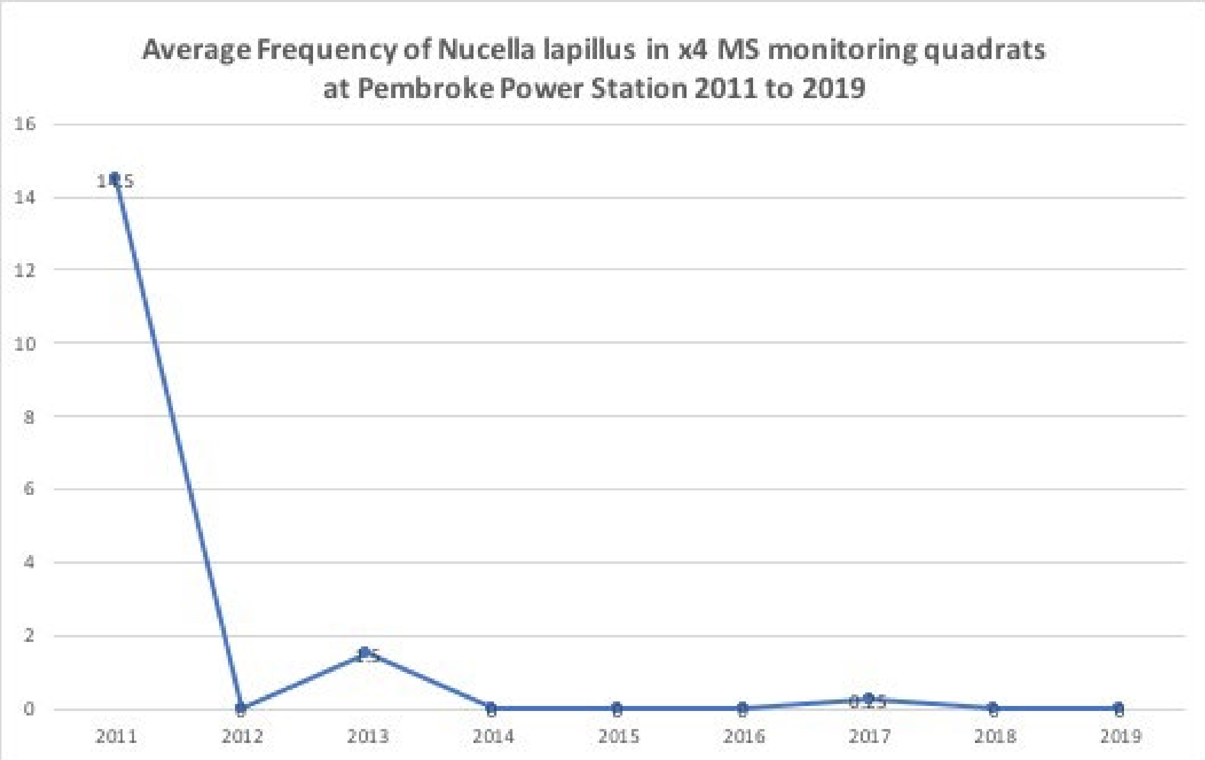
MS Q3 2014

MS Q3 2016

MS Q3 2018

MS Q3 2019

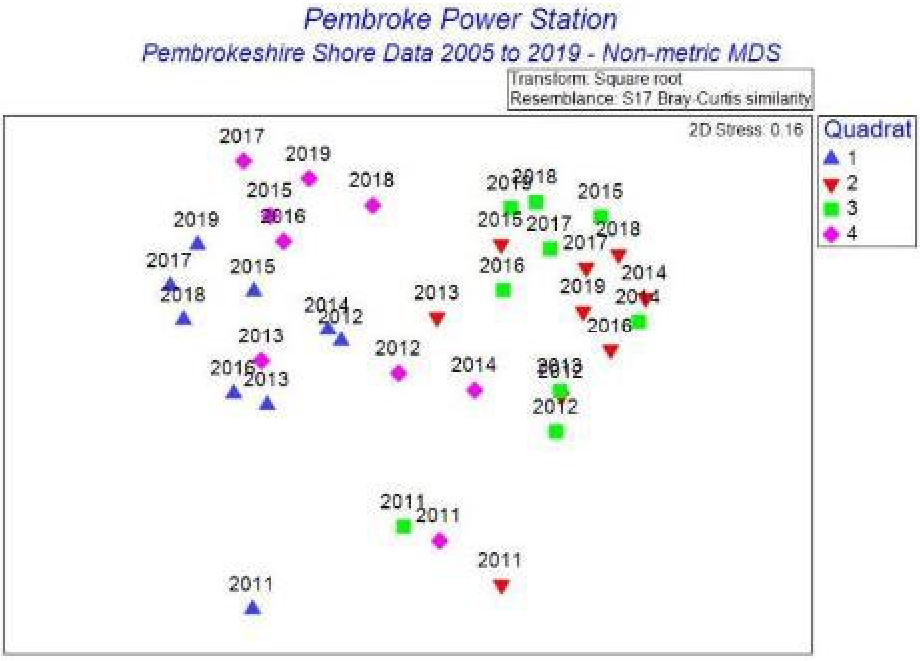
Figure 37. Graph to show changes in average frequency of *Nucella lapillus* between 2011 and 2019



3.11.2 Multidimensional scaling (MDS)

An MDS plot presenting the data for all taxa recorded in the MS quadrats are shown in Figure 38. The stress is low (below 0.2) suggesting there is a good fit of the data to the two-dimensional plot generated. The MDS plot shows the data from 2011 to separate out from the rest of the data (2012 to 2019). The general pattern in the data is for individual quadrats to group together across the years e.g. all of the MS Q1 together, all of the MS Q2s together and so on, illustrating that each quadrat has its own consistent character over time.

Figure 38. Non-metric MDS plot showing the data for all taxa (for which frequency was recorded) in all quadrats on Pembroke Power Station US between 2011 and 2019



3.11.3 Analysis of similarity percentages (SIMPER)

A SIMPER analysis of the Pembroke Power Station MS quadrat data was undertaken to determine which species were responsible for the differences between data from 2011 compared with 2012 to 2019 (as highlighted in the MDS plot in Figure 38). The results of the SIMPER analysis are summarised in Table 12.

The average dissimilarity between the two groups was 38.85%. The species in Table 12 are listed in ranked order with those contributing the most to the dissimilarity at the top of the list. The dissimilarity results from changes in the abundance of common species since 2011 (see Table 12). There was decrease in the sponge *Hymeniacidon perlevis* and in the common shore gastropods *Nucella lapillus and Steromphala umbilicalis.* There were increases in green algae (Chlorophyta film, fuzz or threads), the anemone *Actinia equina* and the gastropod *Littorina littorea*.

Table 12. Results of SIMPER test calculating the similarity and dissimilarity of species frequency records in two year groups at Pembroke Power Station Middle shore; 2011 and 2012 to 2019

2011 Average similarity: 76.03

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Cirripedia all except *P. perforatus*	5	15.71	9.67	20.66	20.66
Patella	5	15.71	9.67	20.66	41.32
Gastropoda small in crevices	4.84	14.79	5.66	19.46	60.78
Steromphala umbilicalis	4.13	11.88	8.36	15.63	76.4

2012 to 2019 Average similarity: 68.60

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Cirripedia all except *P. perforatus*	4.99	18.37	4.95	26.78	26.78
Patella	4.85	17.6	4.73	25.65	52.43
Gastropoda small in crevices	4.42	14.7	3.9	21.42	73.85

2011 and 2012 to 2019 Average dissimilarity = 38.85

Species	Group 2011 Av.Abund	Group 2012 to 2019 Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Nucella lapillus	3.63	0.13	6.12	2.41	15.75	15.75
Chlorophyta film, fuzz or threads	2.56	0.19	4.15	1.34	10.68	26.43
Steromphala umbilicalis	4.13	2.02	3.69	1.69	9.5	35.93
Littorina littorea	0	1.88	3.22	1.11	8.28	44.21
Corallinaceae crusts	1.39	1.5	2.22	1.29	5.72	49.93
Hymeniacidon perlevis	1.25	0	1.98	1.24	5.1	55.03
Ulva flat	0.43	1.01	1.68	0.96	4.32	59.36
Actinia equina	0	1.02	1.54	0.85	3.98	63.33
Catenella caespitosa	0.71	0.71	1.38	1.11	3.56	66.89
Cereus pedunculatus	0.68	0.83	1.38	1.19	3.56	70.45

3.12. South Hook US

The results of data analyses for South Hook US are summarised below.

3.12.1 Visual change

The frequency data of *Pelvetia canaliculata* in the US, (averaged from all quadrats) and plotted over time is shown in Figure 39. The frequency data shows ups and downs, but the 95% confidence limits show the change measured not to be statistically significant.

The change in cover of *Pelvetia canaliculata* as seen in photographs of US Q1 (Figure 40 and Figure 41) shows cyclical decreases and increases in cover of *Pelvetia canaliculata* over the monitoring period. There is evidence of an overall decline over the monitoring period illustrated by the contextual photographs in Figure 42.

Figure 39. Graph to show the mean abundance (frequency) of *Pelvetia canaliculata* in the US of South Hook Point fixed monitoring quadrats, with standard deviation bars

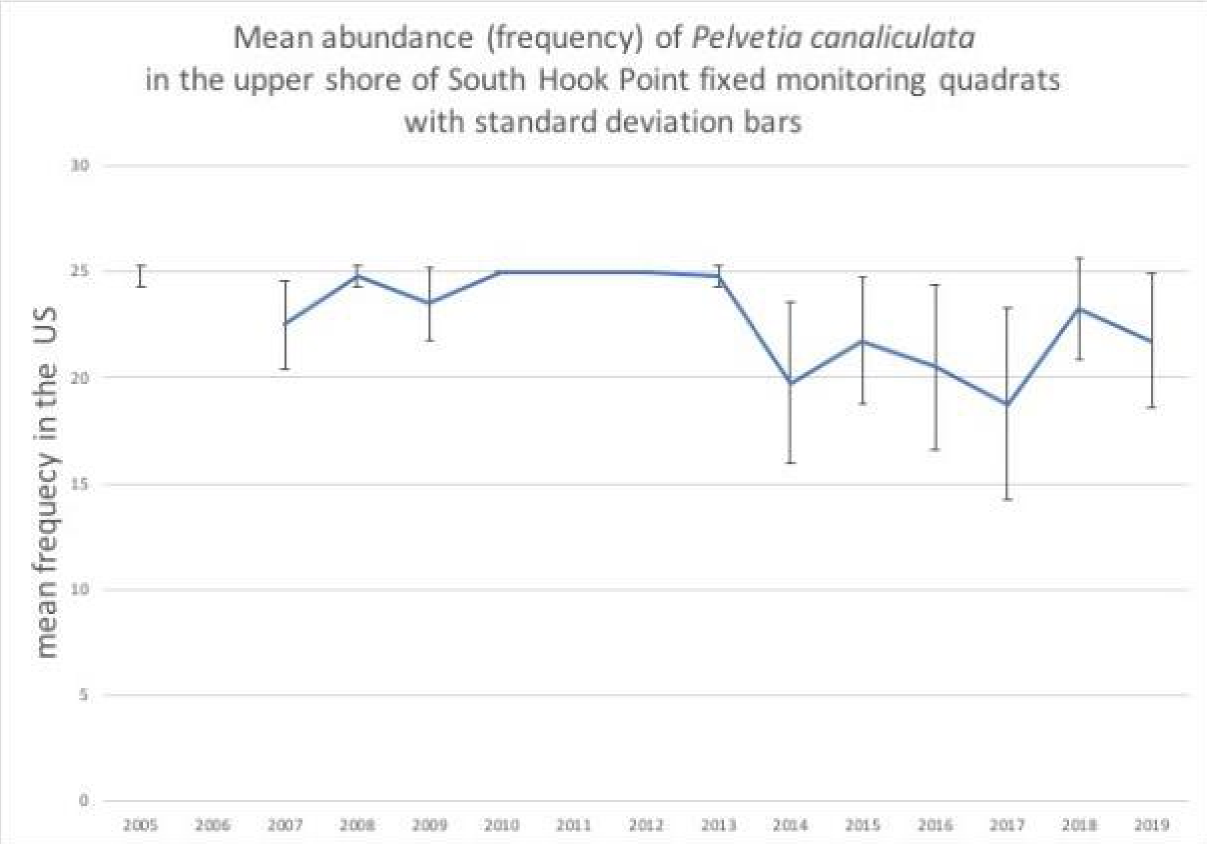


Figure 40. US Q1 at South Hook Point showing a cyclical decline and increase in fucoid cover (mainly *Pelvetia canaliculata*) between 2005 and 2013.

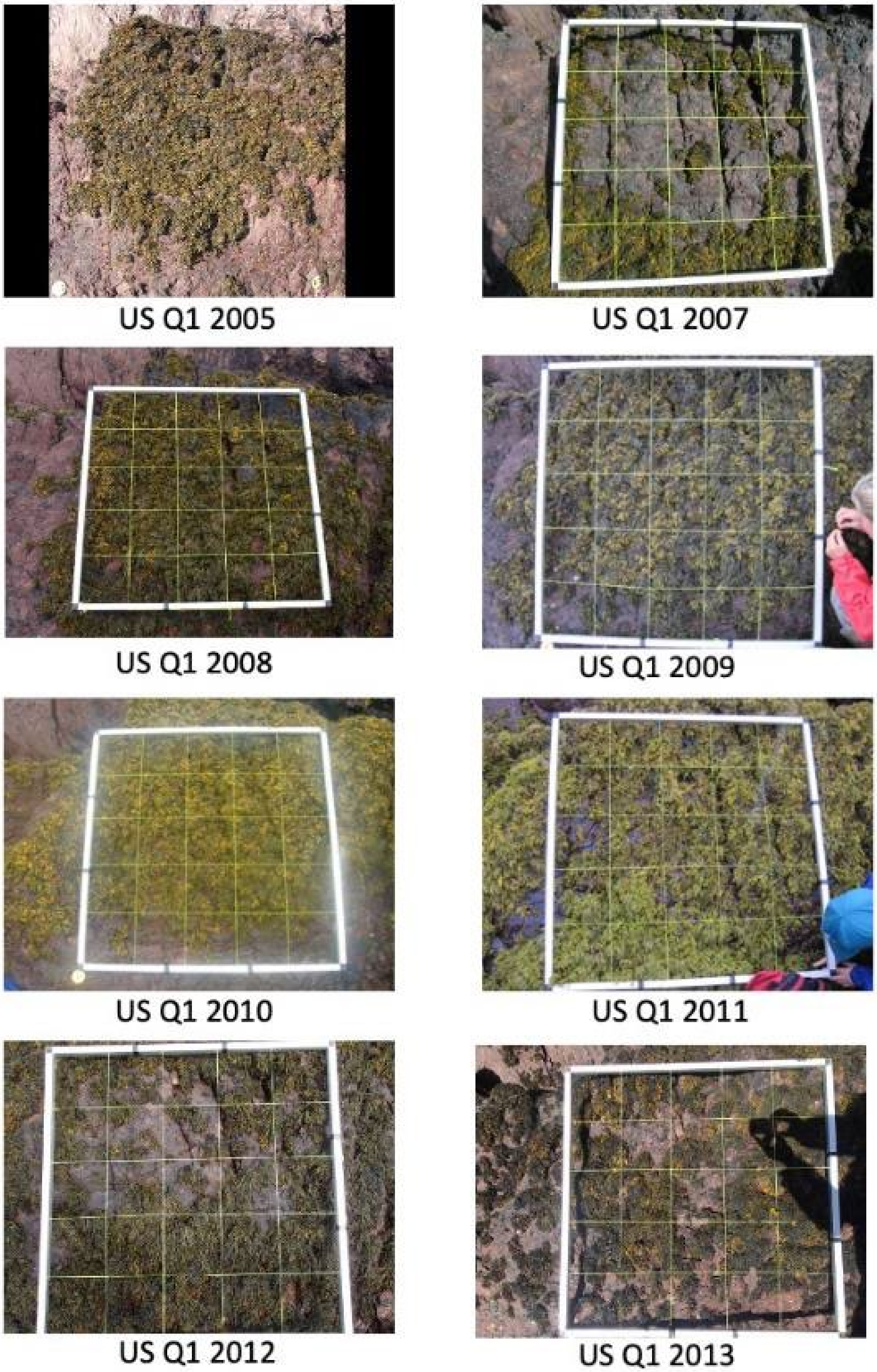


Figure 41. US Q1 at South Hook Point showing a cyclical decline and increase in fucoid cover (mainly *Pelvetia canaliculata*) between 2014 and 2019.

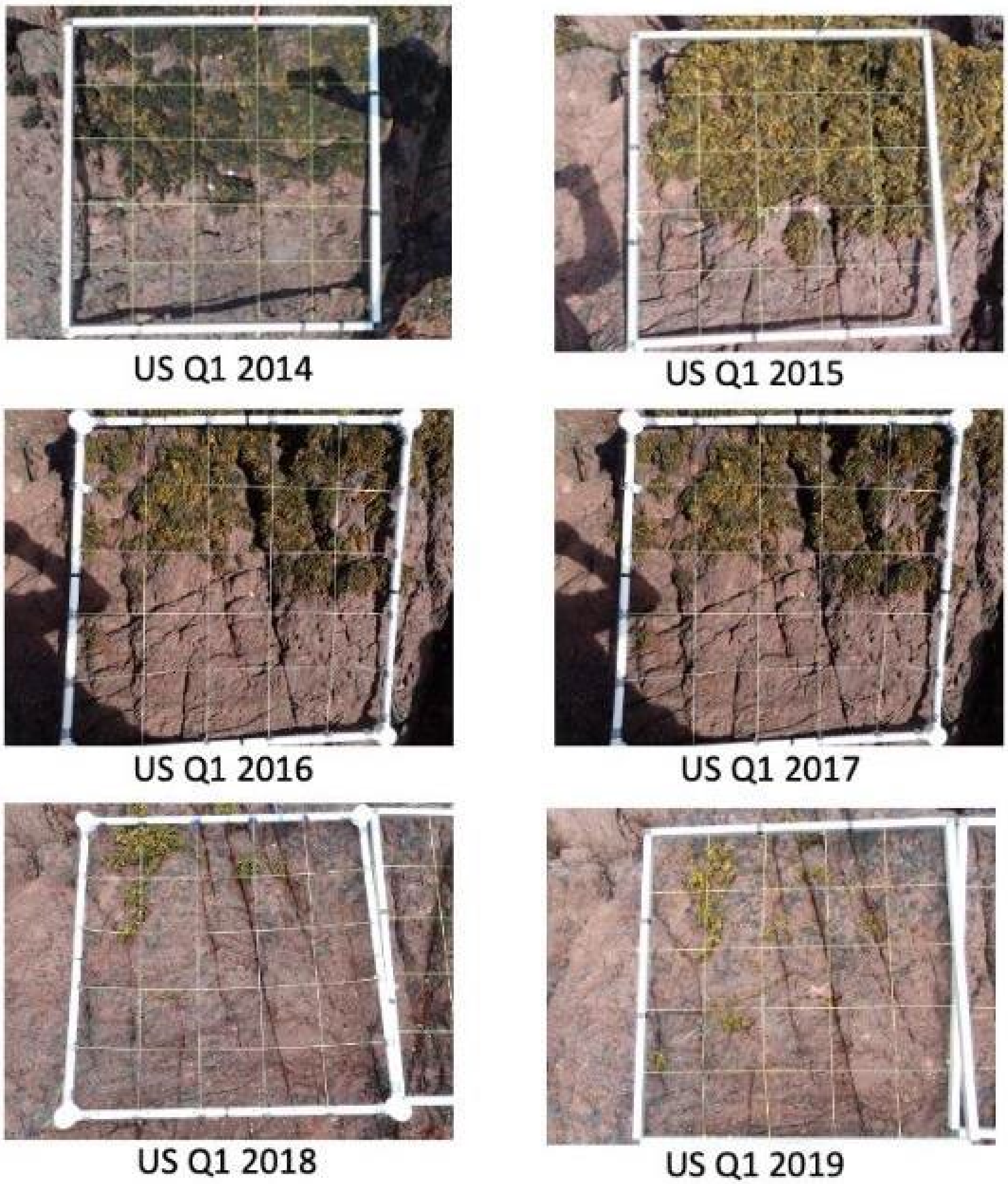


Figure 42. Photographs of the South Hook Point US monitoring area in 2005 and 2019 to illustrate the decline in *Pelvetia canaliculata*.

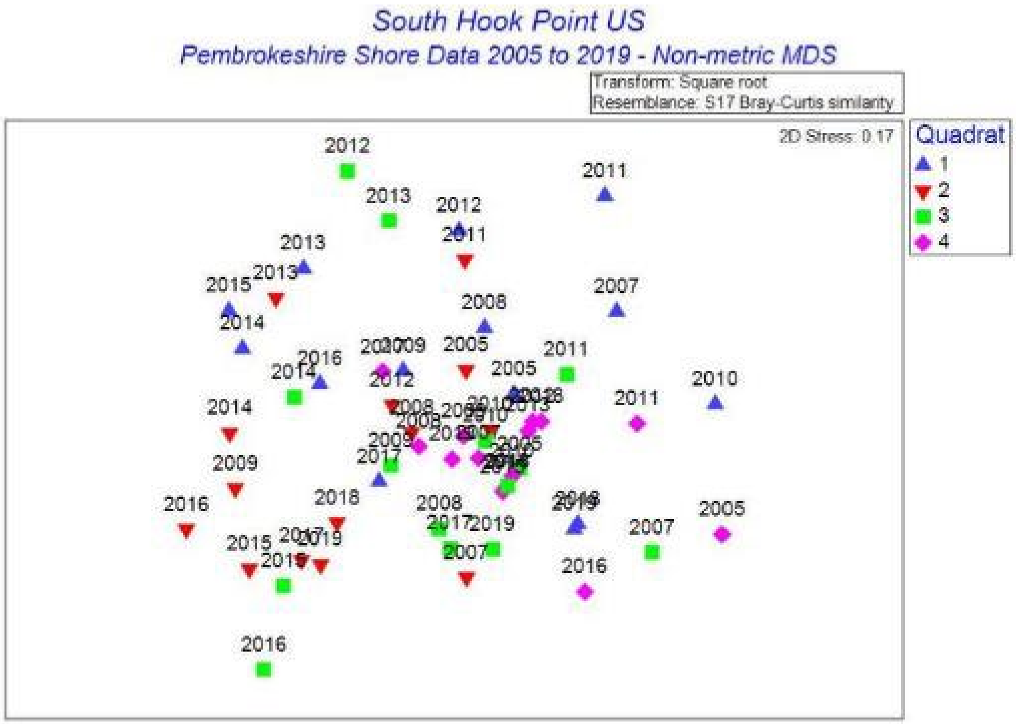
South Hook US monitoring area 2005

South Hook US monitoring area 2019

3.12.2 Multidimensional scaling (MDS)

An MDS plot presenting the data for all taxa recorded in the US quadrats is shown in Figure 43. The stress is low (below 0.2) suggesting there is a good fit of the data to the two-dimensional plot generated. The pattern in this MDS plot shows a tendency for individual quadrats to group together across the years e.g. all of the US Q1 together, all of the US Q2s together and so on.

Figure 43. Non-metric MDS plots showing the data for all taxa (for which frequency was recorded) in all quadrats on South Hook Point US between 2005 and 2019



3.13. South Hook MS

The results of data analyses for South Hook MS are summarised below.

3.13.1 Visual change

The photographs of the SH MS quadrats show little indication of change over the years, apart from fluctuations in the density of barnacles (see Figure 44).

Figure 44. Photos MS Q4 at South Hook Point in 2005, 2011 and 2019.

MS Q4 2005

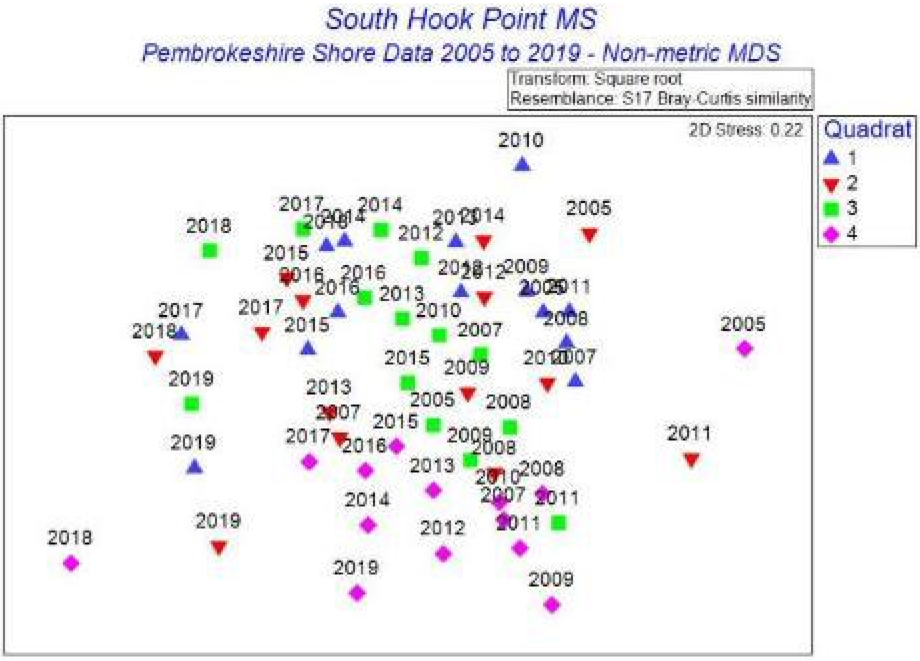
MS Q4 2011

MS Q4 2019

3.13.2 Multidimensional scaling (MDS)

An MDS plot presenting the data for all taxa recorded in the SH MS quadrats are shown in Figure 45. The stress is fairly low suggesting there is a reasonably good fit of the data to the two-dimensional plot generated. The pattern in this MDS plot shows a loose tendency for individual quadrats to group together across the years e.g., all of the MS Q1 quadrats together, all of the MS Q2 quadrats together and so on.

Figure 45. Non-metric MDS plot showing the data for all taxa (for which frequency was recorded) in all quadrats on South Hook Point MS between 2005 and 2019



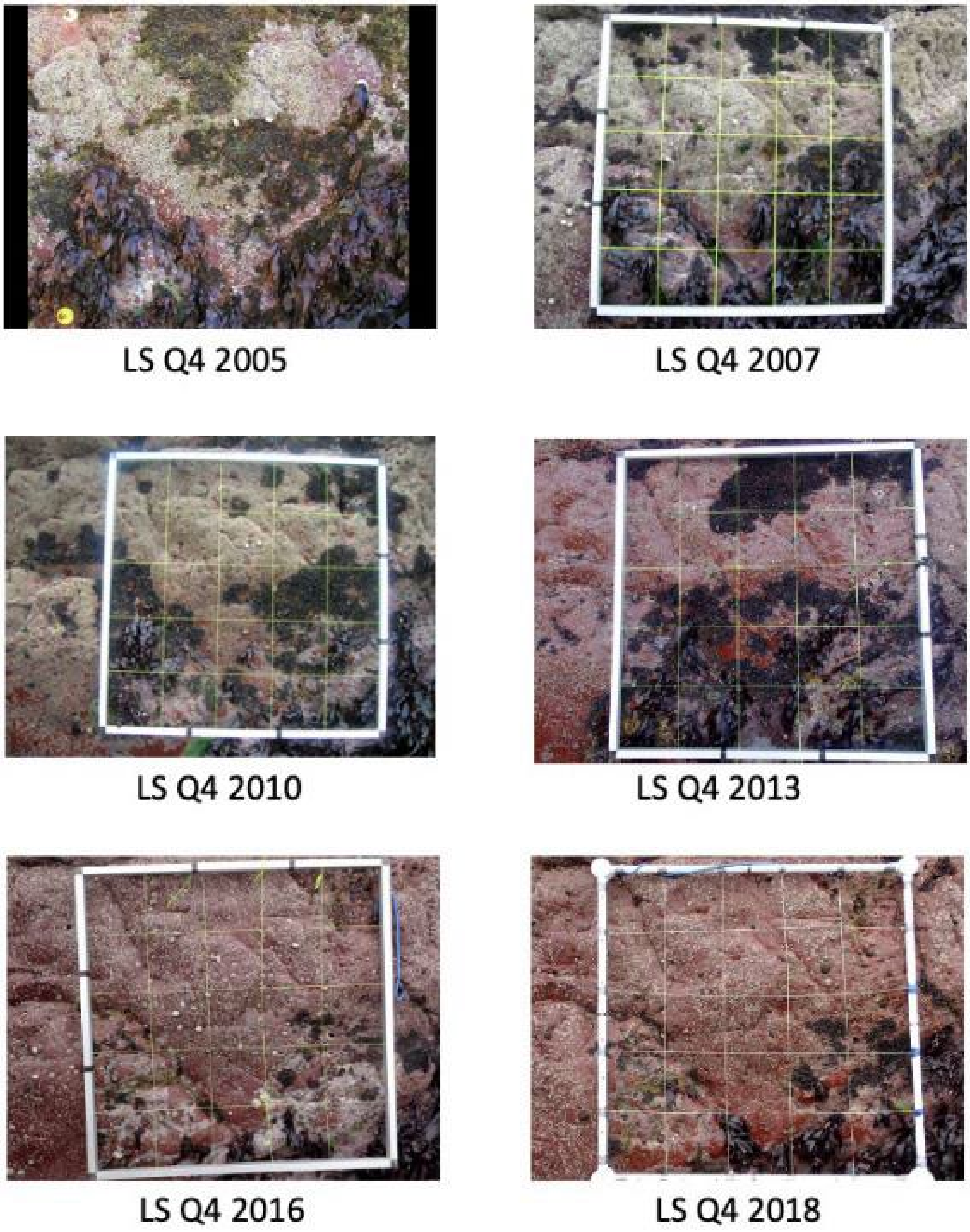
3.14. South Hook LS

The results of data analyses for South Hook LS are summarised below.

3.14.1 Visual change

There has been a decline in cover, especially algae cover in the South Hook LS quadrats over the years. This is illustrated in selected photos of SH LS Q4 over the years in Figure 46.

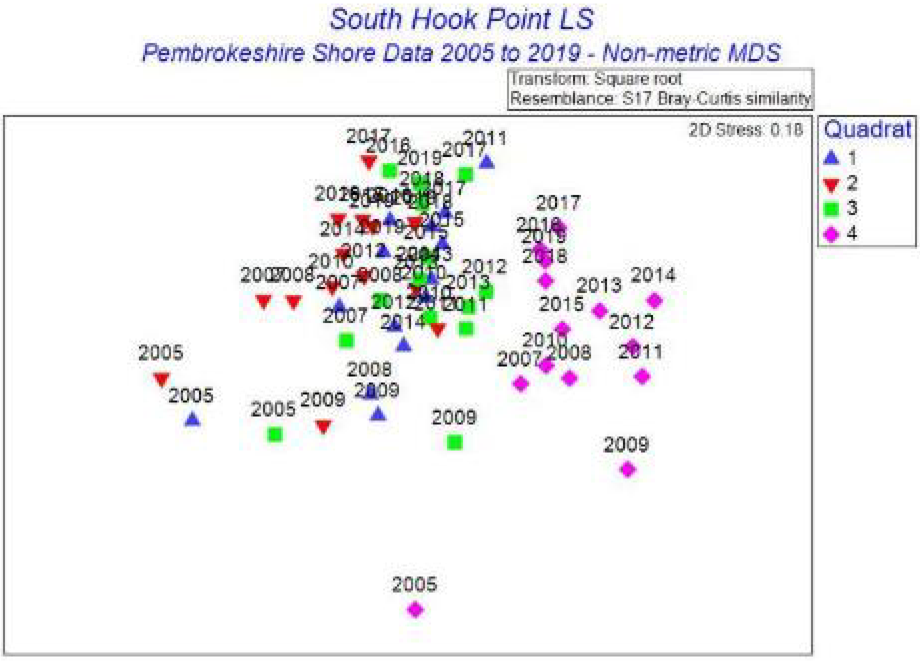
Figure 46. Photos LS Q4 at South Hook Point taken between 2005 and 2018 selected show obvious changes in algal cover.



3.14.2 Multidimensional Scaling (MDS)

An MDS plot presenting the data for all taxa recorded in the SH LS quadrats is shown in Figure 47. The stress is low (below 0.2) suggesting there is a good fit of the data to the two-dimensional plot generated. The pattern shows a tendency for the data for individual quadrats to cluster together, with the data points for LS Q4 to be separate from the rest.

Figure 47. Non-metric MDS plots showing the data for all taxa (for which frequency was recorded) in all quadrats on South Hook Point LS between 2005 and 2019



3.14.3 Analysis of similarity percentages (SIMPER)

In order to help understand patterns seen in the MDS plot in Figure 47, a SIMPER analysis of the SH LS quadrat data was undertaken to determine the species which separated out LS Q4 from the rest. The results of this SIMPER analysis are summarised in Table 13.

In summary, the dissimilarity between LS Q4 and the other quadrats is low, at 36.77%. SH LS Q4 has similar biota to the other quadrats but has higher abundances of some key species which make the data separate out in the MDS plot (Figure 47).

Table 13. Results of a SIMPER analysis to calculate the average similarity between species similarities and dissimilarities between two quadrat groups: SH LS Q1 to Q3 and LS Q4

Group Q1-3 Average similarity: 71.97

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Cirripedia all except *P. perforatus*	5	10.22	7.83	14.2	14.2
Patella	5	10.22	7.83	14.2	28.39
Corallinaceae crusts	4.5	8.09	2.39	11.24	39.63
Gastropoda small in crevices	3.97	6.45	1.73	8.97	48.6
Osmundea pinnatifida	3.35	5.85	2.94	8.13	56.73
Actinia equina	2.76	4.98	4.05	6.91	63.64
Hymeniacidon perlevis	2.85	4.44	2.05	6.17	69.82
Nucella lapillus	2.19	3.71	2.89	5.15	74.97

Group Q4 Average similarity: 71.17

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Patella	4.95	7.22	18.08	10.15	10.15
Cirripedia all except *P. perforatus*	4.84	6.96	11.32	9.78	19.93
Corallinaceae crusts	4.46	5.82	2.42	8.17	28.1
Osmundea pinnatifida	4.25	5.8	7.24	8.14	36.25
Hymeniacidon perlevis	3.61	5.08	14.26	7.14	43.39
Spirorbinae	3.57	4.91	10.01	6.9	50.28
Gastropoda small in crevices	3.29	3.89	2.06	5.47	55.75
Palmaria palmata	3.02	3.6	2.17	5.06	60.81
Halichondria (*Halichondria*) *panicea*	2.31	2.83	4.05	3.98	64.8
Corallina all species	2.13	2.52	2.07	3.54	68.33
Actinia equina	1.82	2.28	4.56	3.21	71.54

Groups Q1-3 & Q4 Average dissimilarity = 36.77

Species	Group Q1-3 Av.Abund	Group Q4 Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Spirorbinae	1.32	3.57	1.96	1.83	5.33	5.33
Palmaria palmata	1.08	3.02	1.81	1.82	4.93	10.25
Hildenbrandia all species	1.52	2.04	1.7	1.23	4.63	14.89
Ralfsia verrucosa	2.5	2.28	1.58	1.36	4.3	19.19
Rhodophyta indet. (non calc. crusts)	2.22	2.46	1.57	1.3	4.26	23.45
Corallina all species	0.54	2.13	1.42	2.11	3.85	27.31
Gastropoda small in crevices	3.97	3.29	1.41	1.27	3.82	31.13
Lomentaria articulata	0.11	1.71	1.37	1.93	3.72	34.85
Bryozoa indet crusts	0.37	1.82	1.32	1.7	3.58	38.44
Verrucariaceae	1.32	0.47	1.1	1.09	3	41.44
Ulva tubular	0.74	1.54	1.08	1.33	2.95	44.39
Spirobranchus	0.3	1.36	1.05	1.46	2.85	47.24
Nucella lapillus	2.19	1.23	1	1.51	2.72	49.96
Dictyota dichotoma	0	1.14	0.97	2.14	2.62	52.59
Electra pilosa	0.03	1.08	0.93	1.08	2.54	55.13
Halichondria (*Halichondria*) *panicea*	1.52	2.31	0.93	1.36	2.53	57.66
Osmundea pinnatifida	3.35	4.25	0.92	1.27	2.5	60.16
Actinia equina	2.76	1.82	0.89	1.58	2.43	62.59
Hymeniacidon perlevis	2.85	3.61	0.87	0.98	2.35	64.94
Perforatus perforatus	0.97	0.27	0.79	1.13	2.14	67.08
Corallinaceae crusts	4.5	4.46	0.78	0.51	2.13	69.21
Steromphala cineraria	0.27	0.86	0.75	1.06	2.04	71.25

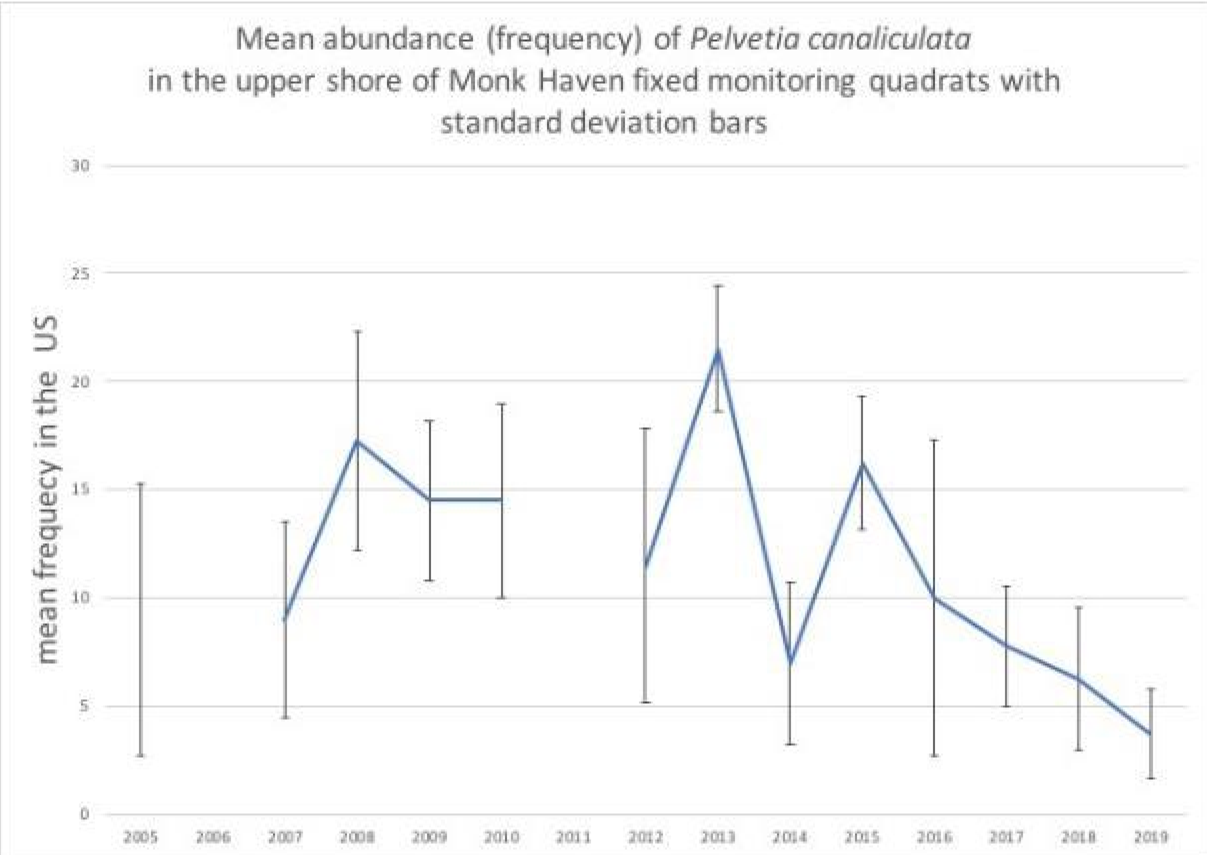
3.15. Monk Haven US

The results of data analyses for Monk Haven US are summarised below.

3.15.1 Visual change

The frequency data for a fucoid in the US, *Pelvetia canaliculata* (averaged from all quadrats), was plotted over time in Figure 48. Although there is much overlap in the standard deviation bars between years, the increase in frequency from 2005 to 2013 and the subsequent decrease to 2019 is significant. The data shows no significant difference in abundance (frequency) between 2005 and 2019.

Figure 48. Graph to show the mean abundance (frequency) of *Pelvetia canaliculata* in the US of Monk Haven fixed monitoring quadrats, with standard deviation bars



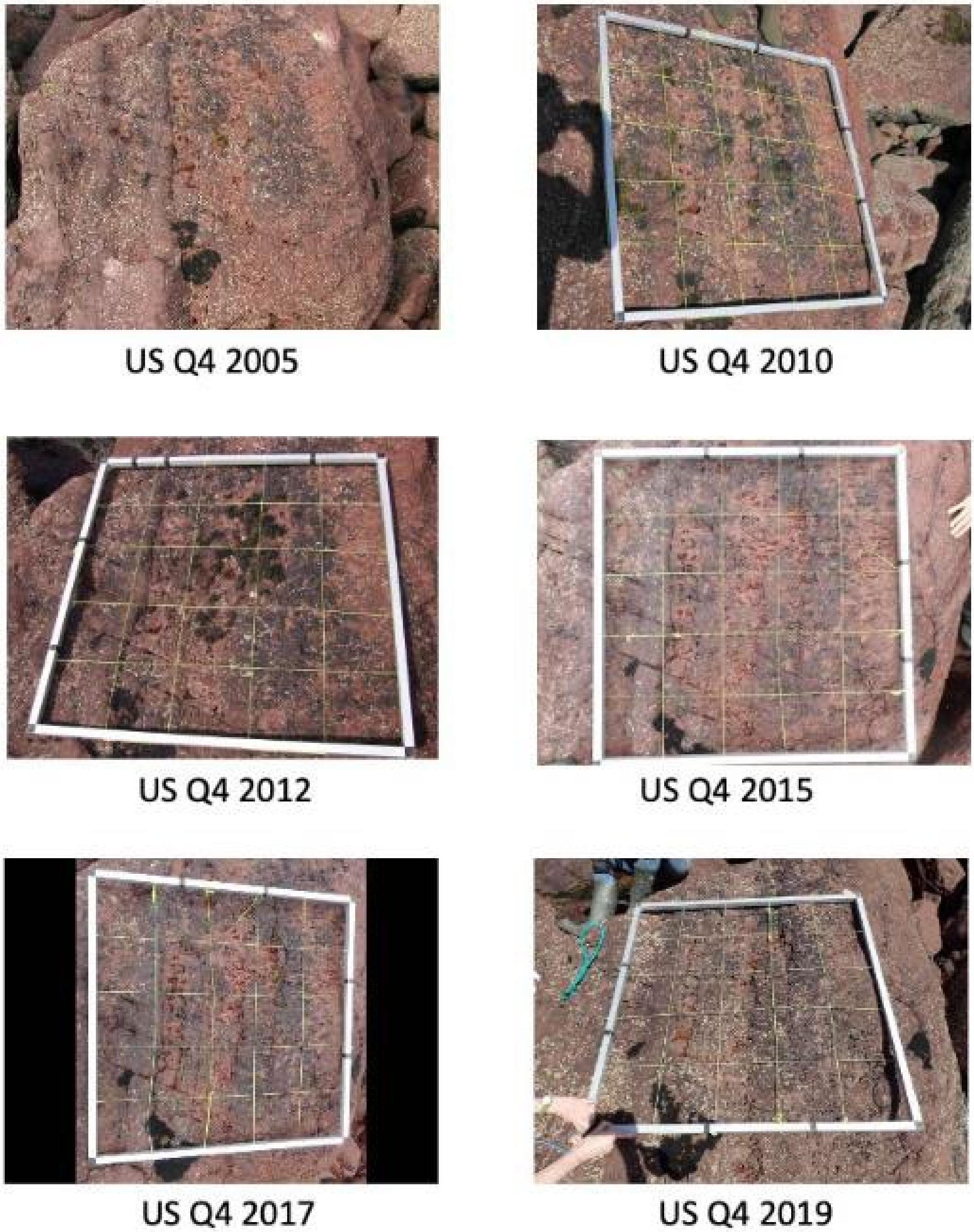
The contextual photographs shown in Figure 49 and those showing US Q4 over time (Figure 49) illustrate the rather barren nature of the US rocks at Monk Haven. Whereas *Pelvetia canaliculata* has increased and decreased over time at this site, the growths of *Lichina pygmaea* have remained fairly constant over the time period.

Figure 49. Photographs of the Monk Haven US monitoring area in 2005 and 2019 to illustrate how little obvious change has occurred to the habitat and its biota.

Monk Haven US monitoring area 2005

Monk Haven US monitoring area 2019

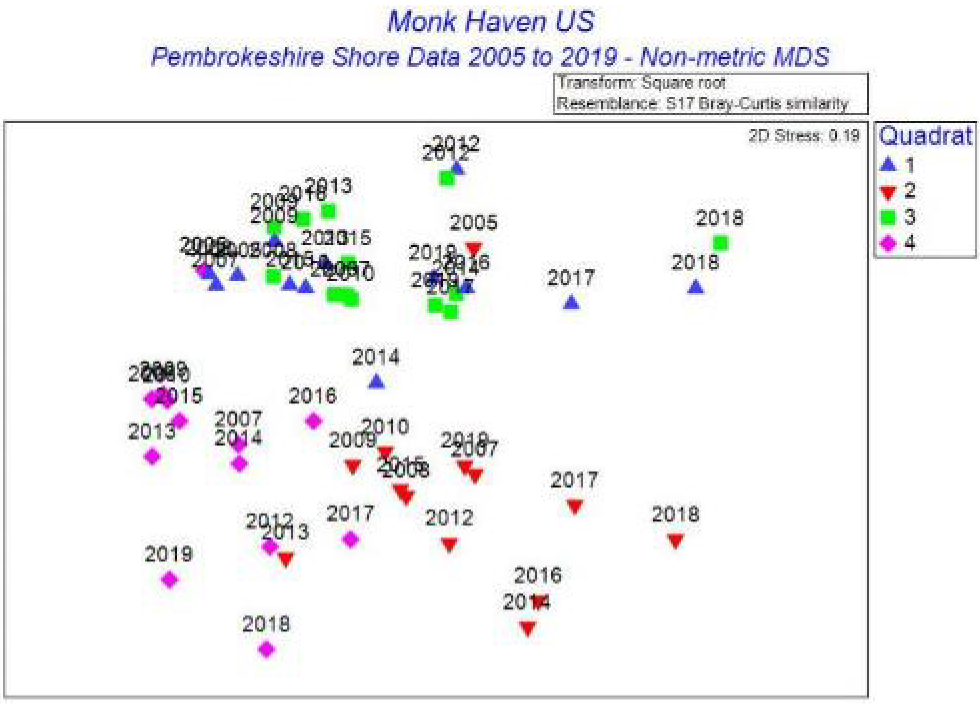
Figure 50. US Q4 at Monk Haven to illustrate the regular changes in biota over time. Whereas the abundance of *Pelvetia canaliculata* changes over time, the abundance of *Lichina pygmaea* (bottom left of quadrat) stays fairly constant.



3.15.2 Multidimensional Scaling (MDS)

An MDS plot presenting the data for all taxa recorded in the US quadrats are shown in Figure 51. The stress is low (below 0.2) suggesting there is a good fit of the data to the two-dimensional plot generated. The general pattern is for individual quadrats to group together across the years e.g. all of the USQ1 together, all of the US Q2s together and so on.

Figure 51. Non-metric MDS plot showing the data for all taxa (for which frequency was recorded) in all quadrats on Monk Haven US between 2005 and 2019



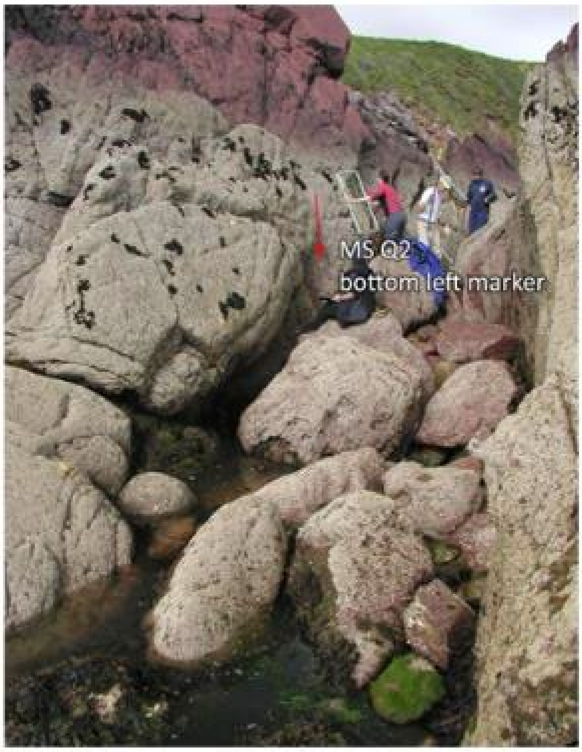
3.16. Monk Haven MS

The results of data analyses for Monk Haven MS are summarised below.

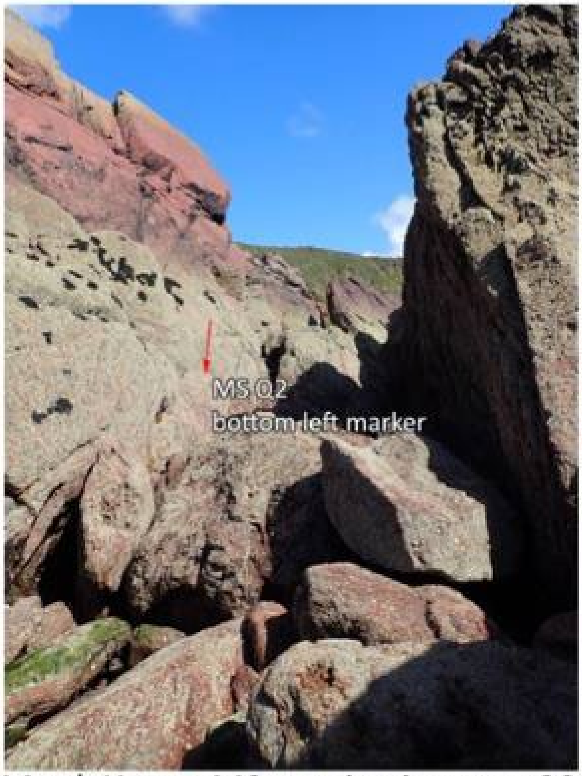
3.16.1 Visual change

There has been little visible change in the quadrat area of Monk Haven MS since monitoring started in 2005. The monitoring site is illustrated in contextual photographs (Figure 52) and a time series of photographs showing MS Q1 (Figure 53). This monitoring site is on steep rock faces which are adjacent to a boulder filled gulley. MS Q4 has been obscured by a large boulder moving in front of the quadrat in some years. These years were left out of the analysis. The patches of *Lichina pygmaea* have remained very similar over the course of the monitoring.

Figure 52. Photographs of the Monk Haven MS monitoring area in 2005 and 2019 to illustrate how little obvious change has occurred to the habitat and its biota.



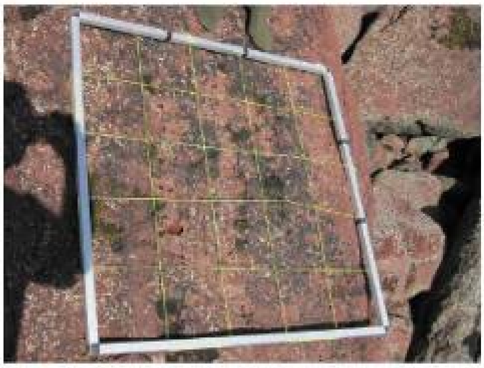
Monk Haven MS monitoring area 2005



Monk Haven MS monitoring area 2019

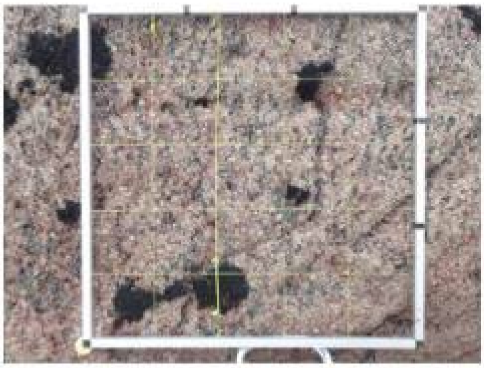
Figure 53. MS Q1 at Monk Haven to illustrate the appearance of the biota over time. Whereas barnacle density varies, the abundance of *Lichina pygmaea* has stayed fairly constant.

MS Q1 2005

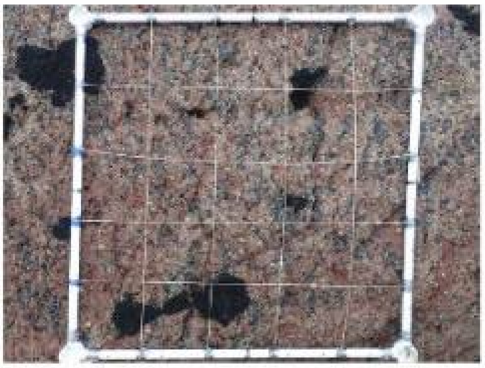


MS Q1 2009

MS Q1 2013



MS Q1 2015



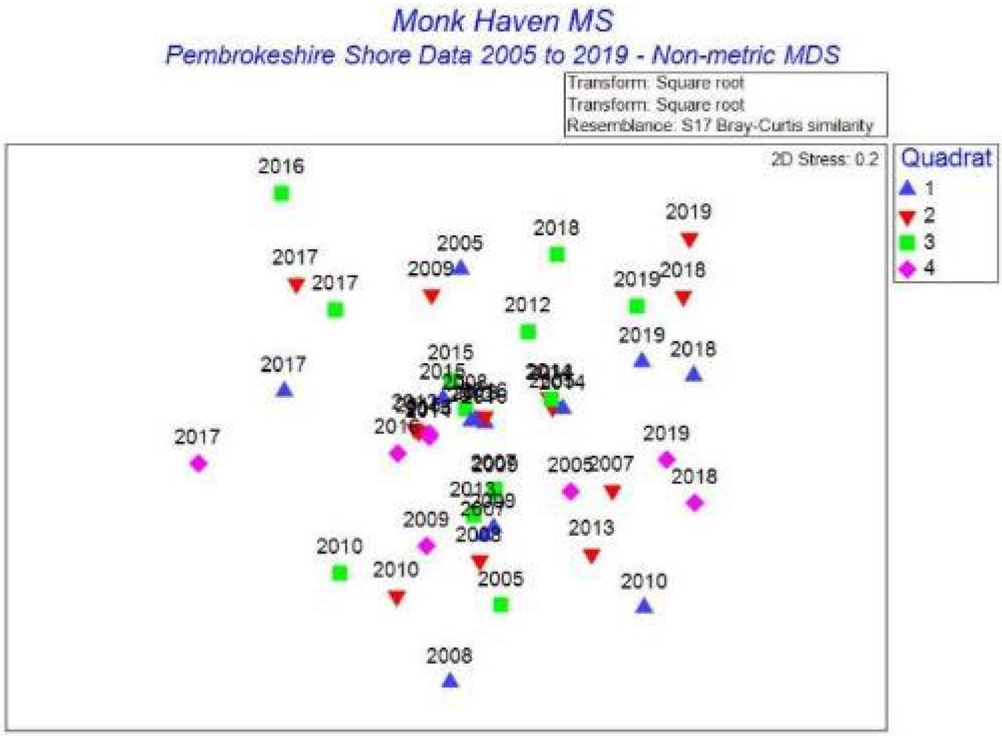
MS Q1 2017

MS Q1 2019

3.16.2 Multidimensional Scaling (MDS)

An MDS plots presenting the data for all taxa recorded in the MS quadrats are shown in Figure 54. The stress is low suggesting there is a good fit of the data to the two-dimensional plot generated. There is little variation between the quadrats over the time series.

Figure 54. Non-metric MDS plot showing the data for all taxa (for which frequency was recorded) in all quadrats on Monk Haven MS between 2005 and 2019. Note that MS Q4 was not surveyed every year as it was occasionally obscured by a shifting boulder.



3.17. Monk Haven LS

The results of data analyses for Monk Haven LS are summarised below.

The lower shore site at Monk Haven is on the boundary between the middle and lower shore. It was established adjacent to a rockpool but since this time, boulders from the LS have been moved into the pool during storms and have had a scouring effect on the site and from time to time have obscured LS Q1 and LS Q4 preventing them from being surveyed (see Figure 55).

3.17.1 Visual change

There has been little change in the barnacle dominated communities of MH LS over the time of the survey. Contextual photos taken in 2015 and 2018 illustrate the site (Figure 55) and a time series of pictures showing LS Q1 over time (2005 to 2019) is shown in Figure 56.

Figure 55. Photographs of the Monk Haven LS monitoring area in 2015 and 2018 to illustrate how the area is affected by boulders which have shifted over time, sometimes, obscuring quadrats as well as scouring the site.

Monk Haven LS monitoring area 2015

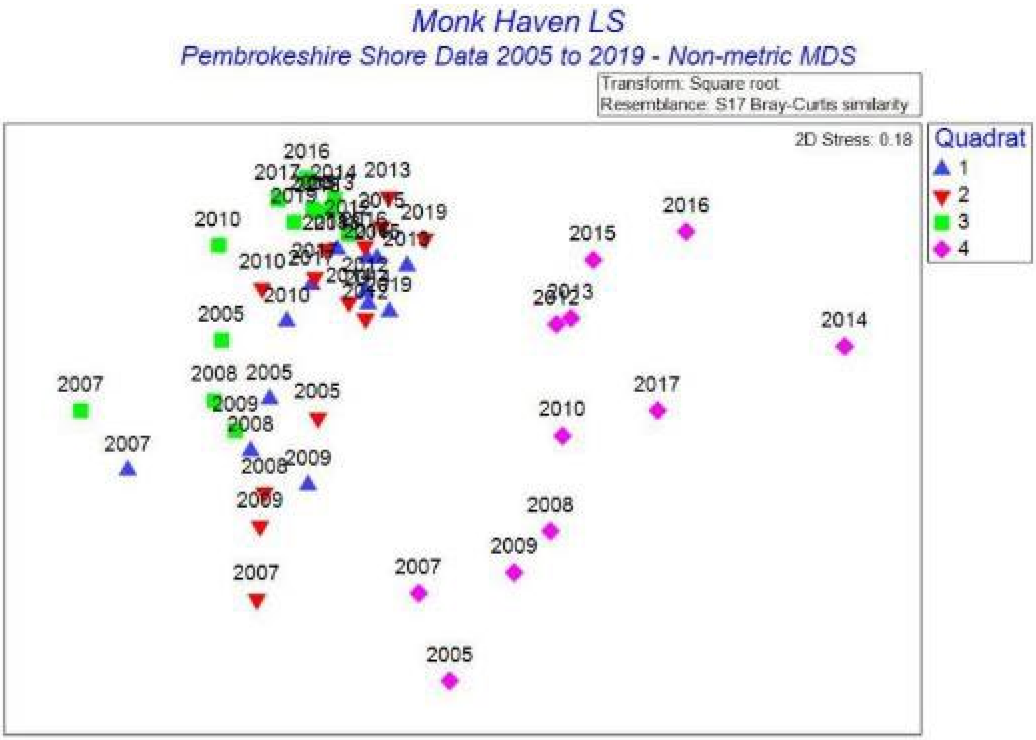
Monk Haven LS monitoring area 2018

Figure 56. LS Q1 at Monk Haven to illustrate the appearance of the biota over time. Note the boulder obscuring part of the quadrat in 2014.

3.17.2 Multidimensional Scaling (MDS)

An MDS plot presenting the data for all taxa recorded in the MH LS quadrats are shown in Figure 47. The stress is low (below 0.2) suggesting there is a good fit of the data to the two-dimensional plot generated. The pattern in this MDS plot shows the data from LS Q4 data to be separate from the other quadrats. Despite this separation of LS Q4, the spread the stress in the MDS plot is low, signifying that there hasn't been much change over time. This trend is further analysed in the SIMPER analyses Table 14.

Figure 57. Non-metric MDS plot showing the data for all taxa (for which frequency was recorded) in all quadrats on Monk Haven LS between 2005 and 2019. Both LS Q1 an LS Q4 were obscured by shifting boulders at intervals with the result that these quadrats could not be surveyed every year.



3.17.3 Analysis of similarity percentages (SIMPER)

In order to explain the pattern seen in the MDS plot of the MH LS quadrat data shown in Figure 57, a SIMPER analysis was conducted. The analysis compared the data collected over time from LS Q1 to LS Q3 with that from LS Q4 and the results are shown in Table 14.

Each of quadrat groups (LS Q1 to LS Q3 and LS Q4) show a fairly high average similarity but there is a fairly low dissimilarity between the two groups (Table 14). The pattern seen in the MDS plot in Figure 57 which separates these two quadrat groups is explained by differences in the abundances of the species recorded in each, especially Verrucariaceae, Gastropods in small crevices and *Ralfsia verrucosa* all of which are of a higher abundance in LSQ1 to LS Q3. Differences in the abundances of other species also contribute to the differences seen (Table 14).

Table 14. Results of SIMPER test calculating the similarity and dissimilarity of species frequency records in LS Q1 and 3 in comparison to LS Q4 at Monk Haven.

Quadrats 1 to 3 Average similarity: 74.03

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Cirripedia all except P. perforatus	4.97	10.43	10.83	14.1	14.1
Patella	4.97	10.42	10.73	14.08	28.18
Gastropoda small in crevices	4.73	9.59	8.75	12.96	41.14
Steromphala umbilicalis	4.05	7.96	9.42	10.75	51.89
Corallinaceae crusts	3.56	6.78	6.63	9.16	61.05
Verrucariaceae	3.24	5.69	2.59	7.69	68.74
Ralfsia verrucosa	3.44	4.87	0.94	6.58	75.32

Quadrat 4 Average similarity: 66.64

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Cirripedia all except P. perforatus	4.91	13.21	11.14	19.82	19.82
Patella	4.9	13.18	10.71	19.78	39.6
Corallinaceae crusts	2.62	6.34	3.55	9.51	49.11
Ulva tubular	2.95	6.31	1.97	9.47	58.57
Steromphala umbilicalis	2.65	5.27	1.81	7.91	66.48
Ralfsia verrucosa	2.62	3.61	0.76	5.42	71.9

Quadrats 1 to 3 & 4 Average dissimilarity = 40.92

Species	Quadrats 1 to 3 Av.Abund	Quadrat 4 Av.Abund	Av.Diss	Diss/SD	Contrib %	Cum. %
Verrucariaceae	3.24	0	3.87	3.09	9.45	9.45
Gastropoda small in crevices	4.73	1.67	3.69	2.87	9.01	18.45
Ralfsia verrucosa	3.44	2.62	2.94	1.17	7.18	25.63
Ulva tubular	0.83	2.95	2.72	1.99	6.65	32.28
Rhodophyta indet. (non calc. crusts)	1.3	2.3	2.53	1.4	6.17	38.45
Hymeniacidon perlevis	1.69	0.49	1.8	1.53	4.4	42.86
Chlorophyta film, fuzz or threads	0.87	1.31	1.79	1.01	4.36	47.22
Steromphala umbilicalis	4.05	2.65	1.77	1.23	4.32	51.54
Ulva flat	1.96	2.1	1.56	1.35	3.81	55.35
Hildenbrandia all species	0.6	0.76	1.35	0.7	3.3	58.66
Fucus sporelings	0.26	1.24	1.34	1.3	3.27	61.93
Actinia equina	1.14	0.09	1.33	1.44	3.24	65.17
Mytilus edulis	1	0.18	1.27	0.69	3.11	68.28
Corallinaceae crusts	3.56	2.62	1.22	1.48	2.98	71.26

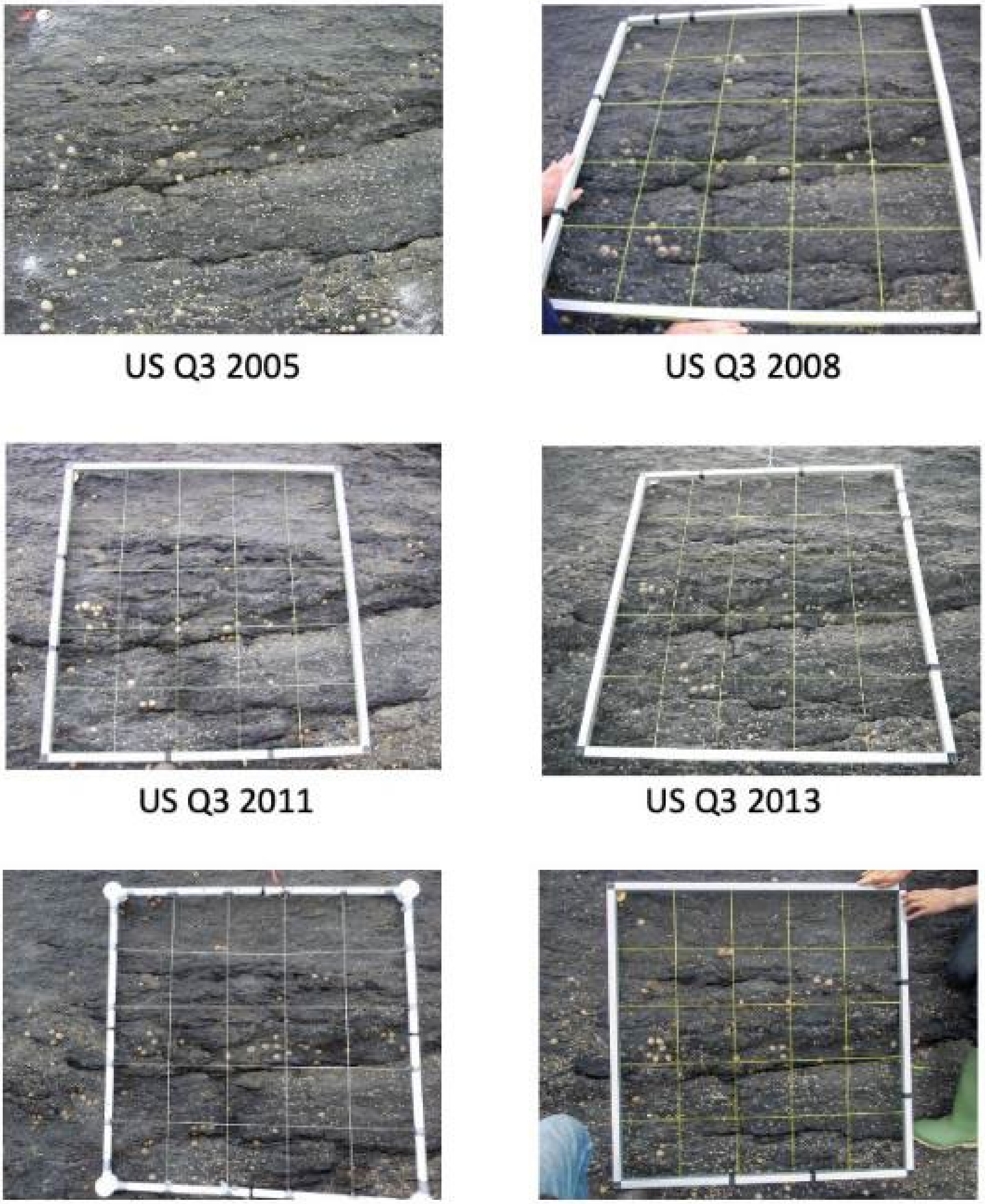
3.18. West Angle Bay US

The results of data analyses for West Angle Bay US are summarised below.

3.18.1 Visual change

The US monitoring area at West Angle Bay is sparely populated by marine organisms. The common species are Verrucariaceae lichens, barnacles, limpets and gastropods in small crevices (mainly *Littorina saxatilis* and *Melarhaphe neritoides*). A few growths of *Pelvetia canaliculata* have been recorded on occasional years but it has never become established as a turf. Little obvious visual change over the monitoring time period was observed and this is illustrated in photographs of US Q3 over time in Figure 58.

Figure 58. US Q3 at West Angle Bay to illustrate changes in biota over time.



US Q3 2005

US Q3 2008

US Q3 2011

US Q3 2013

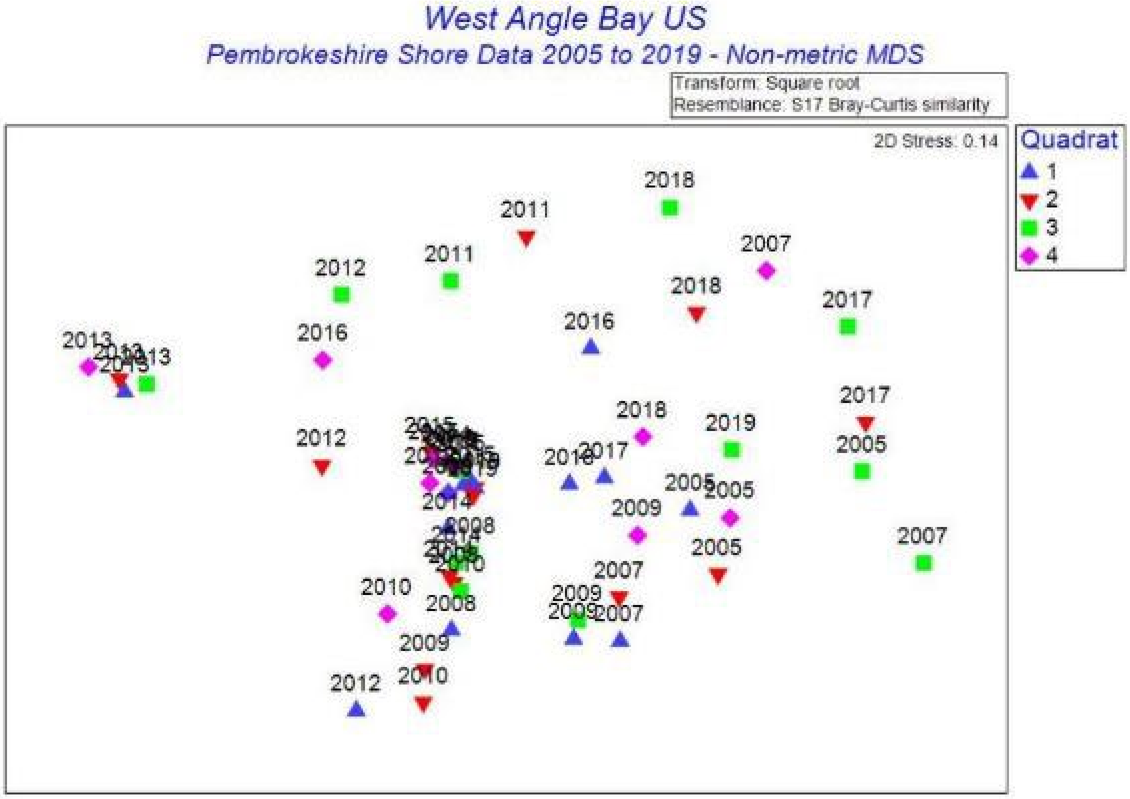
US Q3 2016

US Q3 2019

3.18.2 Multidimensional Scaling (MDS)

An MDS plot presenting the data for all taxa recorded in the US quadrats are shown in Figure 59. The stress is low (below 0.2) suggesting there is a good fit of the data to the two-dimensional plot generated. The data shown in Figure 59 shows little in the way of discernible patterns. The 2013 data clusters together but this is due to *Ralfsia verrucosa* not being recorded during that year which is probably an oversite.

Figure 59. A non-metric MDS plot showing the data for all taxa (for which frequency was recorded) in all quadrats on West Angle Bay US between 2005 and 2019.



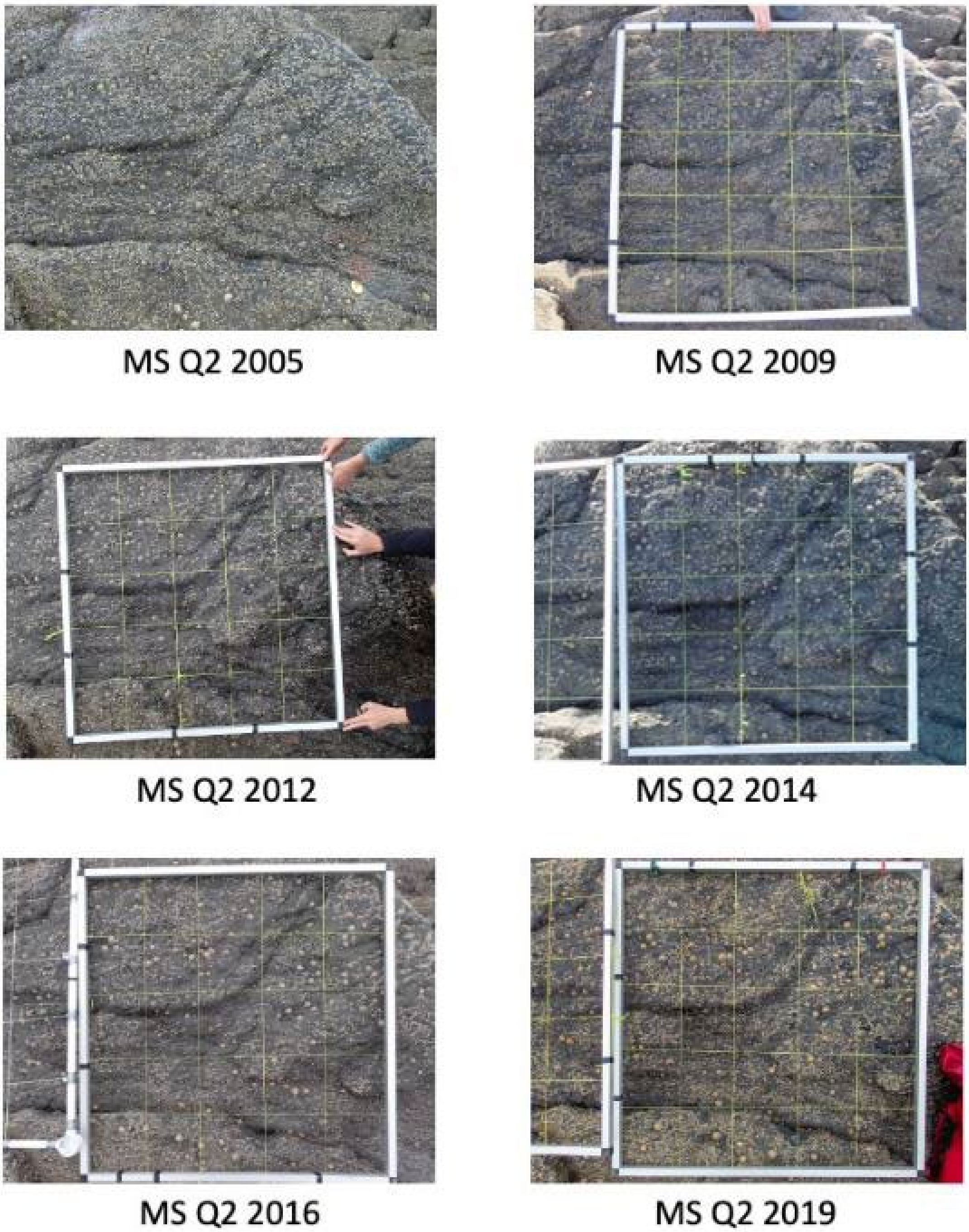
3.19. West Angle Bay MS

The results of data analyses for West Angle Bay MS are summarised below.

3.19.1 Visual change

The MS monitoring area at West Angle Bay is dominated by barnacles, limpets and small gastropods in crevices (mainly *Littorina saxatilis* and *Melarhaphe neritoides*). Other species e.g., larger gastropods, anemones and seaweeds can be found in bigger crevices, but the open rock surfaces are very grazed and species poor. Little obvious visual change has been seen over the monitoring time period and this is illustrated in photographs of MS Q2 in Figure 60.

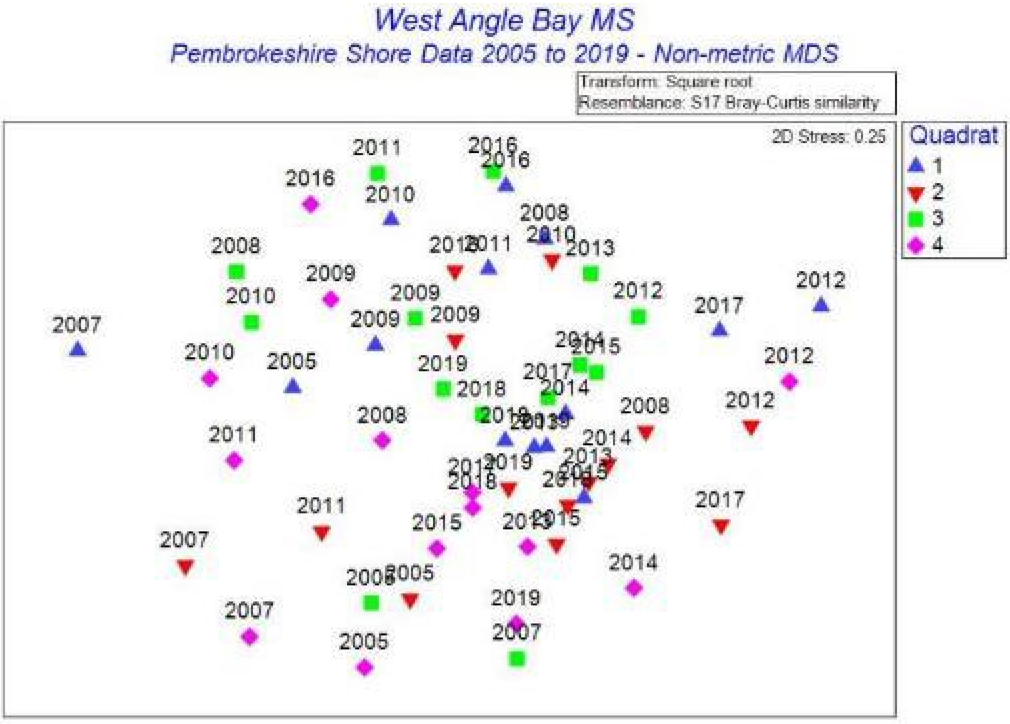
Figure 60. MS Q2 at West Angle Bay to illustrate changes in biota over time.



3.19.2 Multidimensional Scaling (MDS)

An MDS plot presenting the data for all taxa recorded in the MS quadrats is shown in Figure 61. The stress is fairly low suggesting there is a reasonably good fit of the data to the two-dimensional plot generated. The algae and animals recorded in crevices varies over the years and most likely accounts for the wide spread of the data.

Figure 61. A non-metric MDS plot showing the data for all taxa (for which frequency was recorded) in all quadrats on West Angle Bay US between 2005 and 2019.



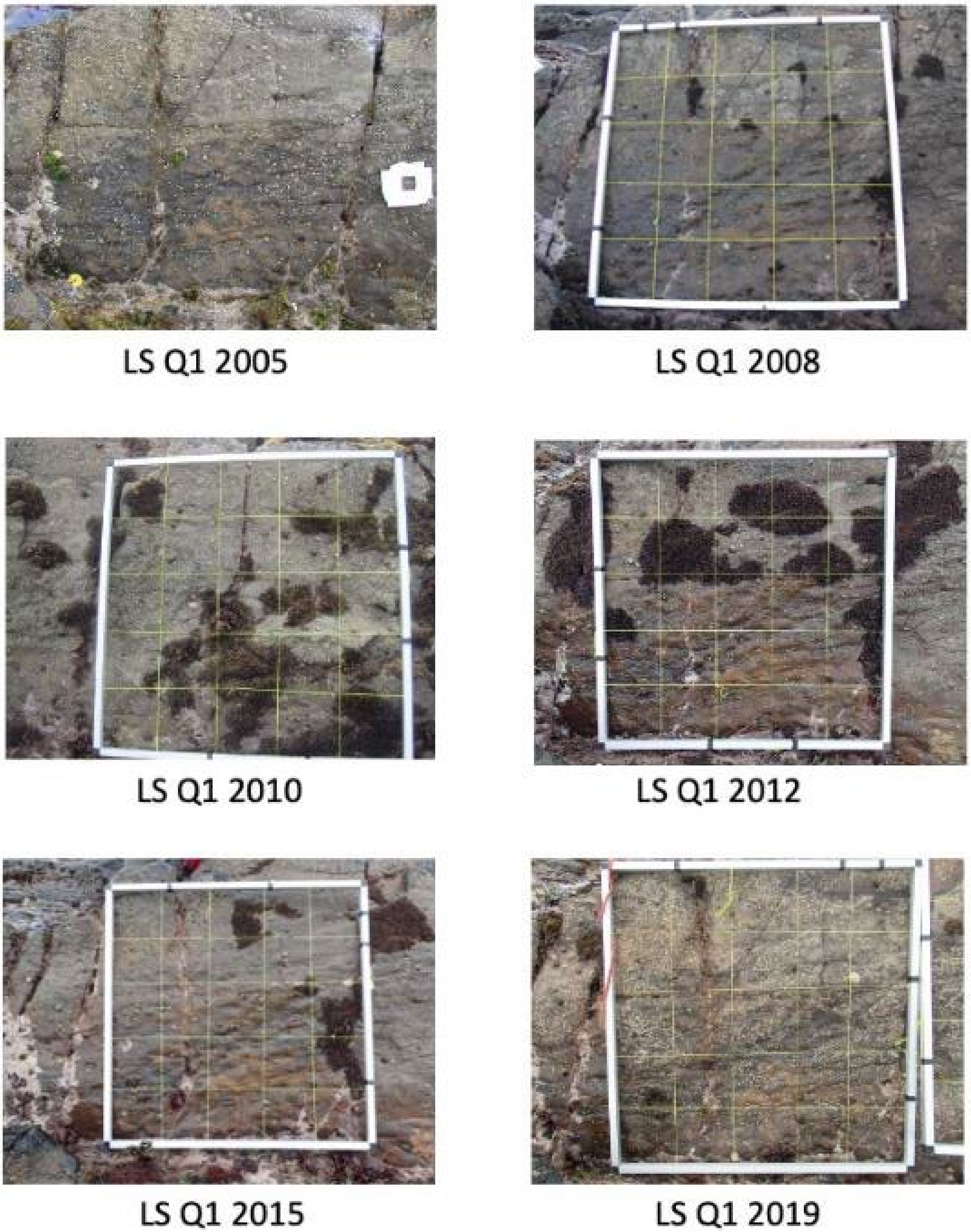
3.20. West Angle Bay LS

The results of data analyses for West Angle Bay LS are summarised below.

3.20.1 Visual change

The LS monitoring area at West Angle Bay is dominated by barnacles, limpets and Gastropods in small crevices (mainly *Littorina saxatilis* and *Melarhaphe neritoides*). The only alga found in any abundance is *Osmundea pinnatifida*, although crevices contain various other species, particularly crustose Corallinaceae and gastropods such as *Nucella lapillus* and *Steromphala umbilicalis*. The main visual change over time is in the abundance of *O. pinnatifida* which comes and goes, as illustrated with LS Q1 in Figure 62.

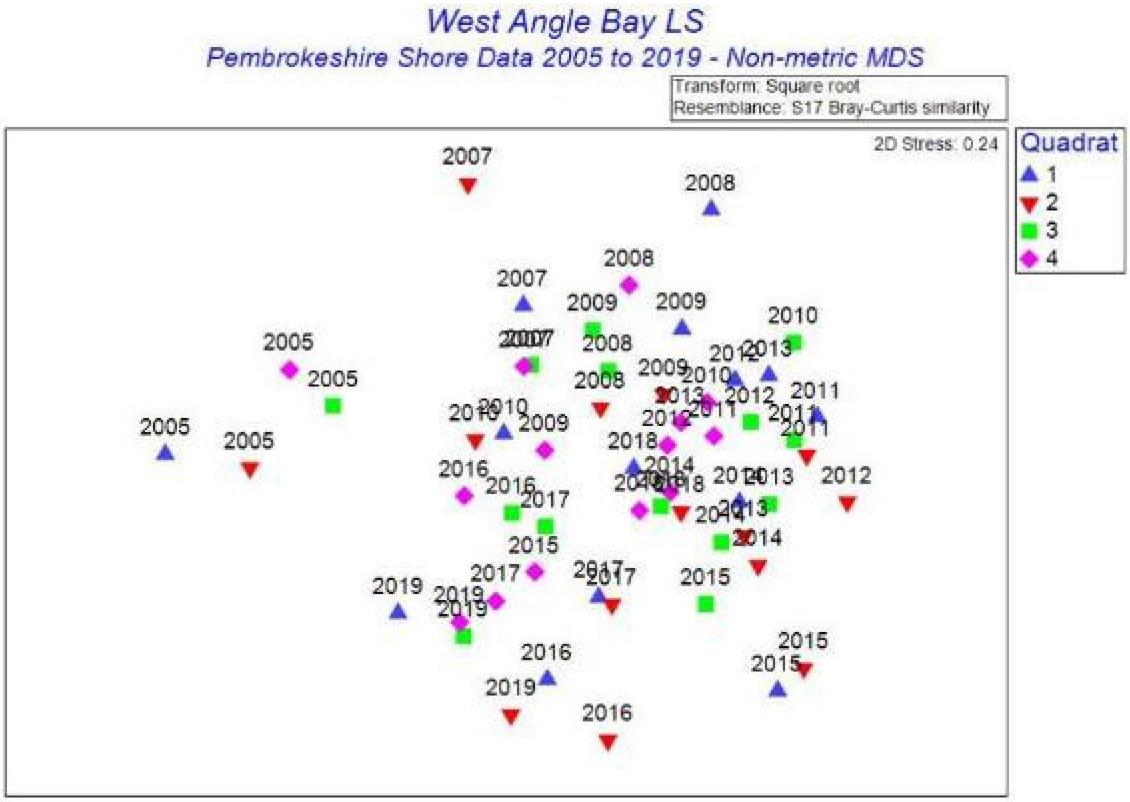
Figure 62. LS Q1 at West Angle Bay to illustrate changes in biota over time.



3.20.2 Multidimensional scaling (MDS)

An MDS plot presenting the data for all taxa recorded in the LS quadrats are shown in Figure 63. The stress is fairly low suggesting there is a reasonably good fit of the data to the two-dimensional plot generated. The algae and animals recorded in crevices varies over the years and most likely accounts for the wide spread of the data. The 2005 data separates away from the rest as *Ralfsia verrucosa* wasn't recorded in that year but was in all the other years. Otherwise, the community has changed little over time.

Figure 63. A non-metric MDS plot showing the data for all taxa (for which frequency was recorded) in all quadrats on West Angle Bay LS between 2005 and 2019.



3.21. Nolton Haven US

The results of data analyses for Nolton Haven US are summarised below.

3.21.1 Visual change

There has been little visual change in Nolton Haven US (see Figure 64 and Figure 65), apart from variation in cover (not frequency counts) of barnacles. A chunk of rock was found to be missing in US Q4 in 2019 (Figure 65).

Figure 64. Nolton Haven upper shore quadrat area (Q1 and Q2) in 2007 and 2019

US contextural (with Q1 and Q2) 2007

US contextural (with Q1 and Q2) 2019

Figure 65. Photos of the four monitoring quadrats in the US at Nolton Haven, comparing 2007 to 2019 (2018 in the case of US Q3 as the 2019 photo was of poor quality). Note the broken rock in US Q4 in 2019.


US Q1 2007


US Q1 2019


US Q2 2007


US Q2 2019


US Q3 2007


US Q3 2018

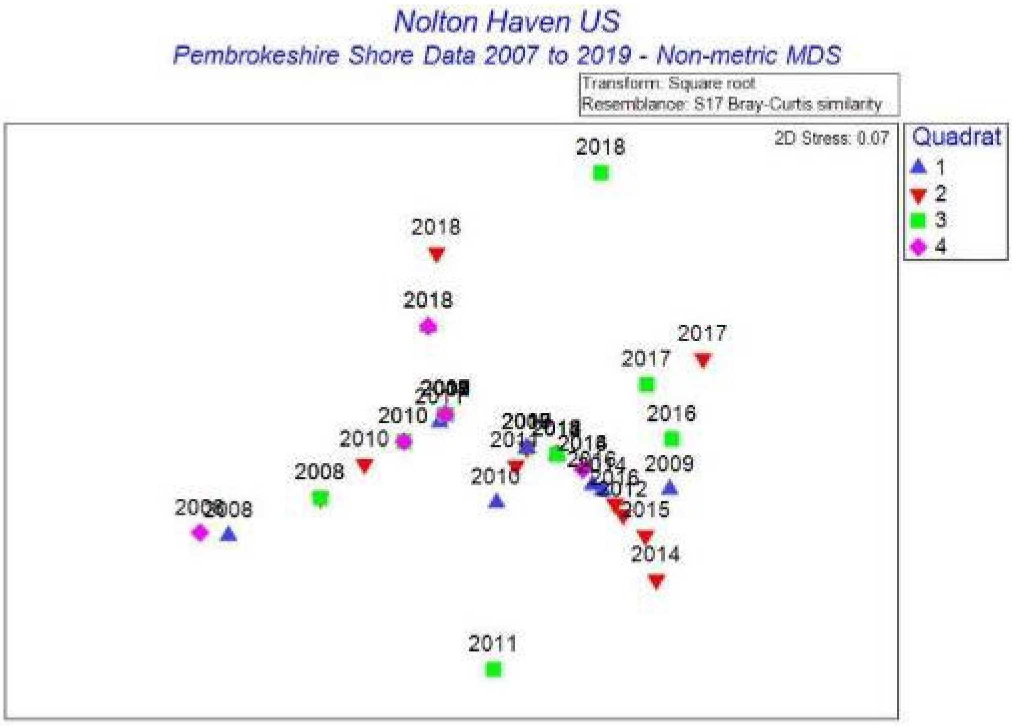

US Q4 2007


US Q4 2019

3.21.2 Multidimensional scaling (MDS)

An MDS plot presenting the data for all taxa recorded in the US quadrats are shown in Figure 66. The stress is low (below 0.2) suggesting there is a good fit of the data to the two-dimensional plot generated. The 2018 data doesn't cluster with the other data so well and quadrat 3 data appears more different in different years than the data for the other quadrats.

Figure 66. Non-metric MDS plots showing the data for all taxa (for which frequency was recorded) in all quadrats on Nolton Haven US between 2005 and 2019



3.22. Nolton Haven MS

The results of data analyses for Nolton Haven MS are summarised below.

3.22.1 Visual change

A striking visual change in the MS at Nolton Haven was from barnacle covered rock to cover of *Fucus vesiculosus* var. *linearis* (see Figure 67). The pattern observed over the monitoring years is given in Table 15.

Figure 67. The middle shore monitoring area of the Nolton Haven monitoring site illustrating a change from barnacles being visually dominant in 2007 to *Fucus vesiculosus* var. *linearis* being dominant in 2017.

MS contextural (with Q1 and Q2) 2007

MS contextural (with Q1 and Q2) 2017

3.22.2 Multidimensional scaling (MDS)

MDS plots presenting the data for all taxa recorded in the MS quadrats is shown in Figure 68 and Figure 69. The stress is low (below 0.2) suggesting there is a good fit of the data to the two-dimensional plot generated. The MDS plot shows different years clustering into four main groups or periods; 2007, 2010 to 2011, 2012 to 2016 and 2008 to 2009 with 2017 to 2019. This can be seen clearly in Figure 69. See also Table 15.

Figure 68. A non-metric MDS plots showing the data for all taxa (for which frequency was recorded) in all quadrats in Nolton Haven MS between 2007 and 2019

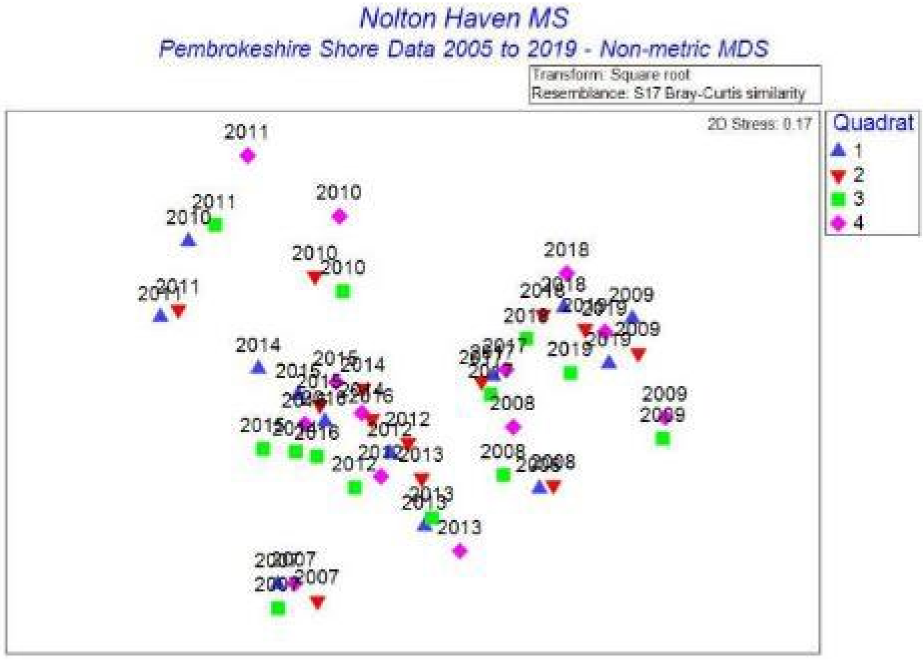


Figure 69 A Non-metric MDS plot showing the data for all taxa (for which frequency was recorded) in all quadrats in Nolton Haven MS between 2007 and 2019, with four periods; 2007, 2010 to 2011, 2012 to 2016 and 2008 to 2009 with 2017 to 2019.

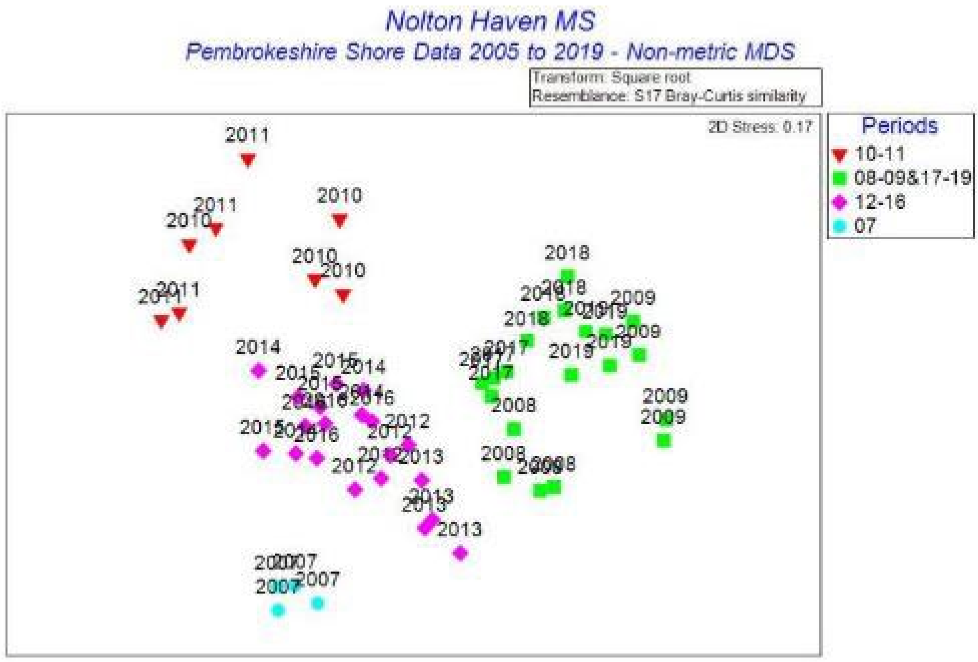


Table 15. Years in which barnacles or thalli of *Fucus vesiculosus* var. *linearis* were the most visually conspicuous in Nolton Haven MS monitoring area. (07 = 2007, 08 = 2008 etc) and periods defined by MDS (see Figure 69).

Barnacle	07	08			11	12	13	14	15	16			
Fucoid		08	09	10							17	18	19
Period	07	08-09 & 17-19		10-11		12-16					08-09 & 17-19		

3.22.3 Analysis of similarity percentages (SIMPER)

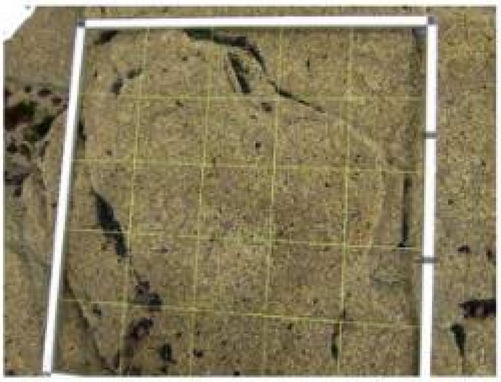
A SIMPER analysis of Nolton Haven MS quadrat data was undertaken to determine which species characterised the different ‘periods’ which separated out in the MDS plot (Figure 69). The results of the SIMPER analysis are summarised in Table 16 and Table 17.

The average similarity of the data in each of the four periods was high. The species in each period are listed in Table 16 and ranked with those contributing the most to the similarity at the top of the list. Cirripedia (all except *Perforatus perforatus*) were the most frequent species in all the periods, but the abundance of other species varied in the different periods.

The periods 2007 and 2012 to 2016 were all barnacle dominated with little seaweed whereas the 2008 to 2009 with 2017 to 2019 period had a high abundance of *Fucus vesiculosus* var. *linearis* (and / or fucoid sporelings). Period 2010 to 2011 differs from the other barnacle dominated periods in that fucoids were conspicuous in 2010 (but not 2011) but in lower abundance than found in the 2008 to 2009 with 2017 to 2019 period. (See Figure 70).

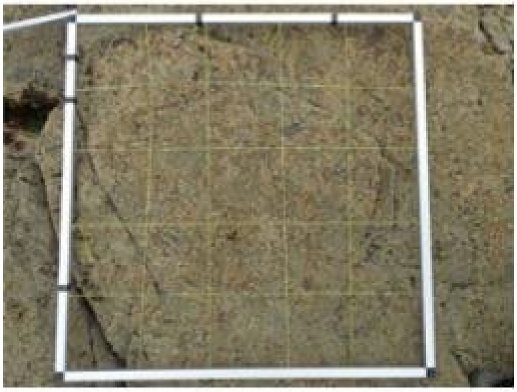
The average dissimilarity between each period was low (<50% in each case). For each period, the species are listed in ranked order in Table 17, with those contributing the most to the dissimilarity at the top of the list. There were a lot of species in common between the periods and the main dissimilarity between groups was related to differences in abundances.

Figure 70. Photos to illustrate the four periods recognised in Nolton Haven MS following MDS analysis (see Figure 69). Three of the periods are barnacle dominated and differ in the abundance of associated species (see Table 17).



Period 2007
(photo MS Q2 2007)

Period 2008 to 2009
with 2017 to 2019
(photo MS Q2 2019)



Period 2012 to 2016
(photo. MS Q2 2015)

Period 2010 to 2011
(photo MS Q2 2011)

Table 16. Results of SIMPER test to show a calculation of the average similarity of the species abundance (frequency) data from Nolton Haven MS between 2007 and 2019 with four periods: 2007, 2010 to 2011, 2012 to 2016 and 2008 to 2009 with 2017 to 2019.

Group 07 Average similarity: 90.04

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Cirripedia all except P. perforatus	5	13.7	30.65	15.22	15.22
Gastropoda small in crevices	5	13.7	30.65	15.22	30.44
Mytilus edulis	5	13.7	30.65	15.22	45.66
Patella	5	13.7	30.65	15.22	60.87
Ulva tubular	5	13.7	30.65	15.22	76.09

Group 08-09&17-19 Average similarity: 79.80

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Cirripedia all except P. perforatus	5	11.31	8.05	14.18	14.18
Mytilus edulis	5	11.31	8.05	14.18	28.36
Patella	5	11.31	8.05	14.18	42.53
Fucus vesiculosus var. linearis	4.98	11.22	8.03	14.07	56.6
Elachista fucicola	4.78	10.4	7.34	13.03	69.63
Steromphala umbilicalis	2.72	5.28	4.29	6.62	76.25

Group 10-11 Average similarity: 77.04

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Cirripedia all except *P. perforatus*	5	21.69	8.86	28.15	28.15
Patella	5	21.69	8.86	28.15	56.3
Ralfsia verrucosa	*3.53*	*12.41*	*4.27*	*16.11*	*72.42*

Group 12-16 Average similarity: 80.18

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Cirripedia all except *P. perforatus*	5	14.92	14.05	18.61	18.61
Patella	5	14.92	14.05	18.61	37.21
Gastropoda small in crevices	4.9	14.27	8.1	17.79	55
Mytilus edulis	4.82	13.91	9.46	17.35	72.35

Table 17. Results of SIMPER test to show a calculation of the dissimilarity of the species abundance (frequency) data from Nolton Haven MS between 2007 and 2019 with four periods: 2007, 2010 to 2011, 2012 to 2016 and 2008 to 2009 with 2017 to 2019.

Groups 08-09&17-19 & 10-11 Average dissimilarity = 43.69

Species	Group 08-09 & 17-19 Av. Abundance	Group 10-11 Av. Abundance	Av.Diss	Diss/SD	Contrib %	Cum.%
Elachista fucicola	4.78	0	7.11	7.13	16.27	16.27
Fucus vesiculosus var. *linearis*	4.98	1.07	5.92	2.43	13.55	29.82
Mytilus edulis	5	1.26	5.54	2.72	12.68	42.5
Fucus sporelings	1.93	1.58	3.22	1.86	7.38	49.88
Gastropoda small in crevices	2.58	3.1	3.17	1.42	7.27	57.14
Littorina obtusata / fabalis	2.03	0.13	2.8	1.25	6.41	63.55
Ulva tubular	1.87	0	2.72	1.17	6.22	69.77
Steromphala umbilicalis	2.72	1.02	2.57	1.75	5.88	75.65

Groups 08-09&17-19 & 12-16 Average dissimilarity = 33.07

Species	Group 08-09 & 17-19 Av. Abundance	Group 12-16 Av. Abundance	Av.Diss	Diss/SD	Contrib%	Cum.%
Elachista fucicola	4.78	0	6.15	8.26	18.59	18.59
Gastropoda small in crevices	2.58	4.9	3.19	1.12	9.65	28.23
Fucus vesiculosus var. *linearis*	4.98	2.52	3.14	1.74	9.49	37.72
Fucus sporelings	1.93	2.02	2.98	1.08	9	46.72
Steromphala umbilicalis	2.72	0.47	2.9	2.5	8.78	55.5
Ralfsia verrucosa	3.06	3.04	2.39	1.18	7.22	62.72
Littorina obtusata / fabalis	2.03	0.2	2.38	1.27	7.21	69.93
Ulva tubular	1.87	1.27	1.9	1.23	5.74	75.68

Groups 10-11 & 12-16 Average dissimilarity = 32.58

Species	Group 10-11 Av. Abundance	Group 12-16 Av. Abundance	Av.Diss	Diss/SD	Contrib%	Cum.%
Mytilus edulis	1.26	4.82	6.24	2.65	19.15	19.15
Fucus vesiculosus var. *linearis*	1.07	2.52	3.69	1.4	11.33	30.48
Fucus sporelings	1.58	2.02	3.56	1.59	10.92	41.4
Gastropoda small in crevices	3.1	4.9	3.38	1.35	10.39	51.79
Corallinaceae crusts	0	1.67	2.93	1.68	8.99	60.78
Ralfsia verrucosa	3.53	3.04	2.7	1.23	8.29	69.07
Ulva tubular	0	1.27	2.22	1.41	6.81	75.87

Groups 08-09&17-19 & 07 Average dissimilarity = 41.11

Species	Group 08-09 & 17-19 Av. Abundance	Group 07 Av. Abundance	Av.Diss	Diss/SD	Contrib%	Cum.%
Fucus vesiculosus var. *linearis*	4.98	0	6.18	9.81	15.03	15.03
Elachista fucicola	4.78	0	5.92	8.94	14.4	29.43
Ulva tubular	1.87	5	3.93	1.83	9.57	39
Fucus sporelings	1.93	4.26	3.69	1.46	8.97	47.97
Ralfsia verrucosa	3.06	0	3.64	1.84	8.86	56.83
Gastropoda small in crevices	2.58	5	3.1	1.11	7.54	64.37
Steromphala umbilicalis	2.72	0.25	3.06	3.13	7.45	71.82

Groups 10-11 & 07 Average dissimilarity = 42.27

Species	Group 10-11 Av. Abundance	Group 07 Av. Abundance	Av.Diss	Diss/SD	Contrib %	Cum. %
Ulva tubular	0	5	8.4	13.68	19.87	19.87
Mytilus edulis	1.26	5	6.24	2.86	14.75	34.62
Ralfsia verrucosa	3.53	0	5.86	3.95	13.87	48.49
Fucus sporelings	1.58	4.26	4.54	2.04	10.74	59.23
Gastropoda small in crevices	3.1	5	3.28	1.34	7.77	67
Bangiales bladed	0	1.42	2.37	1.42	5.6	72.59

Groups 12-16 & 07 Average dissimilarity = 29.98

Species	Group 12-16 Av. Abundance	Group 07 Av. Abundance	Av.Diss	Diss/SD	Contrib %	Cum. %
Ulva tubular	1.27	5	5.35	3.88	17.84	17.84
Ralfsia verrucosa	3.04	0	4.3	1.92	14.34	32.18
Fucus sporelings	2.02	4.26	3.82	1.43	12.73	44.91
Fucus vesiculosus var. *linearis*	2.52	0	3.64	1.75	12.14	57.05
Bangiales bladed	0	1.42	2.01	1.44	6.72	63.77
Nucella lapillus	0.57	1.75	1.78	1.91	5.95	69.72
Steromphala cineraria	0	1.06	1.5	1.71	5.02	74.74

3.23. Nolton Haven LS

The results of data analyses for Nolton Haven LS are summarised below.

3.23.1 Visual change

Obvious visual changes have been recorded in the LS at Nolton Haven over the years, mainly in the degree of cover of *Fucus vesiculosus* var. *linearis*, barnacles (including *Perforatus perforatus*) and *Mytilus edulis*. These changes are illustrated in a contextual view of the shore comparing 2007 and 2011 in Figure 71 and views of a quadrat (LS Q4) over the years of the study in Figure 72 and Figure 73.

The percentage cover of *F. vesiculosus*, barnacles and *M. edulis* was estimated from the photographs of LS Q4 shown in Figure 72 and Figure 73 and is shown plotted graphically in Figure 74. Although there may be an inverse correlation between cover of *M. edulis* and barnacles, it is not straightforward and in many of the years there are large patches of bare rock in the quadrat.

Figure 71. Photos of the LS monitoring site at Nolton Haven in 2007 and 2011 illustrating changes that have taken place over time.

LS contextural 2007

LS contextural 2011

Figure 72. Photographs of the LS Q4 monitoring quadrat at Nolton Haven each year from 2007 to 2014.

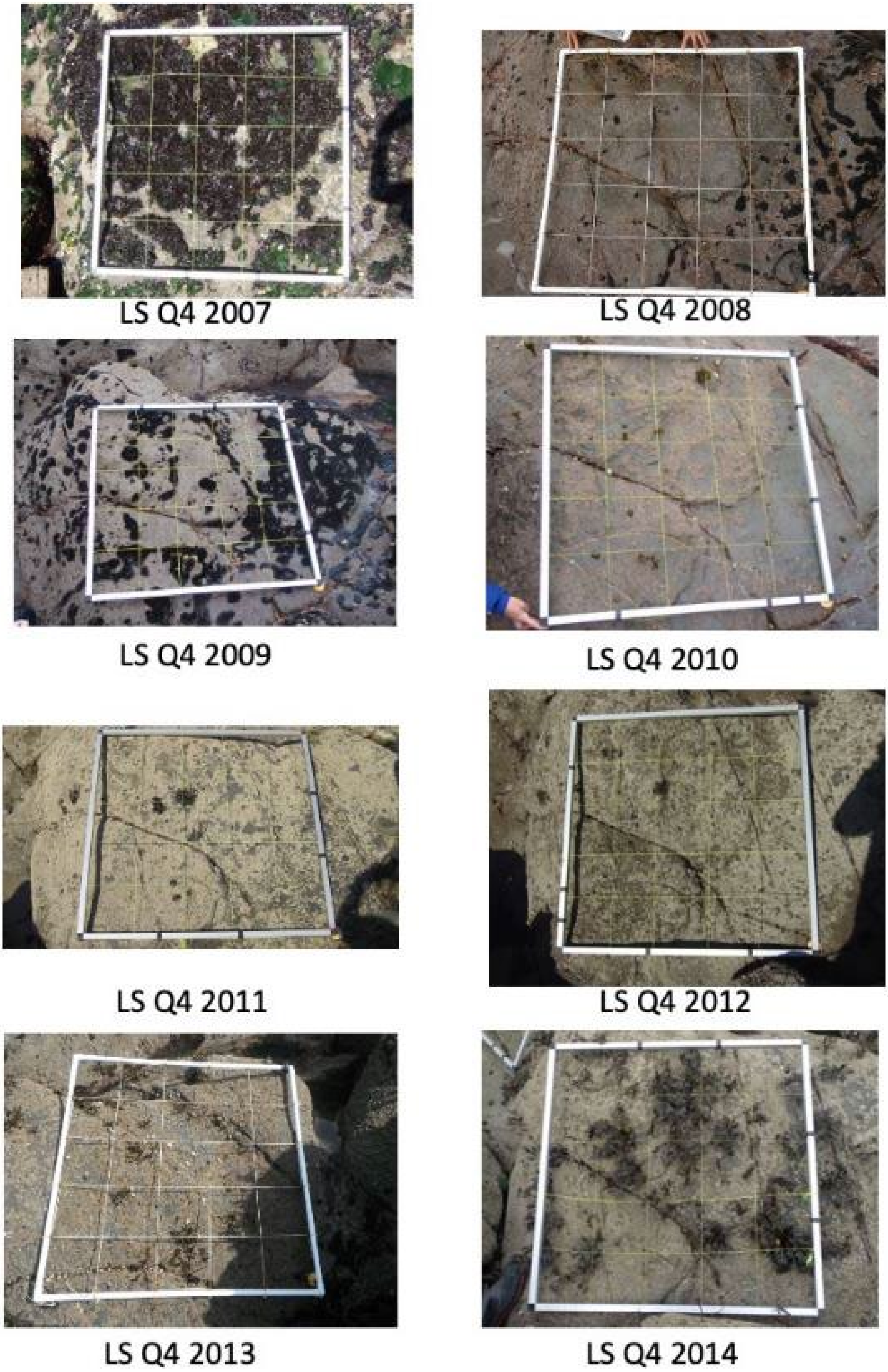


Figure 73. Photographs of the LS Q4 monitoring quadrat at Nolton Haven each year between 2015 and 2019.

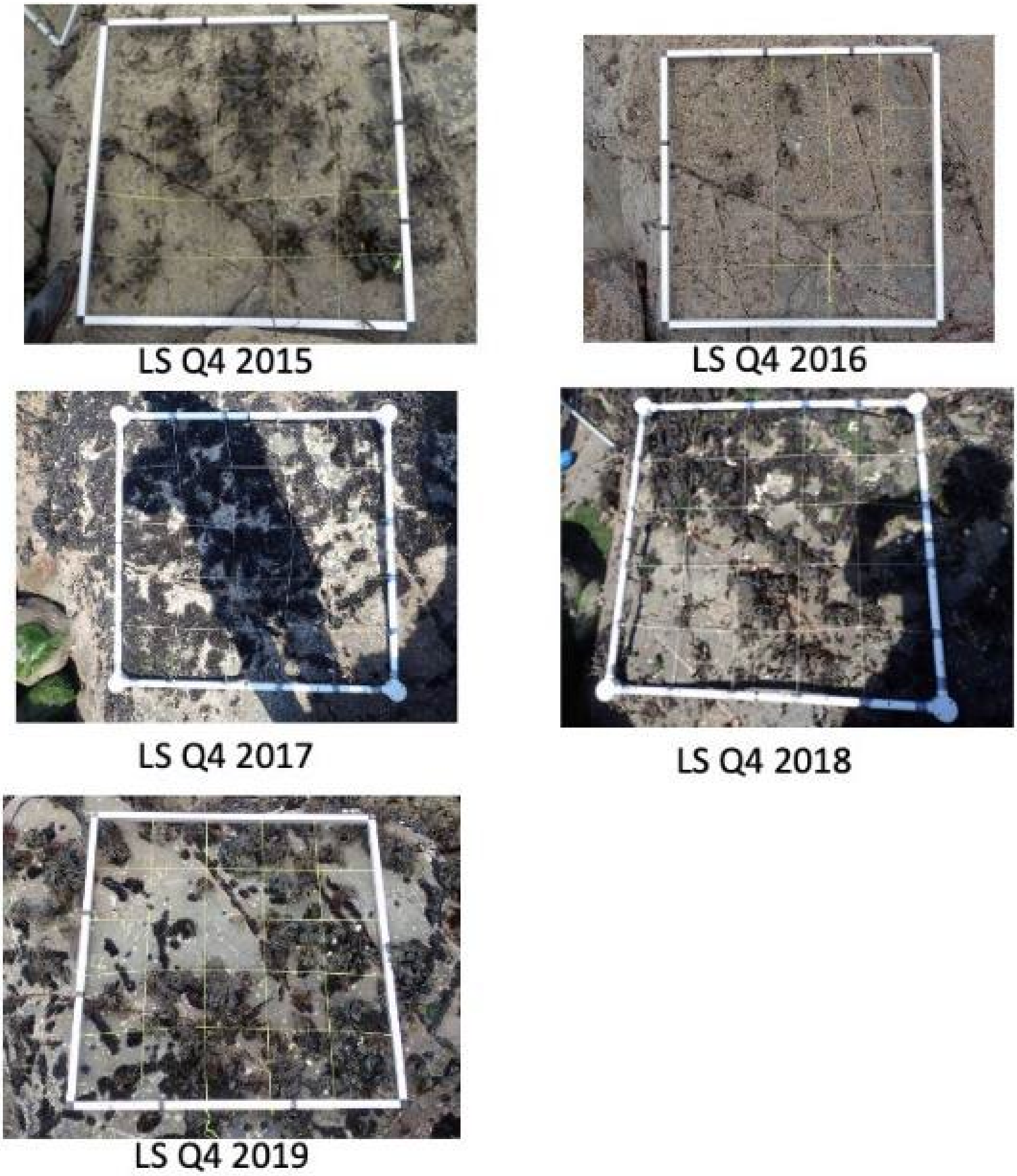
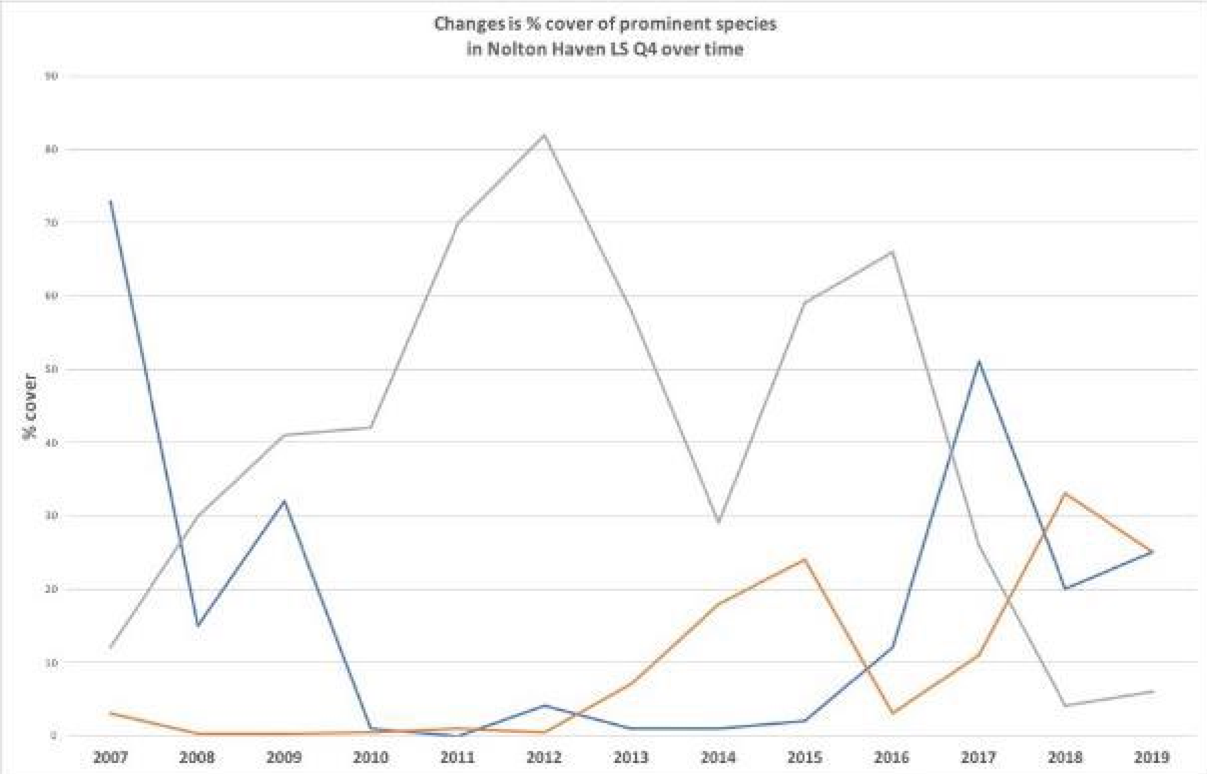
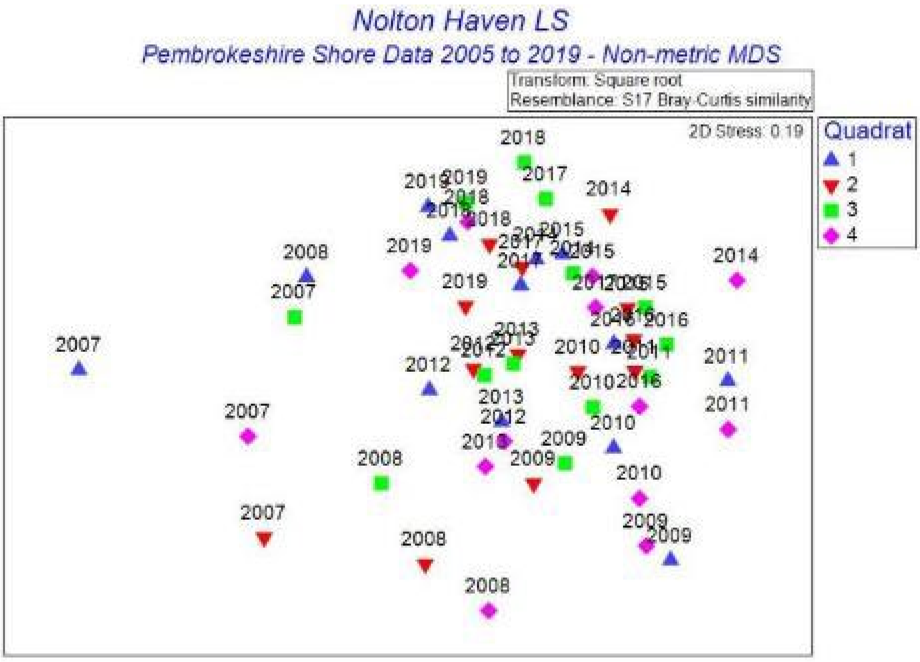


Figure 74. Percentage cover of *Fucus vesiculosus* var. *linearis* (orange line), *Mytilus edulis* (blue line) and barnacles (grey line) estimated from the photographs of Nolton Haven LS Q4 as shown in Figure 72 and Figure 73.



3.23.2 Multidimensional scaling (MDS)

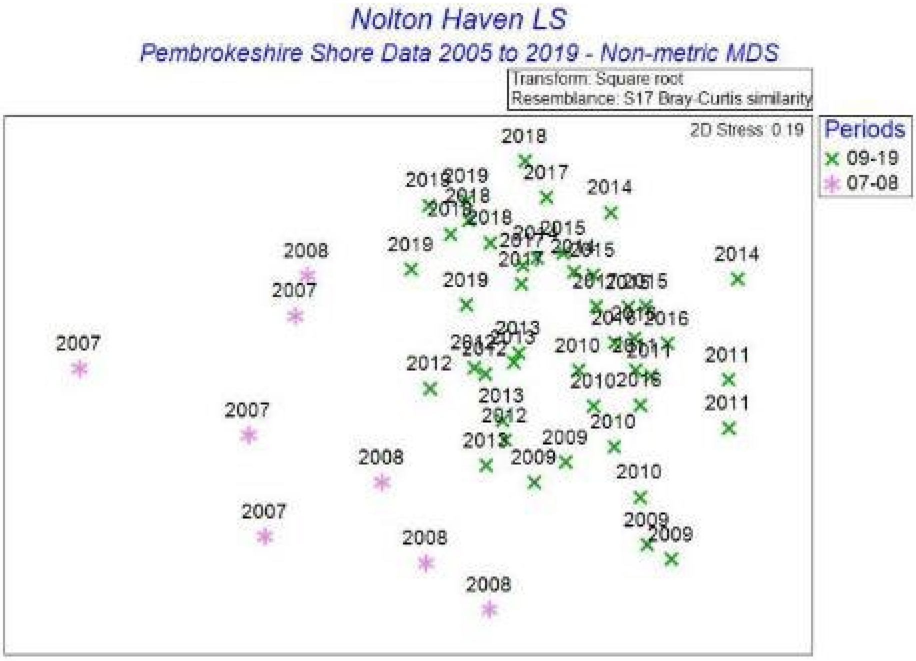
Figure 75. A non-metric MDS plots showing the data for all taxa (for which frequency was recorded) in all quadrats in Nolton Haven LS between 2007 and 2019



An MDS plot presenting the data for all taxa recorded in the LS quadrats are shown in Figure 75 and Figure 76. The stress is low (below 0.2) suggesting there is a good fit of the data to the two-dimensional plot generated. The MDS plot shows the data falling into two main groups or periods: 2007 to 2008 and 2009 to 2019. This can be seen clearly in Figure 76.

This would seem to contradict the suggested groupings shown in Figure 74, where 2007 to 2009 plus 2016 would appear to be largely *Mytilus edulis* dominated, 2010 to 2013 barnacle dominated and 2014 to 2015 plus 2017 and 2018 have a higher density of *Fucus vesiculosus* var. *linearis*. This difference is due to the limited power of discrimination of dominant species using the cell frequency method, which may record present in 25 cells, whether the percentage cover is, for example 10% (widely distributed across all cells) or approaching 100%.

Figure 76. A non-metric MDS plot showing the data for all taxa (for which frequency was recorded) in all quadrats in Nolton Haven LS between 2007 and 2019, with two periods; 2007 to 2008 and 2009 to 2019.



3.23.3 Analysis of similarity percentages (SIMPER)

A SIMPER analysis of Nolton Haven LS quadrat data was undertaken to determine which species characterised the different 'periods' which separated out in the MDS plot (Figure 76). The results of the SIMPER analysis are summarised in Table 18.

The average similarity of the data in each of the two periods was high. The species in each period are listed in Table 16 and ranked with those contributing the most to the similarity at the top of the list. *Mytilus edulis* and Cirripedia (all except *Perforatus perforatus*) were the most frequent species both periods.

The 2007 to 2008 period separated out from the 2009 to 2019 period due to differences in abundance of common species, rather than changes of species (see Table 18).

Table 18. Results of SIMPER test to show a calculation of the average similarity and dissimilarity of the species abundance (frequency) data from Nolton Haven LS between 2007 and 2019 with two periods: 2007 to 2009 and 2010 to 2019.

Group 07-08 Average similarity: 67.46

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Mytilus edulis	5	12.62	7.51	18.7	18.7
Cirripedia all except *P. perforatus*	4.94	12.3	7.86	18.23	36.93
Patella	4.3	9.35	3.4	13.86	50.79
Nucella lapillus	3.08	6.69	3.04	9.92	60.71
Fucus vesiculosus var. *linearis*	2.98	5.38	1.99	7.97	68.68
Bangiales bladed	2.93	4.73	1.01	7.01	75.69

Group 09-19 Average similarity: 72.70

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Cirripedia all except P. perforatus	5	9.61	6.51	13.22	13.22
Mytilus edulis	4.97	9.51	6.25	13.08	26.3
Patella	4.96	9.49	6.09	13.06	39.35
Ralfsia verrucosa	3.9	6.53	4.1	8.99	48.34
Perforatus perforatus	3.59	5.8	3.34	7.98	56.32
Ulva tubular	3.31	4.95	2.83	6.82	63.14
Nucella lapillus	3.07	4.45	1.91	6.12	69.26
Fucus vesiculosus var. *linearis*	3.26	4.17	1.49	5.73	74.99

Groups 07-08 & 09-19 Average dissimilarity = 38.76

Species	Group 07-08 Av.Abund	Group 09-19 Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Ralfsia verrucosa	0.5	3.9	3.73	2.66	9.61	9.61
Ulva tubular	0.56	3.31	3.28	2.48	8.47	18.08
Bangiales bladed	2.93	0.6	2.95	1.44	7.62	25.7
Fucus sporelings	0	2.57	2.77	1.49	7.14	32.84
Elachista fucicola	2.02	1.73	2.3	1.2	5.94	38.78
Fucus vesiculosus var. *linearis*	2.98	3.26	1.92	1.34	4.95	43.73
Perforatus perforatus	2.35	3.59	1.83	1.22	4.73	48.47
Gastropoda small in crevices	0.3	1.76	1.8	0.94	4.65	53.11
Corallinaceae crusts	2.73	2.38	1.59	1.17	4.1	57.22
Palmaria palmata	1.3	1.23	1.5	1.25	3.87	61.09
Osmundea pinnatifida	0.46	1.56	1.48	1.45	3.83	64.92
Nucella lapillus	3.08	3.07	1.27	1.16	3.27	68.19
Ulva flat	0.92	0.69	1.22	0.99	3.15	71.34

4. Discussion

The steep environmental gradient that occurs from the top to the bottom of the shore allows for different communities to develop in the each of the upper, middle and lower zones. Also, different communities develop on the different shores in this study, with primary environmental drivers including exposure to wave action and salinity, see Lewis (1964). The shores chosen for this study range from the sheltered low salinity shore of Lawrenny Quay to the exposed open coast of Nolton Haven. The difference and similarities between the shores and zones were examined in detail in Bunker and Brazier (2013). The marked separation between the zones, even within a single shore, makes it sensible to consider the data for each zone as a whole.

Much data (including photographs) have been collected during the 15 years of this monitoring study. This report concentrates on the frequency data collected at the monitoring sites and observations from examining the photographs.

Collating the frequency data in a form suitable for PRIMER analyses and cataloguing the photographs has been a very time consuming business. In comparison, the actual analyses carried out for this report, have been rapid. Only basic multivariate tests have been used here and further analyses are possible. However, it is believed that the current suite of tests used here is sufficient to tease out long term changes and trends to be able to assess the site condition. The photographs have assisted with data interpretation and have been particularly useful in highlighting visual change that is not obvious from the frequency data, particularly regarding cover of conspicuous species.

Some data have not been considered here. The species ‘presence / absence’ data from the quadrats was not analysed but in future could give an indication of change in species composition and / or diversity over time.

The limpet counts and measurements are not considered here, nor the barnacle percentage cover data, nor the proportion of the different barnacle species (obtained from photograph quadrats). Limpets and barnacles are some of the most numerous and important species on rocky shores and how they change over time is of fundamental importance to the communities. These data should be analysed and reported in a future document.

Other data not considered here are those of the *Ascophyllum nodosum* age structure at Lawrenny Quay. Again, these data are analysed and will be reported in a future (Mercer in prep).

The results from each site are discussed in the following sections and there is a summary table reporting on site condition in section 4.9.

4.1. Lawrenny Quay

Lawrenny Quay is the most sheltered shore studied in the PMS monitoring series. The communities here (particularly in the MS and LS) are very silted and different to the other monitoring stations.

4.1.1 Lawrenny Quay US

Similar changes in the abundance of *Pelvetia canaliculata* recorded at Lawrenny Quay (see Section 3.1) have been recorded at the other US sites (especially Pembroke Ferry, Hazelbeach, Pembroke Power Station and South Hook.

Morrell (2014) recorded increases and decreases of *P. canaliculata* cover at two sites around Dale Fort Field Centre which have been monitored since 1996. At one site there was a strong inverse correlation with the grazing snail, *Littorina saxatilis* but not at another site where similar increases and decreases in *P. canaliculata* occurred. The thalli of *P. canaliculata* are known to live between two and five years (White 2008) and it is thought probable that the changes in *P. canaliculata* cover could be due to dense old and bushy large thalli dying off over time to be replaced with new settlements of small thalli. If this is the case, then the changes are part of a natural cycle and the fluctuations in density will continue in the future. This long term data set enables us to establish natural cycles and therefore makes it particularly useful as a tool when looking for anthropogenic change.

4.1.2 Lawrenny Quay MS

The dense cover of *Ascophyllum nodosum* at Lawrenny Quay is of interest because this site is the only one in the series where it is currently abundant.

Surveying the MS monitoring quadrats requires extra care so as not to dislodge the long strands of *Ascophyllum nodosum*. A gentle saltwater spray is used to clean silt off the rock making small species visible for recording (e.g. encrusting Corallinaceae, *Gelidium pusillum*, *Ceramium deslongchampsii* and encrusting bryozoa). A torch is necessary when searching for species under the dense seaweed canopy and in crevices. There is difficulty accurately counting littorinids (which drop off the fucoids) and also epibiota such as Spirorbinae and hydroids which grow on the fronds and are part of the *A. nodosum* community.

Borges *et al.* (2020) discusses the importance of *Ascophyllum nodosum* and describes it as a structuring species with high ecological importance and economic applications supporting a network of trophic interactions between a diversity of organisms such as crustaceans, gastropods and isopods.

Watt and Scrosati (2013) found how in the US and MS, a low canopy cover of seaweed had fewer species than habitats with a high canopy cover, and the species that occurred in both situations were generally less abundant under a low canopy cover. It was concluded that canopies seem to enhance the performance of most understory algae and invertebrates on the shore and greatly influence benthic community structure.

Pocklington *et al.* (2019) studied seaweed canopy cover in temperate areas of New Zealand and emphasised the importance of algal cover in determining whole community composition, describing the species involved as ‘ecosystem engineers. *Ascophyllum nodosum* at Lawrenny Quay is an ecosystem engineer with its own distinct community composition. The suite of gastropods, epiphytes and silt and shade tolerant species living beneath the canopy are not present in adjacent areas of limpet and barnacle dominated grazed rock without cover (see Figure 8 and Figure 77).

Figure 77. Photographs to illustrate some of the species associated with the *Ascophyllum* canopy in the MS at Lawrenny Quay

Hildenbrandia sp. under the canopy in the MS

Hymeniacidon perlevis in the MS and silted growths of *Ceramium deslongchampsii*

Ulva pseudocurvata, Dynamena pumila and Flustrellidra hispida on *Ascophyllum* in the MS

Clava multicornis on *Ascophyllum* in the MS

Small thalli of *Ascophyllum nodosum* settled In the MS under the canopy.

Crustose coralline algae and *Littorina obtusata / fabalis* in the MS

The global distribution of *Ascophyllum nodosum* is restricted to the temperate north Atlantic. In the north east Atlantic, it occurs from Northern Norway and the White Sea to the North of Portugal (Viana *et al.* 2014). *A. nodosum* often dominates the middle zone of sheltered rocky shores. It is dioecious and a long-lived slow growing species (Baardseth 1970; Aberg 1992) which shows reproductive constraints including low recruitment rate and dispersal potential (Petraitis & Dudgeon 2015).

Ascophyllum nodosum is considered to be a species susceptible to loss due to climate change (Davies *et al.* 2007). Yesson *et al.* (2015) considered changes in the abundance of large brown seaweeds in the British Isles over four decades (1974 to 2010). Analysis of the data sets found no significant changes in abundance for *A. nodosum* in the south of the British Isles, although an insignificant decline was seen in western Scotland and a significant increase in NE England. At the south of the range for *A. nodosum* in northern Portugal, Borges *et al.* (2020) considered populations at the south of their range to be not viable for harvesting and at risk from climate change. Menge *et al.* (2017) states how a decline of the *A. nodosum* community has been documented along the New England coast, particularly in the south and how this has been correlated with climate change.

The monitoring of the *A. nodosum* populations at Lawrenny Quay and Milford Haven as a whole is an important aspect of this current study program. Photographs of the MS monitoring area at Lawrenny Quay show a decline in *A. nodosum* on the west side of the reef (see Figure 7 and Figure 8). In 2005, MS Q1 was covered in *A. nodosum* but this cover has been steadily lost and the rock of MS Q1 is now limpet barnacle dominated with little *A. nodosum*.

Views of the MS reefs north of Lawrenny quay show a similar pattern of bare areas devoid of *Ascophyllum nodosum* on the outer edges. It could be that the MS habitat is now changing from *A. nodosum* dominated to limpet and barnacle dominated (see Figure 78).

Figure 78. View north from monitoring area to show grazed rock areas in the MS (highlighted with red arrows), otherwise covered by *Ascophyllum nodosum*, September 2018.

A study of aerial photographs from Strangford Lough, Northern Ireland (Davies *et al.* 2007) indicated a decline in cover of sheltered shores by *Ascophyllum nodosum* over 44 years, resulting in a change to barnacle covered rock. This change was accompanied by increases in limpet densities since the 1980's and an increase in rate of cover by barnacles since 1990. Several studies have shown that high densities of limpets prevent the development of algal canopies due to their grazing activities, e.g. (Hawkins & Hartnoll 1983). Davies *et al.* (2008) showed that high densities of limpets consumed more *A. nodosum* than low densities.

Davies *et al.* (2007) surmised that increases in limpet densities since the 1980's due to a series of mild winters has led to the decline of *Ascophyllum nodosum*. It is also postulated that climate change may have a role in causing canopy loss, not by direct effects on the growth of fucoids, but by increasing the severity of grazing through changes to limpet populations. Both *Patella vulgata* and *A. nodosum* are known to be strong regulators of rocky shore communities and disruption to either species can lead to major changes throughout the shore.

Menge *et al.* (2017) gives the findings of a 38 year study on an *Ascophyllum nodosum* dominated sheltered shore on the Maine coast. Experimental areas were completely cleared of *A. nodosum* and over a short period, the rock became colonised by *Fucus* species and barnacles. Despite the abundance of *A. nodosum* on adjacent rocky surfaces, settlement of new plants had not occurred after nearly four decades. Menge *et al.* (2017) suggest that the *A. nodosum* community and the *Fucus / barnacle* community exist as two stable ‘alternative states’ and that once lost, the *A. nodosum* would not return. Dudgeon *et al.* (2001) studied recruitment of *A. nodosum* at Swan Island on the Maine coast. They found that more than 50% of zygotes dispersed more than 6 m but that successful germination declined 40-fold after 2 m from their origin and even more than this further away. It is of concern that once *A. nodosum* cover has been lost from shores, it does not seem to return.

The author considers it likely that *Ascophyllum nodosum* was previously widespread in the middle shore areas of much of the Daugleddau and upper reaches of Milford Haven (between the Cleddau bridge and Milford Haven town). Currently, most of this sheltered shoreline of the Milford Haven and Daugleddau waterway is limpet barnacle dominated in the mid-shore (e.g. Pembroke Ferry, Hazelbeach and Pembroke Power Station monitoring stations) rather than fucoid dominated. It is probable that these sheltered shores are now existing in an ‘alternative stable state’ as described by Menge *et al.* (2017). It would be useful to source photographs of this shoreline from before 1960 and the arrival of the oil industry to gauge historic fucoid cover.

Precisely why *Ascophyllum nodosum* cover is lost is unclear. The possibility of climate change has been raised but other explanations should be considered. Trussell *et al.* (2017) explains how barnacles on rocky shores help in the development of fucoid communities by ameliorating desiccation stress, providing a substrate for settlement and spaces that give shelter to sporelings from herbivores. They showed how interactions between the common species, *Carcinus* maenas, *Littorina littorea, Nucella lapillus* and barnacles all affect the development of fucoids. Without *Carcinus* and *L. littorea*, *Nucella* reduced barnacle density by 62% and caused a 52% reduction in fucoid density, whereas *Nucella* had no measurable impact on either barnacle or fucoid density in the presence of *Carcinus* and *L. littorea. Nucella* foraging is thought to reduce fucoid density by incidentally removing fucoids that were attached to consumed barnacles. A disturbance in the food web could be another factor leading to community change.

A. nodosum breaks easily when trodden on or pulled. It is not thought that this could be a reason for its decline at Lawrenny Quay. Great care is taken by the surveyors and although a few strands do get broken (caught in the quadrat, or torn when lifted back to see the species underneath), the same treatment occurs in all 4 MS quadrats. If this was a factor in its decline the decline would likely be seen in all 4 quadrats. Also, it can be seen in Figure 78 that the ends of other rocky ridges are also bare of *A. nodosum.*

4.1.3 Lawrenny Quay LS

Differences between the 2005 data and subsequent data from the Lawrenny Quay LS were highlighted, and it is probable that in the first year of the survey, a full understanding of the species present had yet to be obtained, as fewer species were recorded than in subsequent years. The results show differences between the steeply sloping quadrats LS Q1 and LS Q2 and those in LS Q3 and LS Q4. This was only to be expected and the biota is visually different between these quadrat groups in the field, with more species being present on the steeper slopes, presumably because they are less prone to thick silt cover.

4.2. Pembroke Ferry

In 2014 a large oak tree collapsed over the shore onto the Pembroke Ferry monitoring area. By selectively removing some branches, continued monitoring of quadrats US Q1, Q3 and Q4 has been possible, but not US Q2. None of the MS or LS quadrats were directly impacted.

4.2.1 Pembroke Ferry US

There are few grazing molluscs in Pembroke Ferry US and algal cover is ubiquitous. Fluctuations in abundance of the different fucoids (see Figure 14) can be linked with their longevity, with *Pelvetia canaliculata* living between 2 and 5 years (White 2008) and *Fucus vesiculosus* living for 2 to 4 years (Kerser & Larson 1984).

Thalli of *Ascophyllum nodosum* in the upper shore appear to have changed little over the years of monitoring but this would be expected as it is a long-lived and slow growing species (Baardseth 1970; Aberg 1992).

The separation of the 2005 data from the rest of the data set (Sections 3.4.2 and Figure 17) is due to several species not being recorded in 2005, these include *Hildenbrandia*, Chlorophyta (film, fuzz or threads), *Rhodothamniella floridula*, *Fucus* sporelings, *Rhizoclonium riparium* and *Ulva* (tubular). As 2005 was the first year of monitoring, these species were probably overlooked. In summary, there have been no unexpected changes in the US of Pembroke Ferry.

4.2.2 Pembroke Ferry MS

Whereas little visual change was noted in Pembroke Ferry MS over the monitoring period, analysis of the quadrat data shows the data from the period 2005 to 2014 separated from the period 2015 to 2019 (Section 3.5.2). This data separation was largely the result of an increase in algae, particularly *Ulva* spp, diatom film and a decrease in *Mytilus edulis* from the 2005 to 2014 year-grouping to the 2007 to 2019 year-grouping (Section 3.4.2).

The increase in *Ulva* spp warrants further investigation, particularly relating this to possible changes to populations of the main grazer, *Patella vulgata*. Size and density data for *Patella vulgata* is currently awaiting analysis. The decrease in *Mytilus edulis* is in line with decrease in this species at the other monitoring sites in Milford Haven over the time period (Bunker 2015).

The grazed nature of many of the sheltered shores in Milford Haven were discussed in Section 3.2.2 and the current state of this shore is relevant to that discussion.

4.2.3 Pembroke Ferry LS

At many sites it is impossible to find enough uniform rock for four similar quadrats, and Pembroke Ferry LS is such a case. The dissected nature of the rock here is illustrated in Figure 21, which also shows photographs of LS Q2 and LS Q4.

The quadrat LS Q2 differs from the other quadrats, being very uneven and bearing growths of the large seaweeds *Fucus serratus* and *Palmaria palmata*. Analysis of the data shows LS Q2 to be an outlier in the quadrat series and the SIMPER data lists the main species accounting for this difference (Table 7. Results of SIMPER test to show a calculation of the dissimilarity of the species abundance (frequency) data from Pembroke Ferry LS between the two factor groups LS Q1, Q3 and Q4 and LS Q2.Table 7). Other than this difference between quadrats, no major changes over time have been found in Pembroke Ferry LS.

Two rarely recorded species have been found in Pembroke Ferry LS (see Figure 79), the fine green seaweed *Cladophora coelothrix*, Kützing, 1843 and the yellow springtail *Anurida thalassophila* (Bagnall 1939). Both these species were first recorded in 2016 and have been found each year since.

Figure 79. Photographs of two rarely recorded species found in Pembroke Ferry LS, the springtail *Anurida thalassophila* (approx. 2 mm long; photo F. Bunker) and the fine green alga *Cladophora coelothrix* (in amongst red algal species; clumps approx. 3-4 cm long; photo A. Bunker).

Anurida thalassophila at Pembroke Ferry LS

Cladophora coelothrix at Pembroke Ferry LS

4.3. Hazelbeach

Hazelbeach is a south facing sheltered shore with steep bedrock sloping from the supralittoral to the MS. The LS is gently sloping mixed substrata.

4.3.1 Hazelbeach US

Similar changes were noted in Hazelbeach US to those seen at Lawrenny Quay and Pembroke Ferry, where fucoid populations increased and decreased over time. For a discussion of these patterns see sections 4.1.1 and 4.2.1

4.3.2 Hazelbeach MS

Hazelbeach MS is barnacle dominated and heavily grazed by limpets and other molluscs, rather than seaweed dominated. This situation occurs on many of the sheltered shores of Milford Haven, and was discussed in sections 4.1.2 and 4.2.2.

The decline in *Mytilus edulis* over the monitoring period has been widespread at the Milford Haven monitoring sites and was discussed in Bunker (2015).

4.3.3 Hazelbeach LS

Unlike the other monitoring sites in this series, the LS stations at Hazelbeach are not physically marked and fixed, rather, the quadrat positions are measured out by tapes from the middle shore. This makes comparing photographs of the quadrats over time problematical. Figure 29 shows that the substrata in LS Q3 changed over the years and this may or may not be affecting the data. It is probable that the substrata is mobile, moving during winter storms. Despite that, the biota is fairly constant within year groupings.

Figure 80 shows the monitoring area and the shore below it. The monitoring area is on the boundary between the MS and LS and is poor in species compared with the true lower shore zone below. Non-native species such as *Undaria pinnatifida* and *Crepidula fornicata* together with rarely recorded native species such as *Chondracanthus teedei* occur below the monitoring area but (apart from the occasional *Crepidula fornicata*) are absent in the actual monitoring area.

It would be useful to establish some systematic recording for the zone below the monitoring area.

Figure 80. Photographs of Hazelbeach LS monitoring area, depicted by the red arrow in photograph a. Photograph b and c are typical views of the upper side of rocks with b being typical of the monitoring area and c being typical of the (darker) zone below.

4.4. Pembroke Power Station

Pembroke Power Station is a north facing shore with rocky substrata in the US and MS descending to mudflats in the lower shore and is adjacent to the Pembroke Power Station cooling water outfall pipe (Figure 81). A cooling water outfall was on stream at this site between 1972 and 1996 functioning for the old oil fired Pembroke Power Station. The cooling water function ceased in 1996 following the mothballing of the power station and resumed in 2011 following the opening of a new gas fired power station (the same year this monitoring commenced). Permitted emissions from the outfall are specified (Environment Agency 2011) and include chlorination by-products limited at 50 µg/l and ammonia.

A review on the impacts of anthropogenic stresses on intertidal communities by Crowe *et al.* (2000) reported that studies of rocky substrata exposed to thermal pollution were scarce. Also, that although there had been a few species related studies, there was little known about effects at a community level.

Figure 81. Foaming waste-water exiting the Pembroke Power Station cooling water outfall. (Date of photo 5th September 2012)

4.4.1 Pembroke Power Station US

A major change seen in the upper shore (and the adjacent MS area) is the decline in *Ascophyllum nodosum*. Most of the *Ascophyllum* on this shore occurs below the quadrats but some is (or has been) present in the quadrats (see Figure 34). The possible decline of *Ascophyllum* in Milford Haven generally has been discussed in Section 4.1.2 and it is probable that once this fucoid disappears, it will not return. It is possible that effluent from the outfall pipe is having a deleterious effect. A study of a cooling water outfall in Maine (Vadas *et al*. 1978 cited Crowe *et al.* 2000) demonstrated that *Fucus vesiculosus* and probably *Ascophyllum nodosum* declined rapidly and was detrimentally affected by thermal extremes and rapid diurnal fluctuations in temperature.

4.4.2 Pembroke Power Station MS

The SIMPER analysis of the quadrat monitoring data comparing 2011 to all the later years (2012 to 2019) showed changes in the occurrence and abundance of common shore species (see section 3.11.3). To interpret these changes, especially with possible relation to the outfall effluent is beyond the scope of this report.

A study in Swansea Docks (Naylor 1965) showed how the barnacles *Austrominius modestus* and *Balanus amphitrite* showed enhanced breeding in the thermally affected dock. In this study it was found that *Austrominius modestus* replaced *Balanus crenatus* (which failed to breed in the warm water).

The barnacle *Austrominius modestus* is abundant in the MS at the Pembroke Power Station monitoring site but information on changes in this species over time is currently unavailable[1].

The data show that the dogwhelk, *Nucella lapillus*, which was common at the start of the monitoring in 2011 has declined in abundance at the monitoring site but they do occur at the same height of the shore to the west (Anne Bunker personal communication).

Of interest at this location are records of small patches of *Cladophora coelothrix* in silty crevices in the MS and the presence of the non-native encrusting bryozoan *Watersipora subtorquata* in the outfall channel in the LS.

4.5. South Hook Point

South Hook Point is a south west facing shore, exposed to the open entrance of the Milford Haven Waterway, but has some protection from St Anne's Head and the Angle Peninsula. Because of the nature of the shore, the monitoring quadrats in the three zones are all in different habitats. The US is situated on gently sloping south facing bedrock, the MS and LS are north facing on vertical bedrock, but LS has been periodically scoured by boulders in a surge gulley.

4.5.1 South Hook Point US

The pattern of declines and increases in cover of *Pelvetia canaliculata* has been discussed in section 4.1.1. Although similar patterns have been recorded at South Hook Point as at other sites, there is evidence (from photographs) of an overall decline of *Pelvetia canaliculata* at South Hook Point US, especially in recent years. The reasons for this are unknown.

4.5.2 South Hook Point MS

South Hook Point MS is barnacle dominated and heavily grazed by limpets and other molluscs, and is typical of steep semi-exposed rock in Milford Haven. The commonest barnacle species here is *Semibalanus balanoides.* Three other species also occur in lesser abundance: *Austrominius modestus, Chthamalus montagui* and *Chthamalus stellatus*. Photographs taken to ascertain the abundance of each species are yet to be analysed.

4.5.3 South Hook Point LS

The South Hook Point LS monitoring quadrats are on a steep bedrock wall of a surge gulley lined with boulders and smaller loose substrata. The loose material is mobile during storms and scours the gulley sides with scouring effects decreasing towards the mouth of the rocky gulley. LS Q1 to LS Q3 are the most scoured quadrats and LS Q4 is least scoured. This is illustrated in A SIMPER analysis compared LS Q1 to LS Q3 with LS Q4 (section 3.14.3) and found these two quadrat groups to have a dissimilarity of only 36.77%, the main difference being that most species were more

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[1] The data are held by NRW but hasn't been analysed at the time of writing

abundant in LS Q4 than in the other quadrats. It is suggested that this difference is due to scour.

Figure 82 and Figure 83.

A SIMPER analysis compared LS Q1 to LS Q3 with LS Q4 (section 3.14.3) and found these two quadrat groups to have a dissimilarity of only 36.77%, the main difference being that most species were more abundant in LS Q4 than in the other quadrats. It is suggested that this difference is due to scour.

Figure 82. Panoramic view of SH LS monitoring area showing LS Q1 to left and LS Q4 to the right. This illustrates how the degree of scouring decreases to the right with more foliose algae present. (Date 11th September 2018).

The less scoured bedrock towards the gulley entrance has well developed communities of algae, including sometimes dense growths of *Osmundea pinnatifida* in amongst which the non-native *Caulacanthus okamurae* has been found since 2010 (see Figure 83).

Figure 83. Dense growths of *Osmundea pinnatifida* towards the SH LS monitoring gulley entrance. Bright red growths of *Caulacanthus okamurae* can be seen amongst the turf (Date 1st September 2012).

4.6. Monk Haven

The Monk Haven monitoring site is on a south facing stretch of coast facing the entrance to Milford Haven. Some protection from the open sea is afforded by St Anne's Head and the Angle Peninsula. The monitoring quadrats on each shore zone are on slightly different habitats. The US is on large boulders (which don't appear to have moved during the course of this study). The MS and LS are on steeply sloping / vertical bedrock. During the course of the study, boulders in the LS have moved around, occasionally obscuring the quadrats and scouring the rocks. The amount that large boulders move around on this shore here and at South Hook Point was not known before this study and is a useful observation in understanding the dynamic nature of these shores. This lower shore monitoring area is not an ideal monitoring site and a recommendation to relocate it was implemented in 2020.

4.6.1 Monk Haven US

The population of *Pelvetia canaliculata* at Monk Haven US is sparse but appears to fluctuate in line with that seen on other shores (see discussion in section 4.1.1). Whether or not there is an overall decline as seen in South Hook Point is difficult to tell from the data but there is some indication that this may be the case.

4.6.2 Monk Haven MS

The data have shown little change within the Monk Haven MS monitoring quadrats over time. In order to properly assess this, the separate barnacle and limpet data requires analysis.

4.6.3 Monk Haven LS

As with the other zones at Monk Haven, LS has shown little change over time, apart from boulders periodically moving and scouring the site. The results of a SIMPER analysis showed that LS Q4 differed from the other quadrats due to slight changes in abundances of species, especially Verrucariaceae, Gastropods in small crevices and *Ralfsia verrucose*. It is probable that boulder scouring is the main reason for the differences.

Figure 84. Monk Haven LS monitoring area showing LS Q1 (left) and LS Q4 (right). The boulders which move and scour (particularly the lower part) of the quadrats can be seen. No boulders obscured the quadrats in 2018. (Date of photo 12th September 2018).

4.7. West Angle Bay

The communities in the monitoring areas on the south side of West Angle Bay have changed little over time. Photographs of the site in 2005 and 2015 showing the location of the monitoring stations in the US, MS and LS are shown in Figure 85.

4.7.1 West Angle Bay US

The monitoring quadrats in the US of West Angle Bay are situated on steep north facing limestone with very few crevices. The zone is species poor and grazed by the common shore gastropods (mainly *Patella vulgata*, *Littorina saxatilis*, *Littorina compressa* and *Melarhaphe neritoides*) that live there. It is probable that these grazers prevent an algal turf of *Pelvetia canaliculata* from becoming established.

4.7.2 West Angle Bay MS

Like the US of this site, the MS monitoring area of West Angle Bay is steep bedrock dominated by barnacles and common shore gastropods (mainly *Patella vulgata*, *Littorina saxatilis*, *Melarhaphe neritoides*). The topshell *Steromphala umbilicalis* is commonly found in crevices, together with other typical middle shore species such as the anemone *Actinia equina* and the dogwhelk *Nucella lapillus*. There are few algae present and the whole area is very grazed.

Four barnacle species are present with the most numerous being *Semibalanus balanoides* and *Austrominius modestus. Chthamalus montagui* and *Chthamalus stellatus* are present in low numbers. Photographs taken to ascertain the abundance of each species are yet to be analysed.

4.7.3 West Angle Bay LS

Figure 85. Photographs of the West Angle Bay monitoring areas in 2005 and 2015 for a comparison over time. *Osmundea pinnatifida* and *Palmaria palmata* can be seen to have increased in the lower shore (particularly below the LS monitoring area).

West Angle Bay monitoring area 2005

West Angle Bay monitoring area 2015

The communities in the lower shore monitoring area have changed little over the years, with the most obvious change being a probable cycle of growth and decline of the red alga *Osmundea pinnatifida* (see Figure 62). The rock in the LS here is dominated by barnacles and common shore gastropods (mainly *Patella* spp. and *Littorina saxatilis*) as well as *Osmundea pinnatifida*. Also present is the topshell *Steromphala umbilicalis* and the dogwhelk *Nucella lapillus*. Several species of algae can be found growing in amongst the *Osmundea pinnatifida* turf and in crevices including *Polysiphonia atlantica* and *Plocamium maggsiae.*

The real interest in West Angle Bay LS lies in the zone below the quadrats and it is recommended that a set of new quadrats be established below the existing ones.

4.8. Nolton Haven

Nolton Haven is situated on the open coast of St Bride’s Bay and is included in the monitoring series as a reference site to those in Milford Haven. The shore is a high energy site which is affected by some sand scour in the lower shore.

4.8.1 Nolton Haven US

There is overhanging rock above the US monitoring quadrats area and from time to time rocks fall and impact the site. In the winter of 2018 to 2019, a chunk of rock was displaced from Q4. Examination of the data shows little has changed in the community between 2007 and 2019 except for abundance of barnacles fluctuating over time.

4.8.2 Nolton Haven MS

Visual results from Nolton Haven gave a straightforward picture of a barnacle dominated community with settlement and growth of *Fucus vesiculosus* var. *linearis* followed by its disappearance after two or three years and a reappearance five years later. *F. vesiculosus* is known to live for two to four years and sometimes less on exposed shores (Kerser & Larson 1984). Why *F. vesiculosus* has periods in which it is virtually absent on the shore is not known. Analysis of the grazing limpet population data may give a clue to this.

4.8.3 Nolton Haven LS

The settlement patterns of *Fucus vesiculosus* var. *linearis* in the LS might be expected to mirror that seen in the MS but this hasn’t been the case. Nolton Haven LS is sand scoured which interrupts normal patterns of recruitment and growth. In some years the quadrats are quite populous (see LS Q4 2007 in Figure 72) in other years they have been quite barren (see LS Q4 2010 in Figure 72).

The habitat here seems to favour the barnacle *Perforatus perforatus.* The interstices between the sessile organisms (chiefly *P. perforatus* and other barnacles) provide an ideal habitat for juvenile *Mytilus edulis* and for *Nucella* and other small gastropods.

Figure 86. *Perforatus perforatus* in the LS of Nolton Haven showing settlement of juvenile *Mytilus edulis* (August 2007)

The frequency method of recording doesn't pick up the big changes in abundance of organisms that take place in the community (as seen in Figure 72, Figure 73 and Figure 74) e.g. the frequency of mussels can be 25 if there are thousands of juvenile mussels occurring in each of the 25 squares or just one adult in each square.

4.9. Summary and conclusions

The aims of this report (section 1.1) will now be reviewed.

To collate a 2005 to 2019 dataset suitable for multivariant analysis.

This time consuming work was completed and has resulted in a PRIMER file, the analysis of which provides the basis of this report. This file; "Pembrokeshire Marine SAC shore quadrat data 2005 to 2019.pwk" is available as an electronic appendix to this report.

To catalogue a set of photographs from the monitoring surveys of 2005 to 2019 and undertake visual analyses.

All the digital photographs (over 11,000 images) have been collated into Adobe Lightroom and labelled with keywords which have enabled easy and rapid sorting of images.

To present initial analyses of the quadrat data obtained from 2005 to 2019 designed to identify change and trends.

Basic multivariate analyses of the data have been carried out in PRIMER and are presented. Where change has been detected, this has been highlighted.

To discuss the results of the data analyses in terms of change and condition of the monitoring sites.

The trends and changes detected in the data (and from photographs) have been discussed and where possible related to published work.

Ultimately this report aims is to provide NRW with information to enable completion of a condition assessment of intertidal rocky reefs the Pembrokeshire Marine SAC and report to the UK government (European Commision 1994; Countryside Council for

Wales 2009). It is beyond the scope of this report to complete that condition assessment but rather to put forward the author's opinions on the status of the monitoring sites based on the analyses carried out. A summary of the author's assessment of the monitoring sites is given in Table 19.

Table 19. Table of concerns about the conservation status of each zone of the monitoring study shores in Pembrokeshire Marine SAC covered in this report.

US	MS	LS	Notes on site	Notes
Lawrenny Quay	No Concern	Of concern- decline in *Ascophyllum*	No Concern	Concern about decline of *Ascophyllum nodosum* in the middle shore. Also concern about prevalence of non-native species below the LS monitoring quadrats
Pembroke Ferry	No Concern	No Concern	No Concern	MS is probably in an altered state of being barnacle limpet dominated rather than Ascophyllum dominated
Hazelbeach	No Concern	No Concern	No Concern	MS is probably in an altered state of being barnacle limpet dominated ,rather than *Ascophyllum* dominated
Pembroke Power Station	Of concern decline in *Ascophyllum*	No Concern	N/A	*Ascophyllum nodosum* in disappearing from the US and the MS is probably in an altered state of being barnacle limpet dominated rather than *Ascophyllum* dominated
South Hook Point	No Concern	No Concern	Scoured	Possible concerns about decline in *Pelvetia canaliculata* in the US. Lower shore is a naturally scoured habitat so status is difficult to determine but there has been a decline in species and cover over time
Monk Haven	No Concern	No Concern	Scoured	Possible concerns about decline in *Pelvetia canaliculata* in the US. Current LS monitoring quadrats are too high on the shore to adequately represent the LS community and the area is affected by boulder scour
West Angle Bay	No Concern	No Concern	No Concern	Current LS monitoring quadrats are too high on the shore to adequately represent the algae rich LS Communities of the site
Nolton Haven	No Concern	No Concern	No Concern	Sand scour in the LS but this is a natural feature of the community

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Appendices

Appendix 1 Years where monitoring surveys have taken place

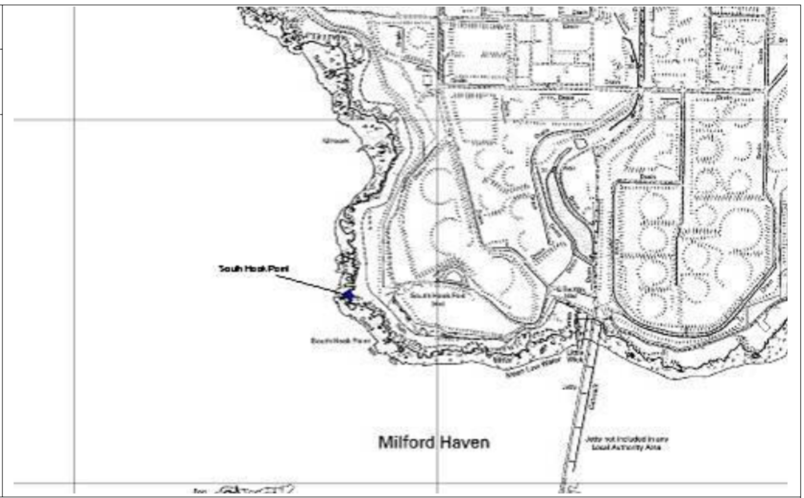
Table 20. Table to show years and rocky shore sites surveyed between 2005 and 2018. LQ = Lawrenny Quay, PF = Pembroke Ferry, HB = Hazelbeach, PP= Pembroke Power Station, SH = South Hook, MH = Monk Haven, WB = West Angle Bay, PH = Pen-y-holt and NH = Nolton Haven

	LQ	PF	HB	PP	SH	MH	WB	PH	NH
2005	✓	✓	✓	-	✓	✓	✓	-	-
2006	-	-	-	-	-	-	-	-	-
2007	✓	✓	✓	-	✓	✓	✓	✓	✓
2008	✓	✓	-	-	✓	✓	✓	-	✓
2009	✓	✓	✓	-	✓	✓	✓	✓	✓
2010	✓	✓	✓	-	✓	✓	✓	-	✓
2011	✓	✓	✓	✓	✓	-	✓	-	✓
2012	✓	✓	✓	✓	✓	✓	✓	-	✓
2013	✓	✓	✓	✓	✓	✓	✓	✓	✓
2014	✓	✓	✓	✓	✓	✓	✓	-	✓
2015	✓	✓	✓	✓	✓	✓	✓	-	✓
2016	✓	✓	✓	✓	✓	✓	✓	-	✓
2017	✓	✓	✓	✓	✓	✓	✓	✓	✓
2018	✓	✓	✓	✓	✓	✓	✓	-	✓
2019	✓	✓	✓	✓	✓	✓	✓	-	✓

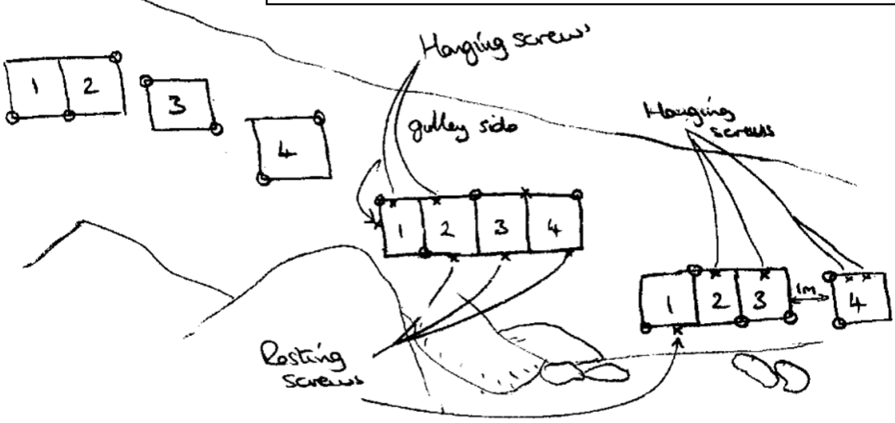
More details are given in the survey field diaries and data sheets, which are available on request.

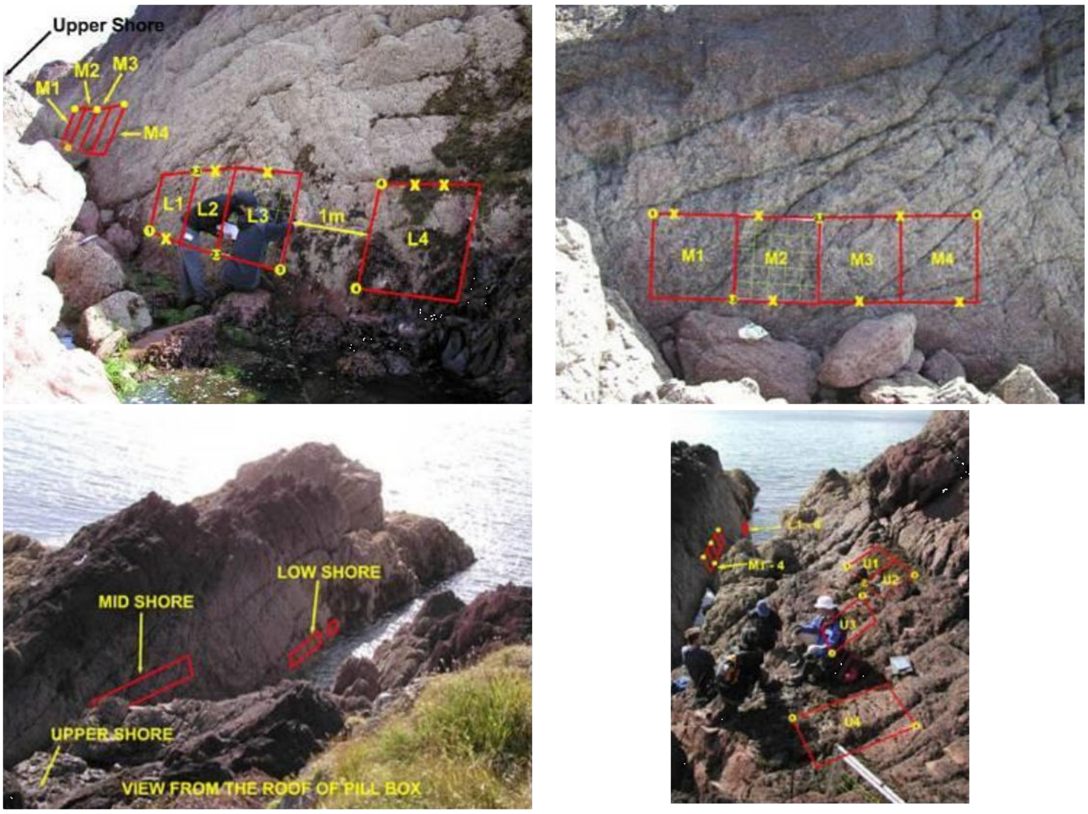
Appendix 2 Example of site location sheet for South Hook Point

South Hook Point site relocation sheets

Site: South Hook Point	
Grid Coords: 186753E 205518N	
Access: Walk down the fisherman's path, west of the Fort. A rough steep path leads down from the Pillbox. Follow the gully to the right.	
Quadrat Relocation: Upper shore quadrats: located within the *Pelvetia* zone the side of the gully. Mid shore quadrats: located down from and west of the upper shore, facing north (inland) Low shore quadrats: below the mid shore on the same gul ly side with barnacles, limpets and sparse a lgae. **SITE MAY NOT BE WORKABLE IN BAD WEATEHR CONDITIONS OR POOR TIDAL RANGES**	

KEY
U = upper shore M = mid shore L= lower shore ● = marker discs x = screws at corners of 1m² quac





KEY
U = upper shore M = mid shore L= lower shore ● = marker discs x = screws at corners of 1m² quadrats

Aquatic Survey and Monitoring Ltd. Thursday, August 15, 2019

Appendix 3 Site-specific monitoring recording protocols (from 2019)

General

- Black Verrucariaceae and green *Verrucaria* species can easily be mistaken for each other, particularly when the rock is wet. Note if this is a problem during the survey.
- Much grey lichen thin crust evident which disappears when surface wet. It is probably one of the *Verrucaria* species, so recorded as part of the *Verrucaria* black aggregate.
- Different coloured mites recorded in one category '*Acarina* (mites)'.
- When recording each species, check the form to ensure whether **frequency or presence / absence** should be recorded.
- Use a torch to scrutinise cracks and crevices when light is poor.
- Take limpet measurements at the same beach level as the monitoring quadrats. There are localised variabilities in limpet size, ensure that the habitat chosen is defined precisely.
- Take general contextual photos of each zone (including the quadrat area).
- Lichens boring into barnacles and limpets are counted as the same: *Collemopsidium* spp
- Brown encrusting algae on limpets is recorded as *Ralfsia* but it is recognised that other species may be present.
- The recorder should always read though the check list once the quadrat is finished. It's easy to miss common species e.g. *Patella* spp., Corallinaceae (crusts), Littorinids (small in crevices and dead barnacles) and Cirripedia.
- If the following genera are present, record an 'all species' count as a frequency score and compile a list of the species recording each as 'p' present: *Ceramium*, *Chaetomorpha*, *Gelidium*, *Corallina*.
- Record brown filamentous algae as Ectocarpales filamentous and record each species found as 'p' present.

Site Specific:

Lawrenny

- Ideally have 3 teams and 3 quadrats to survey the whole shore in one go. Alternatively use a team of 3 and survey the US and MS on one tide and LS on another.
- Barnacles are very silted. Record as Cirripedia indet. and list the species present as 'P'.

- US - Look out for the pseudoscorpion *Neobisium maritimum*
- US - Differentiate between *Bostrychia* and *Catenella* in the US
- US - Verrucariaceae green and black difficult to distinguish when dry or wet.

- MS and LS - Use a water spray to wash away silt from rocks prior to recording
- MS and LS - *Alcyonidium gelatinosum*, *mytili* and *A. polyoum* records are amalgamated as they cannot be distinguished reliably in the field unless reproductive. Record *A. diaphanum* separately.

- MS - Carefully part the *Ascophyllum* order to view the rocks below
- MS - Examine *Ascophyllum* for attached epiphytes e.g. *Clava multicornis*
- MS Barnacle photographs and limpet measures to be taken on the steep craggy rock immediately west of the mid shore quadrats.

- LS - Quadrats flood at 1.2 m which approximates to 1:15 hours after LW.
- LS - Look out for *Botrylloides violacea*
- LS - The small *Gelidium* is *Gelidium pusillum*
- LS - Record *Hildenbrandia* type and *Petrocelis* type red crusts as Rhodophyta – non calcareous red crusts
- LS - Record brown filamentous as Ectocarpaceae. If specimens are taken and species identified then these can be added to the record.

- LS – Take care not to dislodge plants of *Fucus serratus*
- LS – A variety of filamentous red algae grow as epiphytes on *Chondrus crispus*. Complete a frequency counts for Rhodophyta (filamentous on *Chondrus*) and take samples to get a presence species list.
- LS – Look out for specimens of the iridescent *Chondria caerulescens*

Pembroke Ferry

- This shore is steep - wear a life jacket
- Bring kneeling pads, gloves and bungees (for hanging quadrats)
- A torch is essential! It's very dark underneath the overhanging trees in the Upper Shore and in the lower shore overhangs. A torch also helps one see shiny *Diadumene* in empty barnacle shells.
- US and MS - Look out for the pseudoscorpion *Neobisium maritimum*
- US - Differentiate between *Bostrychia* and *Catenella* in the US
- US - It is difficult to differentiate between *Fucus vesiculosus* and *Fucus spiralis* as they probably hybridise. For the purposes of continuity, record as *F. spiralis*.
- US - the red crusts on the red rock in shade are difficult to see. Look carefully. Record as *Hildenbrandia*

- MS and LS - Check crevices and empty barnacles for *Diadumene lineata* using a torch
- MS and LS - red fuzz is *Aglaothamnion hookeri*. Take a bit from one quadrat and check (no need to do all).
- **MS - Do not walk up and down shore in the line of the quadrats or the quadrats get trampled**. Going around it is a pain but there are other routes.
- MS – Bring bungies to help hold quadrats in place.

- LS - Look carefully for small, maybe sparse turf of *Gelidium pusillum* on lower shore (it re-attaches to substratum).
- LS – Look for the resident population of a yellowish-white springtail *Friesea acuminata*.

Hazelbeach 2019

- Ideally need 4 people
- Note that US sketch looks west.
- Bring gloves as rocks and barnacles in steep areas can scratch the skin while surveying.
- Look out for *Littorina compressa* (mainly in US).

- MS - Note that the small rockpool below Quadrat 3 is not recorded within the quadrat. It contains various species not typical of the open rock e.g. *Bryopsis hypnoides*, *Ceramium virgatum* and *Anemonia viridis*.

- LS - Bring measuring tapes to locate the lower shore quadrats
- LS - Recording is only from above / beside the cobbles
- LS – Look out for Wakame *Undaria pinnatifida* (first recorded in 2018).

Pembroke Power Station 2019

- Four surveyors required with two quadrats
- Bring gloves, knee pads, bungees (may need a step ladder but debatable).
- Take care not to stand in one quadrat space when surveying another
- MS - Count out of 23 in Quadrat 1

- Inform Ben Williams of RWEn of date and time of survey

South Hook 2019

- US and MS - Look for *Hildenbrandia* in US and MS quadrats this can be difficult to see against the sandstone (use a torch to look in crevices).

- US - Upper shore quadrats span slopes dominated by *Pelvetia*. Care should be taken not to trample these when accessing the shore.
- US - When dry, small *Littorina* can be very hard to see in US quadrats.

- MS - Bring bungies to hang quadrats and a step ladder
- MS - There are patches of green stain on the middle shore rock face, do not confuse this with green *Verrucaria*.

- LS - is in a surge gulley and the tide will fill this very quickly. Although it is possible to work down with the tide, the LS quadrats should be surveyed at least 50 minutes before low water.
- LS - Check carefully whether or not the *Perforatus perforatus* barnacles you are recording are indeed alive as there are often empty shells present.
- LS - Record each *Corallina* species separately but also do a general frequency score for *Corallina* spp.

- Algal turf scrape taken from coralline pool in lower mid shore.

Monk Haven 2019

- Counting red crusts on the red sandstone rock is tricky. Do carefully and use a torch.
- LS - Quadrat 1 has sometimes been partially obscured by a boulder, reducing the number of cells to 20 (or less). If obscured.
- LS – Quadrat 4 is scoured.
- LS - Cobbles are not lifted to record under-cobble species.

- Algal turf scrape taken from coralline pool in lower mid shore.

West Angle Bay 2019

- US and MS - Bring bungies to hang quadrats.

- US - Look for *Hildenbrandia* in quadrats (use a torch).
- US - When dry, *Melarhaphe neritoides* can be very hard to see.

- LS - Quadrats should be started at least 50 minutes before low water to enable completion before the tide turns.
- LS - Check carefully whether or not the *Perforatus perforatus* barnacles you are recording are indeed alive as there are often empty shells present.
- LS - Record each *Corallina* species separately but also do a general frequency score for *Corallina* spp.
- LS – *Hildenbrandia crouanii* in Lower Shore

Nolton Haven 2019

- 2 quadrats required and ideally four surveyors (but 2 experienced surveyors and a good recorder can work).
- Bring gloves and knee pads.
- Take care not to stand in one quadrat space when surveying another
- MS – Possible confusion between *Hildenbrandia* and *Verrucaria* (black)

- LS - Sand scour and has proved very variable over time. This zone is only uncovered for a short period so it should be surveyed as soon as its uncovered.

- Algal turf scrape taken from coralline pool in lower mid shore.

Appendix 4 Example of site specific data recording sheet - Hazelbeach

Hazelbeach 2019 US

Recorders:

Conditions:

Date

			2019HBUS1	2019HBUS2	2019HBUS3	2019HBUS4
	Time start					
	Time finish					
	Photo Nos.					
ScientificName	**Species Qualifier**	**f / p**				
Cirripedia	all except P. perforatus	f				
Austrominius modestus		p				
Chthamalus montagui		p				
Ligia oceanica		p				
Gammaridae		p				
Gastropoda	small in crevices	f				
Littorina compressa		p				
Littorina littorea		f				
Littorina obtusata / fabalis		f				
Littorina saxatilis		p				
Patella		f				
Peringia ulvae		p				
Phorcus lineatus		f				
Catenella caespitosa		f				
Fucus (Fucaceae)	sporelings	f				
Fucus spiralis		f				
Hildenbrandia		f				
Pelvetia canaliculata		f				
Ulva	flat	f				
Ulva	tubular	f				
Caloplaca marina		f				
Collemopsidium		p				
Verrucariacae		f				
Verrucaria	black	p				
Verrucaria	green	p				

QA Date:
QA By;
Aquatic Survey and Monitoring Ltd.

Hazelbeach 2019 MS

Recorders:
Conditions:

Date

			2019HBMS1	2019HBMS2	2019HBMS3	2019HBMS4
	Time start					
	Time finish					
	Photo Nos.					
ScientificName	Species Qualifier	f / p				
Hymeniacidon perlevis		f				
Actinia equina		f				
Cereus pedunculatus		f				
Cirripedia	all except P. perforatus	f				
Austrominius modestus		p				
Chthamalus montagui		p				
Chthamalus stellatus		p				
Semibalanus balanoides		p				
Carcinus maenas		p				
Anurida maritima		p				
Patella	spp	f				
Phorcus lineatus		f				
Steromphala umbilicalis		f				
Lepidochiton ascellus		f				
Littorina obtusata / fabalis		f				
Littorina littorea		f				
Gastropoda	small in crevices	f				
Littorina saxatilis		p				
Nucella lappilus		f				
Mytilus edulis		f				
Catenella caespitosa		f				
Ceramium	all species	f				
Corallinaceae	crusts	f				
Gelidium pulchellum		f				
Osmundea pinnatifida		f				
Hildenbrandia		f				
Ralfsia verrucosa		f				
Rhodophyta	non calcareous red crusts	f				
Ulva	flat	f				
Fucus	sporelings	f				
Collemopsidium		p				
Verrucariacae		f				
Verrucaria	black	p				
Verrucaria	green	p				

QA Date:
QA By:
Aquatic Survey and Monitoring Ltd.

Hazelbeach 2019 LS

Recorders:
Conditions:

Date

			2019HBLS1	2019HBLS2	2019HBLS3	2019HBLS4
	Time start					
	Time finish					
	Photo Nos.					
ScientificName	**Species Qualifier**	***f* / p**				
Lanice conchilega		*f*				
Spirobranchus		*f*				
Cirripedia	all except P. perforatus	*f*				
Semibalanus balanoides		p				
Austrominius modestus		p				
Carcinus maenas		p				
Patella	spp	*f*				
Steromphala cineraria		*f*				
Steromphala umbilicalis		*f*				
Littorina obtusata/fabalis		*f*				
Littorina littorea		*f*				
Gastropoda	small in crevices	*f*				
Littorina saxatilis		p				
Nucella lapillus		*f*				
Crepidula fornicata		*f*				
Mytilus edulis		*f*				
Ascophyllum nodosum		*f*				
Corallinaceae	crusts	*f*				
Hildenbrandia		*f*				
Mastocarpus stellatus		*f*				
Mastocarpus stellatus	Petrocelis	*f*				
Osmundea hybrida		*f*				
Osmundea pinnatifida		*f*				
Ralfsia verrucosa		*f*				
Rhodophyta	non calcareous red crusts	*f*				
Collemopsidium		p				
Verrucariacae		*f*				
Verrucaria	black	p				
Verrucaria	green	p				

QA Date:
QA By:
Aquatic Survey and Monitoring Ltd.

Appendix 5 Limpet & Barnacle Recording Sheet

Pembrokeshire Marine SAC: Limpet and Barnacle Data

Site ………. Surveyors:…………… Date:…………….. Conditions?...

	U1	U2	U3	U4	M1	M2	M3	M4	L1	L2	L3	L4
Limpet counts												
(5 of 20 x 20 cm)												
Barnacle photos (5 x 25 cm^2) (✓ when done)												
Barnacle %												
(5 x 400 cm^2)												

Limpet measurements	**8**						**25**					
100-200 individuals	**9**						**26**					
Mid shore quadrats only	**10**						**27**					
	11						**28**					
Use tally method to count	**12**						**29**					
each size category (mm)	**13**						**30**					
	14						**31**					
	15						**32**					
	16						**33**					
	17											
	18											
	19											
	20											
	21											
	22											
	23											
	24											

Have you taken your rockpool scrapes? (tick here when done)……

Appendix 6 *Ascophyllum* recording sheet

Pembrokeshire Marine SAC: Lawrenny *Ascophyllum* Data

Lawrenny *Ascophyllum* – number of bladders on longest frond of 50 randomly selected thalli in the middle shore

No. bladders	Tally	Total
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		

Appendix 7 General notes on taking barnacle photographs

Quality of the photographs is key in order to be able to later identify the species. Use a good quality camera, hold camera steady when taking the photograph and check results afterwards. If image quality is poor and barnacles cannot be correctly identified, then re-take. The macro-mode photo-stacking in the Olympus TG cameras is ideal for this work.

Take at least x5 good quality photographs at each zone.

Make 5 cm x 5 cm barnacle photo quadrats out of **grey** waterproof paper. (This can be achieved via a laser printer). Don’t use white paper as this tends to under expose the barnacles.

Avoid putting the quadrat on a very 3D-ish surface if possible as the camera will blur a section of barnacles in a different field.

Avoid crevices and rock that isn’t level as this can blur parts of the photo making identification of species impossible.

An LED ring light is ideal.

Wet barnacles are tricky to identify, if possible dry the patches which will be photographed by dabbing with a towel.

In some lower shore sites, the barnacles have merged into a form of barnacle “cement” and none of the plates are visible. Endeavour to take photographs in non-cemented areas if possible.

If camera has a photo-stacking option, then use this to get a good depth of field.

Appendix 8 Contextual information recording sheet

Site:
Recorders:
Date:

Zone & Species	**% Cover**	**Photo taken? (tick)**
US		
Pelvetia canaliculata		
Fucus spiralis		
Cirripedia		
MS		
Ascophyllum nodosum		
Fucus vesiculosus		
Cirripedia		
Mytilus edulis		
LS		
Fucus serratus		
Caulacanthus okamurae		
Chondrus crispus		
Corallina spp.		
Mastocarpus stellata		
Cirripedia		
Mytilus		

Surveyors to estimate % cover of the species / species groups mentioned above in a 10 m horizontal strip of the zone in which the monitoring quadrats occur, including above or below the quadrats if appropriate (e.g. if quadrats are positioned high in the zone, make sure these observations include the whole zone). Estimate rapidly by eye. Make a record of all non-native species seen.

Aquatic Survey and Monitoring Ltd.

Appendix 9 Recording personnel

Table 21. A list of surveyors who worked on the annual shore monitoring surveys in Pembrokeshire Marine SAC (2005 to 2019).

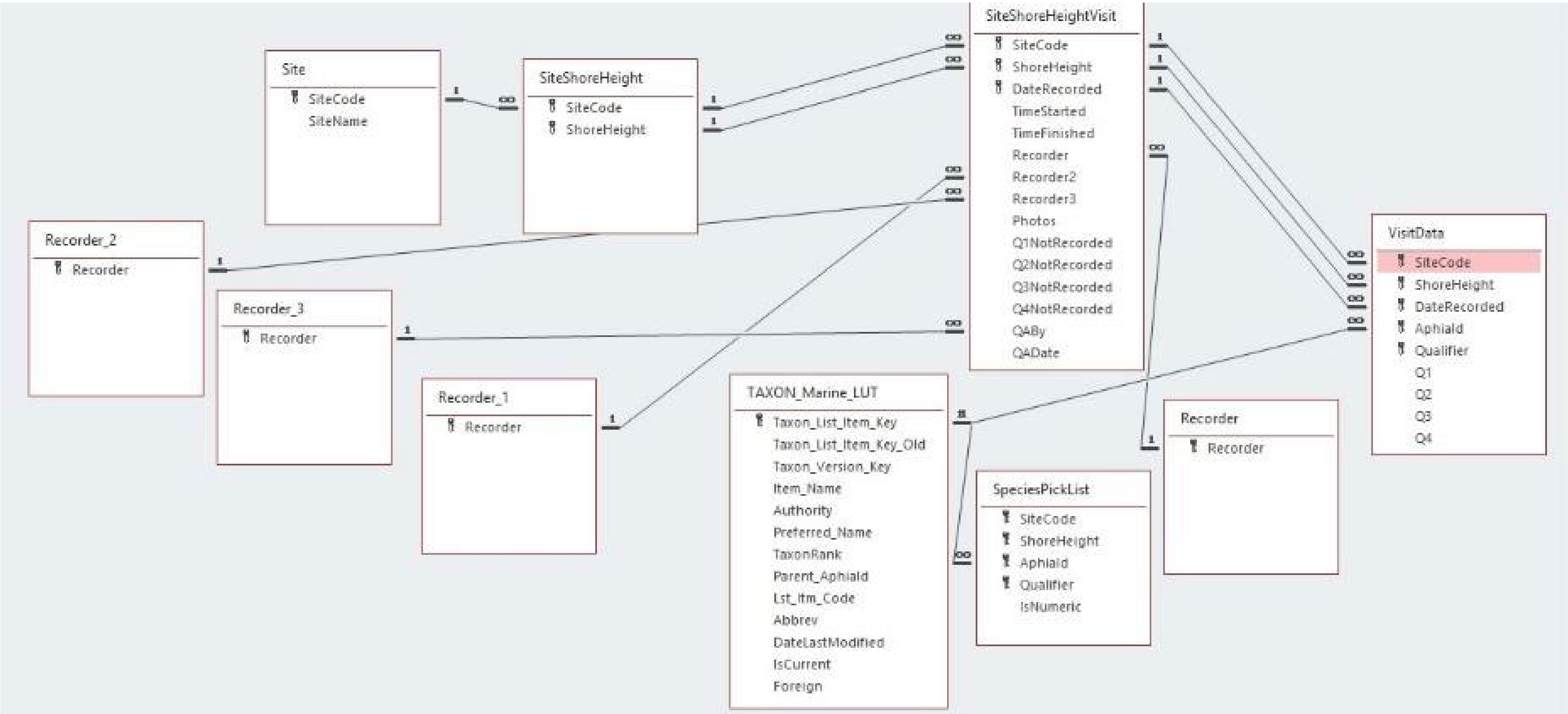
Main Recorders		**2005**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Sue Hull	IECS	X													
Michelle Tobin	IECS	X													
Paul Brazier	CCW/NRW	X	X	X		X	X		X				X		
Anne Bunker	CCW/NRW	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Francis Bunker	ASML		X	X	X	X		X	X	X	X	X	X	X	X
Tom Mercer	ASML		X	X		X		X	X	X	X		X	X	X
Louise Luddington	ASML		X	X	X										
Jon Moore	ASML			X								X			
Christine Howson	ASML				X										
Natasha Lough	CCW/NRW				X				X	X				X	
Gabrielle Wyn	CCW/NRW				X					X			X		
Lucy Kay	CCW/NRW					X	X								
Jennifer Jones	ASML					X						X			
Kathryn Birch	CCW/NRW						X		X			X	X		
John Archer-Thomson	ASML							X	X	X	X	X	X	X	X
Lily Pauls	CCW/NRW							X	X	X	X		X	X	

Assistant Recorders		**2005**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Will Musk	IECS	X													
Mike Camplin	CCW/NRW	X													
Nicky Chapman	JNCC			X											
Emma Verling	JNCC					X									
Katrin Bohn	Bangor Uni						X								
Ben Wray	CCW/NRW							X	X		X				
Adam Cooper	CCW/NRW													X	
Sean Evans	CCW/NRW									X					
James Moon	CCW/NRW										X	X	X	X	X
Megan Parry	JNCC												X		
Tom Tangye	JNCC													X	

Student Helpers		**2005**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Johnny Easter	CCW/NRW		X												
Liz Hobbs	CCW/NRW				X										
Gwen Alun	CCW/NRW						X								
Chloe Jennings	CCW/NRW								X						
Mollie Dugan	CCW/NRW									X					
Brendan Bunker	ASML										X				
Isabelle Nicol	ASML										X				
Eurig Jones	CCW/NRW										X				
Jake Davies	CCW/NRW											X			
Rosie Llewelyn	ASML														X
Rebecca Irvine	CCW/NRW														X

Appendix 10 Design of the Access database used to store the quadrat monitoring data

Figure 87 Diagram to show the relationships between recording fields in the monitoring database design



Appendix 11 Data archive

Data outputs associated with this project are archived in the Document Management System on server–based storage at Natural Resources Wales.

The data archive contains:

[A] The final report in Microsoft Word and Adobe PDF formats.

[B] Excel spreadsheets of data

[C] A Marine Recorder snapshot of the survey for NRW validation purposes.

[D] A full set of images from the survey, in jpg format, and any videos, in mp4 format.

[G] A set of GIS files of spatial data for relocation of survey sites.

Metadata for this project is publicly accessible through Natural Resources Wales' Library Catalogue Across Wales Intertidal Monitoring Survey (naturalresources.wales)by searching 'Dataset Titles'.

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