Cyfoeth Naturiol Cymru
Natural Resources Wales

Menai Strait and Conwy Bay SAC intertidal monitoring of tide-swept boulders 2007-2019

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Aquatic Survey & Monitoring Ltd.

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Mae'r Gyfarwyddeb Cynefinoedd yn datgan y dylid rheoli Ardaloedd Cadwraeth Arbennig (ACAau) gan geisio sicrhau statws cadwraeth ffafriol y cynefinoedd a'r rhywogaethau a restrir o fewn Atodiad I ac Atodiad II yr ACA dan sylw. Yng nghyswllt ACAau yng Nghymru, gofynnir i Cyfoeth Naturiol Cymru (CNC) gyflwyno adroddiad yn rheolaidd ynghylch a oes gan y nodweddion statws cadwraeth ffafriol. Yn ACA y Fenai a Bae Conwy, mae rhaglenni o fonitro cyflwr nodweddion wedi eu datblygu gan CNC a'i gontractwyr.

Mae *riffiau* yn un o'r nodweddion Atodiad I y mae'r ACA wedi'i dynodi ar eu cyfer. Mae meysydd o ddiddordeb penodol yn cynnwys riffiau rhynglanwol a ysgubir gan y llanw (creigwely a chlogfeini) yn Afon Menai, a nodweddir yn aml gan amrywiaeth uchel o rywogaethau. Mae'r adroddiad hwn yn disgrifio rhaglen fonitro a gynhaliwyd ar glogfeini a ysgubir gan y llanw, a gychwynnwyd yn 2005 ac sydd wedi'i hailadrodd bron yn flynyddol. Mae adroddiadau blaenorol wedi disgrifio prif nodweddion y cymunedau; mae'r adroddiad hwn yn disgrifio canlyniadau dadansoddiadau amseryddol dros y cyfnod rhwng 2007 a 2019.

Defnyddiwyd clogfeini ar y glannau isaf ym Mhont Britannia a'r Felinheli fel unedau samplu ar gyfer cofnodi rhywogaethau amlwg. Mae cymunedau gwahanol i'w canfod ar dopiau a gwaelodion y clogfeini ac mae pob un yn cael ei drin fel sampl ar wahân. Mae'r cymunedau hyn yn agored i aflonyddwch wrth i'r clogfeini droi. Cynhaliwyd arolwg o nifer o glogfeini ym mhob safle i fonitro cyflwr y cymunedau. Gweithredwyd gweithdrefnau sicrhau ansawdd a rheoli ansawdd i leihau anghysondeb wrth gofnodi, er bod rhai anghysondebau o hyd ac fe'u disgrifir yn yr adroddiad.

Y canlyniadau mwyaf nodedig o'r dadansoddiadau amseryddol oedd y canlynol:

Cynnydd mewn cyfoethogrwydd rhywogaethau dros bedair blynedd gyntaf y rhaglen, oherwydd datblygiad y fethodoleg a gwybodaeth a chynefindra cynyddol y syrfewyr â'r casgliadau o rywogaethau oedd yn bresennol. Ystyrir bod hyn yn nodweddiadol o ddulliau sy'n seiliedig ar gofnodi cymunedau epifiota yn y fan a'r lle a dylid ystyried hyn wrth ddatblygu protocolau methodolegol ar gyfer rhaglenni o'r fath.

Ar ôl y cynnydd cychwynnol hwnnw, roedd lefel resymol o amrywiad yng nghyfoethogrwydd rhywogaethau Pont Britannia a'r Felinheli, ond cafwyd dirywiad ymddangosiadol dros amser yn y Felinheli.

Yn 2019 ym Mhont Britannia, roedd gostyngiad nodedig yng nghyfoethogrwydd rhywogaethau cymunedau ar waelod y clogfeini, a sbyngau yn enwedig. Roedd y gostyngiad hwn yn annisgwyl ac yn anesboniadwy.

Roedd newid amserol cynyddol yng nghyfansoddiad y gymuned o 2007 i 2019, a chafwyd patrwm tebyg iawn o newid ar y ddau safle ac ar dopiau'r clogfeini ac ar eu gwaelodion. Digwyddodd y newidiadau mwyaf dros y chwe blynedd gyntaf, ac arhosodd y cymunedau yn gymharol sefydlog ar ôl 2013. Fodd bynnag, digwyddodd rhai newidiadau nodedig i gymunedau gwaelodion y clogfeini yn 2019. Cyfrannodd llu o rywogaethau, o nifer o ffyla, at y newidiadau hyn, yn enwedig y sbyngau *Microciona atrasanguinea* a *Halisarca dujardinii* (gostyngiadau mawr). Mae rhywogaethau eraill sy'n dangos newidiadau neu dueddiadau nodedig yn ystod cyfnod y rhaglen yn cynnwys mwydod spirorbid a serpulid (gostyngiadau ers 2014), cregyn llong (lleihad yn y gorchudd ym Mhont Britannia), chwistrelli môr (cynnydd ac yna gostyngiad yn y gorchudd o *Corella eumyota* ac mewn chwistrelli môr cytrefol), morwiail danheddog *Fucus serratus* (gostyngiad o fwy na thraean yn ystod cyfnod y rhaglen).

Mae syrfewyr wedi sylwi ar gynnydd ymddangosiadol y mwd yng ngorsafoedd y Felinheli dros gyfnod y rhaglen ond nid ydynt wedi ei fesur. Trafodir hyn, a’r bygythiad posibl a ddaw wrth i gasglwyr abwyd a gwichiaid droi clogfeini. Mae'r dystiolaeth i ddangos bod troi clogfeini yn rheswm sylweddol am y dirywiad cyffredinol yng nghyfoethogrwydd rhywogaethau'r Felinheli yn oddrychol i raddau. Serch hynny, ystyrir bod casglu abwyd a gwichiaid yn fygythiad i'r cymunedau hyn.

Mae anghysondeb wrth gofnodi rhwng (ac o fewn) arolygwyr yn bryder parhaus wrth wneud y math hwn o fonitro. Fodd bynnag, mae'n eglur fod y fethodoleg yn ddigonol i nodi sawl newid amserol. Amlygir pwysigrwydd gweithrediad parhaus gweithdrefnau sicrhau ansawdd a rheoli ansawdd.

Mae cyflwr y safleoedd wedi cael ei asesu fel a ganlyn:

Pont Britannia: **Ffafriol** – mae'n ymddangos bod newidiadau a gofnodwyd yng nghyfoethogrwydd rhywogaethau, cyfansoddiad a helaethrwydd rhywogaethau o fewn yr amrediad arferol ar gyfer amrywiadau naturiol. Mae angen astudiaeth bellach ar y newidiadau nodedig ymddangosiadol yn 2019.

Y Felinheli: **Anffafriol** – oherwydd pryder am effeithiau parhaus troi clogfeini ar gyfoethogrwydd a chyfansoddiad rhywogaethau wrth i unigolion gasglu abwyd.

Executive Summary

The Habitats Directive establishes that the management of Special Areas of Conservation (SACs) should aim to achieve the favourable conservation status of habitat and species features listed within its Annex I and Annex II. For SACs in Wales, Natural Resources Wales (NRW) is therefore required to report on a regular basis on whether features are in favourable conservation status. In Menai Strait and Conwy Bay SAC, programmes of feature condition monitoring have been developed by NRW and its contractors.

Reefs are one of the Annex I features for which the SAC is designated. Specific areas of interest include intertidal tide-swept reefs (bedrock and boulders) within the Menai Strait, which are often characterised by a high diversity of species. This report describes a monitoring programme carried out on tide swept boulders, which began in 2005 and has been repeated almost annually. Previous reports have described the main characteristics of the communities; this report describes the results of temporal analyses for the period 2007 to 2019.

Lower shore boulders at Britannia Bridge and Felinheli were used as sampling units for recording conspicuous species. The tops and bottoms of the boulders have different communities, each treated as a separate sample. These communities are vulnerable to disturbance from boulder turning. Multiple boulders were surveyed at each site to monitor the condition of the communities. Quality Assurance and Quality Control procedures were applied to minimise inconsistency of recording, though some inconsistencies remained and are described in the report.

The most notable results of the temporal analyses were:

An increase in species richness over the first four years of the programme, due to development of the methodology and the increasing knowledge and familiarity of the surveyors with the species assemblages present. This is considered typical of methods based on *in situ* recording of epibiota communities and should be taken into account when developing methodological protocols for such programmes.

After that initial increase, a reasonable level of fluctuation in species richness at both Britannia Bridge and Felinheli, but with an apparent decline over time at Felinheli.

In 2019 at Britannia Bridge, a notable reduction of species richness in boulder bottom communities, particularly of sponges. This reduction was unexpected and is unexplained.

A progressive temporal change in community composition from 2007 to 2019, with a very similar pattern of change at both sites and on both boulder tops and boulder bottoms. The largest changes occurred over the first six years, and the communities remained relatively stable after 2013. However, some notable changes to boulder bottom communities occurred in 2019. Multiple species, from many phyla, contributed to these changes, particularly the sponges *Microciona atrasanguinea* and *Halisarca dujardinii* (large reductions). Other species showing notable changes or trends over the course of the programme include spirorbid and serpulid worms (reductions since 2014), barnacles (decreasing cover at Britannia Bridge), sea squirts (increase followed by decrease in cover of *Corella eumyota* and in colonial sea squirts), serrated wrack *Fucus serratus* (decreasing cover by more than a third over the course of the programme).

Surveyors have observed, but not measured, an apparent increase in the muddiness of the Felinheli stations over the course of the programme. This, and the potential threat of boulder turning by bait and winkle collectors, are discussed. Evidence to demonstrate boulder turning as a significant cause of overall decline in species richness at Felinheli is to some extent subjective. Nevertheless, bait and winkle collection are considered a threat to these communities.

Inconsistency of recording between (and within) surveyors is a constant concern in this type of monitoring. However, it is clear that the methodology is sufficient to detect many temporal changes. The importance of continued application of QA/QC procedures is highlighted.

The condition of the sites has been assessed as:

Britannia Bridge: **Favourable** - recorded changes in species richness, species composition and abundance appear to be within the normal range of natural fluctuations. The apparent notable changes in 2019 require further study.

Felinheli: **Unfavourable** – due to concern for the impacts of continued boulder turning for bait on species richness and composition.

1. Introduction

The Habitats Directive establishes that the management of Special Areas of Conservation (SACs) should aim to achieve favourable conservation status of habitat and species (*features*) listed within its Annex I and Annex II. Article 17 of the Directive requires reporting of the conservation status of those habitats and species every 6 years. For SACs in Wales, Natural Resources Wales (NRW) is responsible for that reporting. To do this NRW has developed programmes of feature condition monitoring, which include intertidal features of marine SACs. Aquatic Survey & Monitoring Ltd. (ASML) have been contracted by NRW to develop and manage the monitoring programme for these intertidal features for the period 2006 to 2023; working as a team with NRW staff.

Menai Strait and Conwy Bay Special Area of Conservation (SAC) is designated for five Annex I habitats: Sandbanks which are slightly covered by sea water all the time, Mudflats and sandflats not covered by seawater at low tide, Reefs, Large shallow inlets and bays and Submerged or partially submerged sea caves. Conservation objectives for each feature are given in the Regulation 37 advice for the Menai Strait and Conwy Bay SAC (NRW 2018).

Reef within the SAC includes areas of intertidal tide-swept boulders. In some areas of the Menai Strait, the lower shore boulders are characterised by a high diversity of species on both their upper and lower surfaces (see Figure 1). The upper surfaces are typically dominated by a variety of brown, red and green algae, while the lower surfaces are typically dominated by a variety of sponges, worms, crabs, bryozoans, sea squirts and other animals. These communities take years to develop but they can be severely disturbed or destroyed if the boulders are turned over and not turned back promptly.

The collection of shore crabs for fishing bait, by searching under boulders, is a common activity on some shores in the Menai Strait, including Felinheli. Collectors of winkles are also widespread throughout the Menai Strait. Not all collectors on the shore responsibly place the boulders back the right side up.

A programme to monitor the boulder communities at Felinheli and Britannia Bridge was initiated in 2004. Monitoring stations were defined and surveys were carried out then and again in 2005 (Mazik *et al*. 2005). The monitoring survey methodologies were then further developed and the Britannia Bridge stations were surveyed again in 2007 (Moore 2009). Britannia Bridge and Felinheli were surveyed in 2008 and monitoring surveys have been repeated every year to date (2019), with one gap (2011) at Felinheli (see Appendix 1).

The program objectives are:

- To monitor the composition of communities of epibiota present on tide-swept boulders of the lower eulittoral zone (dominated by *Fucus serratus*) at two sites in the Menai Strait: Britannia Bridge and Felinheli.
- To assess the impact of boulder turning on those communities

This is relevant to the following Menai Strait and Conwy Bay SAC feature attributes (NRW 2018):

- Structure and Function: Species composition of reef biotopes in high energy tide-swept wave sheltered locations

- Typical Species: Species composition of under-boulder, overhang and crevice reef biotopes

Figure 1. Selected photographs to illustrate the tide-swept boulder habitat and the survey methodologies. A. Surveyors recording at station BB5. B. Boulder covered in *Fucus serratus*. C. Boulder top with *Fucus* pulled to side. D. Boulder bottom.

The overall aim of the program is to establish reference conditions for the interest features of the SAC and distinguish any deviations from those conditions, using established monitoring stations to describe natural and unnatural changes in the communities. This enables continued development of conservation objectives and informs appropriate management of those SAC features.

Previous reports on this programme include Moore *et al*. (2010), Moore *et al*. (2021) and Moore (2018). Moore *et al*. (2021) assessed the condition of the boulder communities at these sites and gave the following assessment:

- **Britannia Bridge** - Recorded changes in species richness, species composition and abundance appear to be within the normal range of natural fluctuations.
- **Felinheli** – Concerns due to impacts of continued bait collection on species richness and composition. The majority of boulders at this site show evidence of having been repeatedly turned, including the presence of smothered and rotting algae, dead barnacles and low species richness. The average number of taxa per boulder has gradually declined since 2013. Most effect at stations closest to access at Felinheli.

2. Methods

2.1. Data collection

A summary of the monitoring methodology is given below. Detailed methodologies and protocols are given in Moore and Brazier (2016) (common procedures) and Moore (2016) (tide-swept boulders). They include rationale, site and station details, methods, protocols, proformas, equipment lists, QA/QC procedures and modifications that have been made to the methods over the course of the programme up to and including 2016. Figure 2 and Figure 3 show the locations of monitoring stations at the two sites.

Monitoring surveys were normally carried out in June or July each year, during a five day survey period in which surveys of various other sites and features in the SAC were also carried out. Field logs for each annual survey (available from NRW or ASML on request) describe the work carried out, including dates, times and surveyors.

Five monitoring stations are located within the *Fucus serratus* zone (lower eulittoral) at each site: Britannia Bridge stations BB1 to BB5 and Felinheli stations FE1 to FE3, FE5 and FE6. Each station lies at least 50 m from the next. Handheld GPS was used to relocate the stations for each survey during a period of low spring tide. Five boulders were selected randomly, within certain criteria, at each station. The size (length and width) of each boulder was measured and recorded. Upward facing surfaces and under-boulder surfaces were recorded separately onto a pre-prepared recording form, upward surfaces first. All conspicuous taxa were identified, to species level where possible. The abundances of selected algae (e.g. *Fucus serratus*), space occupying animals (e.g. *Mytilus edulis*) and aggregate taxa (e.g. foliose red algae and barnacles) were recorded as percentage cover. Other taxa were mostly recorded simply as Present (P), or, if their abundance was clearly very low, as Trace (T). Photographs of upper surfaces and under-boulder surfaces were also taken.

Quality of the data from these monitoring surveys is reliant on the surveyors' experience, *in situ* identification skills and thoroughness. Quality Assurance procedures include pre-survey training and familiarisation. The same experienced individuals have carried out most of the surveys. Quality Control procedures include some repeated recording of selected boulders by different surveyors. However, significant inconsistencies between surveyors, and by the same surveyors between surveys, are possible.

Figure 2. Locations of the five boulder monitoring stations at Britannia Bridge. The additional locations marked W, M & E, are discussed in Appendix 4. Maps based upon Ordnance Survey material © Crown copyright. All rights reserved. Natural Resources Wales, 100018813 [2022].

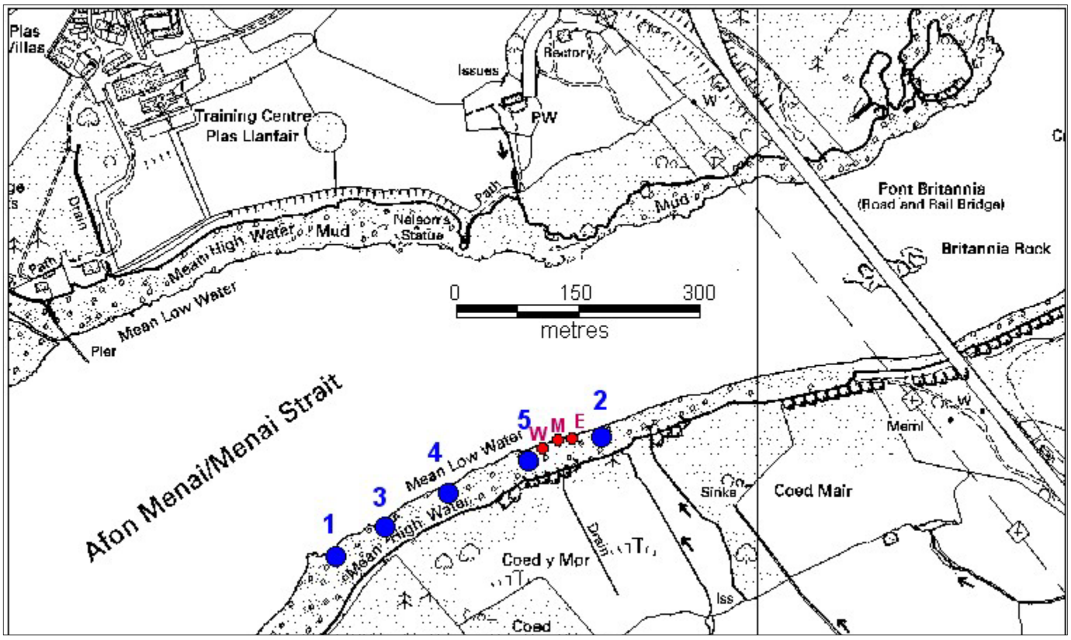
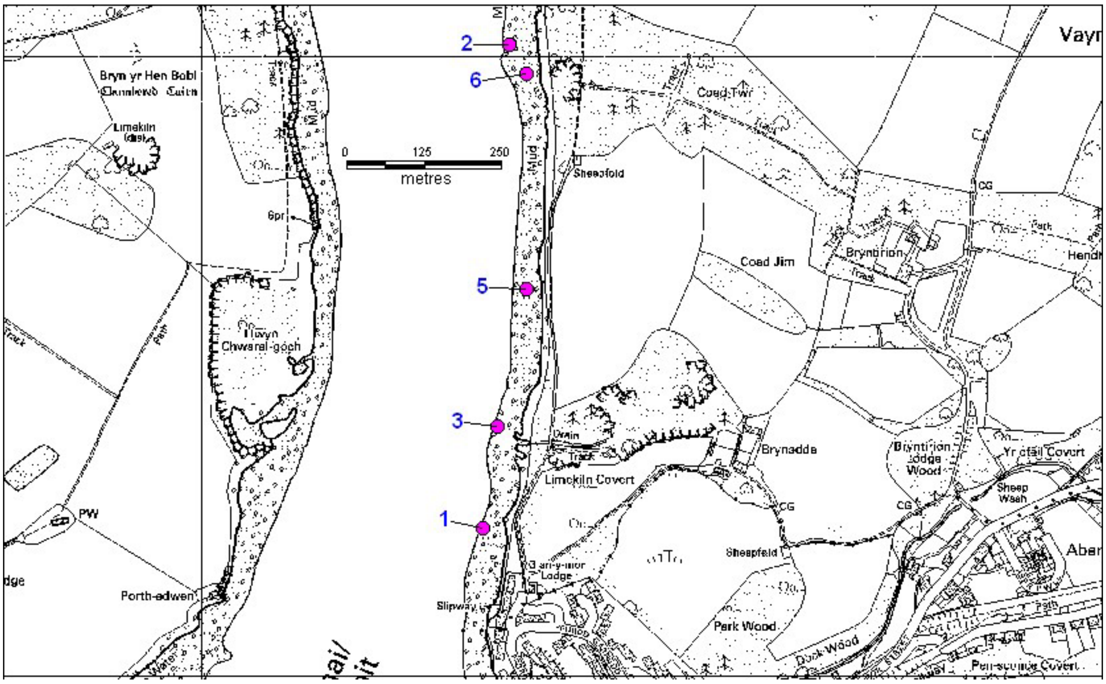


Figure 3. Locations of the five boulder monitoring stations at Felinheli. Maps based upon Ordnance Survey material © Crown copyright. All rights reserved. Natural Resources Wales, 100018813 [2022].



2.2. Data management and analysis

2.2.1 Data structure

Taxa abundance data and all associated metadata are stored in a bespoke Microsoft Access relational database allowing flexible manipulation, querying, summarisation and export in required formats. A summary of the data structure is given in Appendix 3, including various metadata (attributes) that have been applied in the analyses.

The following key attribute data are linked to each taxa abundance record: Year, Site (BB or FE), Station (1 to 5), Boulder replicate (a to s), Side (Top or Bottom), Method (%cover or Presence). Additional attribute data that have been used in analyses include duration of boulder survey, dimensions of boulder (length and width), presence of anoxia under boulder, and surveyor's assessment of whether the boulder had been turned.

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 website) and any qualifiers (e.g. encrusting, juvenile, orange) that are typically recorded. A few new entities are routinely added to the table after each monitoring survey, but only if they are clearly different from those already on the list. Attribute data linked to each entity includes the AphiaID, taxonomic authority and classification details available from the WoRMS website, a taxon code based on the UK Marine Species Directory (used for sorting in a conventional taxonomic order), and tags for entities that are listed on the recording form and entities that are appropriate for temporal analysis. As some taxa are inconsistently recorded, each entity is also linked to a standardised higher entity that is more reliably recorded, allowing straightforward aggregation of abundance data for analysis.

2.2.2 Analysis tools

Summary statistics and tabulation are prepared in the Access database and typically exported to Excel for further analysis and for preparation and formatting of graphs and tables for use in reports. Tabulated data in Excel formats ready for import into Marine Recorder and PRIMER are also exported from the database. Multivariate analyses are carried out in PRIMER, primarily using the following routines and tools:

- Resemblance matrices with Bray-Curtis similarity
- nMDS - non-metric Multi-Dimensional Scaling
- ANOSIM - Analysis of Similarity
- SIMPER – contribution of each taxon to the dissimilarities between groups of samples
- Bootstrap averaging (with metric MDS) - a relatively novel ordination tool available in PRIMER v7 (Clarke and Gorley 2015) that resamples and averages the similarity data within *a-priori* defined groups (e.g. Years), multiple times, to calculate multiple *bootstrap averages* that 'we might have obtained'. Plotting those averages in a 2D mMDS and fitting *bootstrap regions* for each group shows the similarities between each group, with coloured envelopes that nominally represent 95% of the *bootstrap averages* (similar in purpose to 95% confidence intervals). Thus, the coloured points within each envelope do **not** represent individual boulders, but 'other means' which are less scattered and often allow easier interpretation. An overall average point is also displayed within each group (in black), allowing trajectory lines to be applied.

Univariate analyses (including analysis of variance and Spearman rank correlation) were carried out in the statistical package R.

2.2.3 Analysed datasets

Two types of taxon abundance data are available:

Quantitative (percentage cover) data are only available for selected taxa, including some aggregate taxa. Prior to parametric analyses these data were transformed to square roots, cube roots or with log transformation depending on their deviation from normality.

Qualitative (presence/absence) data are available for all taxa and are analysed separately from the percentage cover data. However, with multiple boulders surveyed at each station at each site, frequency of occurrence data (or % frequency of occurrence data to take account of the variable numbers of boulders surveyed), can be calculated from the presence/absence data and analysed quantitatively. They are often presented as percentage occurrence – for example, in 2019 the sponge *Leucosolenia* was recorded from 21 of the 52 boulders surveyed = **40% occurrence. <u>Not to be confused with percentage cover</u>**!

2.3. Inconsistencies and confounding factors

Interpretation of the results must take account of the development of the monitoring programme since it was first established, including improvements in recording protocols and increasing familiarity and recognition of the species present. The following considerations are particularly important:

- Recording in the early years of the programme was relatively less consistent, particularly for some species, e.g. *Clathria (Microciona) atrasanguinea*, which some surveyors were not initially familiar with. Familiarity and routine training sessions greatly improved the recording of this and other such species as the programme progressed.
- Some quite common species were not identified by surveyors in the early years of the programme, e.g. *Protosuberites denhartogi*, was recorded with other buff sponges until approx. 2014 when training from our sponge expert Jen Jones enabled surveyors to distinguish it, fairly reliably, for subsequent surveys.
- % occurrence data for some species in 2007 and 2011 is affected by differences between the sites because there was no recording at Felinheli in those two years, e.g. % occurrence of *Actinia* was 0 in those years because that anemone is rare on the Britannia Bridge boulders, but frequent on the Felinheli boulders.
- The assignment of boulder ‘top’ and ‘bottom’ was more loosely defined in the early years of the programme, so steeply sloping sides (arguably a different sub-habitat) were often included in one or both. This sometimes resulted in more algae being inappropriately included in records for boulder bottoms and encrusting sponges / ascidians etc. included in records for boulder tops.

The size of the boulders could also be a confounding factor as there is a statistically significant positive correlation between size (length x width) and the number of taxa recorded (Figure 4) [correlation coefficient = 0.248, $p < 0.0001$]. However, while the range in boulder sizes surveyed has shown some variation from year to year there is no temporal trend (Figure 5), so this factor has been largely ignored in the analyses presented below.

Section 2.1 highlights the QA/QC procedures, including training, that have been applied to improve consistency, but it is clear that inconsistency of recording between (and within) surveyors can still be high. In 2010 an exercise to measure consistency of recording by multiple surveyors was carried out on three boulders at Britannia Bridge (locations marked W,M,E in Figure 2). A description of the exercise and its results is given in Appendix 1. The results showed considerable inconsistency between surveyors. Some discussion of this issue is given in Section 4.3.

Figure 4. Relationship between boulder size and number of taxa recorded from it, including line of best fit.

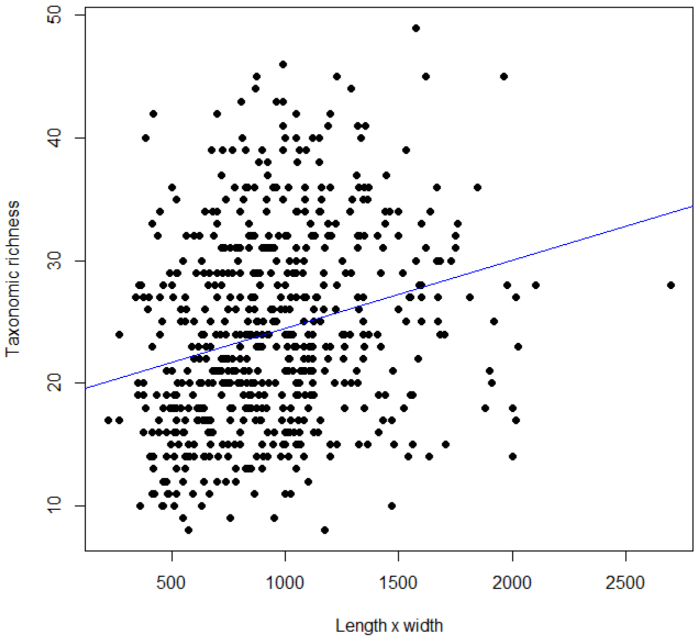
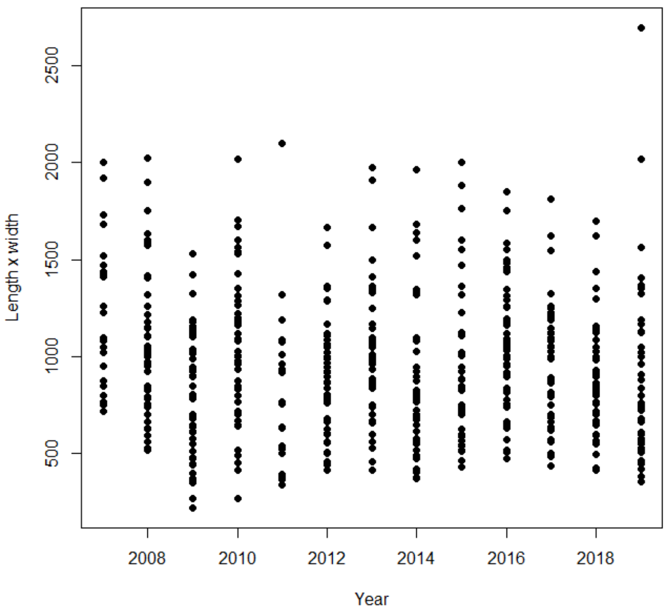


Figure 5. Relationship between monitoring survey year and boulder size (length x width).



3. Results

The boulders are characterised by algal dominated communities on the upper boulder surfaces and encrusting invertebrate dominated communities (sponges, sea-squirts, bryozoa, etc.) on the under-boulder surfaces. Generally, there was a high species richness on the underside, except where water flow under the boulder had been restricted (e.g. where the boulder was sitting on muddy sediment) or where boulders had been frequently turned by bait collectors. Felinheli boulder communities were less well developed compared to Britannia Bridge boulders, due to the more gradually sloping shore retaining more mud.

Previous reports describe the habitats, communities and notable taxa. This report describes notable trends and changes over the period 2007 to 2019, with an emphasis on the most recent years. For most taxa, the recorded fluctuations are considered natural, with no trends of notable interest.

3.1. Species richness

A total of 353 individual taxa (*entities*) have been recorded from the boulders since 2007, plus an additional 7 aggregate taxa. A full list of these taxa is given in Appendix 2. As mentioned in the methods, for the purposes of analyses, data for some of the individual taxa are merged upwards (summed) to more consistently recorded taxa. Also, for the species richness analysis, eggs and tubes (e.g. polychaete tubes) were excluded. The resulting total number of individual taxa for analysis is 233.

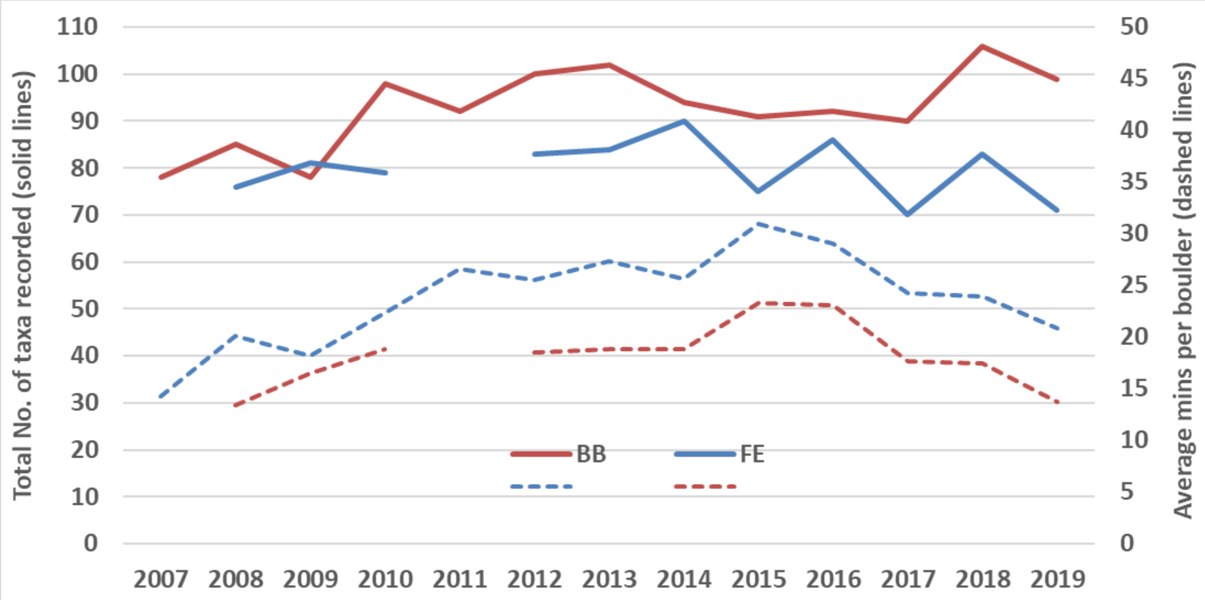
Temporal analysis of species richness has considered both the total number of taxa recorded (by year and site) and the average number of taxa per boulder (by year, site and side). Note: for the analysis of total richness, data were limited to the first five boulders at each station (i.e. the standard monitoring survey).

Figure 6 shows the difference in species richness of conspicuous epibiota between the more steeply sloping shore at Britannia Bridge and the more gradually sloping and muddier shore at Felinheli. It also shows that there was a notable rise in total number of taxa recorded from boulders at Britannia Bridge over the first four years of the monitoring programme, followed by moderate fluctuations at the higher level. Further inspection and significance tests show that this effect is most clearly shown in the boulder top data (2007 to 2009 have significantly lower richness than later years), while for the boulder bottom data the effect is only statistically significant for 2007.

The notable rise is likely due to the development of the methodology and the increasing knowledge and familiarity of the surveyors with the species assemblages present. It is a recognised feature of whole community monitoring programmes, particularly those based on *in situ* recording methods with experienced surveyors. The prolonged effect on boulder top data is likely because it took longer for surveyors to distinguish and become familiar with many of the small red algae present within the dense algal turf. A trend of increasing time spent recording from each boulder, to a peak in 2015, followed by a downward trend, is also notable.

But Figure 6 shows a different pattern in the richness data for the Felinheli boulders. Here there was also a modest increase in richness between 2008 and 2012, but then a notable, if fluctuating, decline.

Figure 6. Annual fluctuations in the total number of taxa recorded from boulders (25) at Britannia Bridge and Felinheli (solid lines, left axis), and the average time (minutes) taken to survey each boulder (dashed lines, right axis).



Analysis of the average species richness per boulder is shown in Figure 7, which also shows the trend of increase at Britannia Bridge and Felinheli over the first few years, followed by significant fluctuations, but the decline at Felinheli is less obvious and it is difficult to interpret the fluctuations. One-way analysis of variance, comparing species richness on Felinheli boulders between the years 2012-2019 finds no significant differences (p=0.103). Further inspection of the Felinheli total richness data finds some reduced numbers of algal taxa in the later years, but this does not explain all the changes.

Other factors that will influence these data include the experience and identification skills of the surveyors and the survey conditions. No further analysis is made in this report, but observations of increased muddiness at Felinheli might explain a reduced diversity of algae. If this mainly affects uncommon species, then the decline would be less obvious in the average number of species per boulder.

Figure 7 also shows an apparent large reduction in species richness between 2018 and 2019 on the Britannia Bridge boulder bottoms. There was also a reduction at Felinheli, but that was well within the variability shown over the course of the programme. Further analysis, to identify the phyla most involved in the apparent decline at Britannia Bridge, is presented in Figure 8. It shows that the decrease was across a number of phyla, but particularly in the sponges. These changes are analysed and discussed further in Section 3.3.1. The notable rise and fall of ascidian species richness, at Britannia Bridge, is discussed further in Section 3.3.5.

Figure 7. Annual fluctuations in average number of taxa per sample (5 replicate boulders) (± standard error).

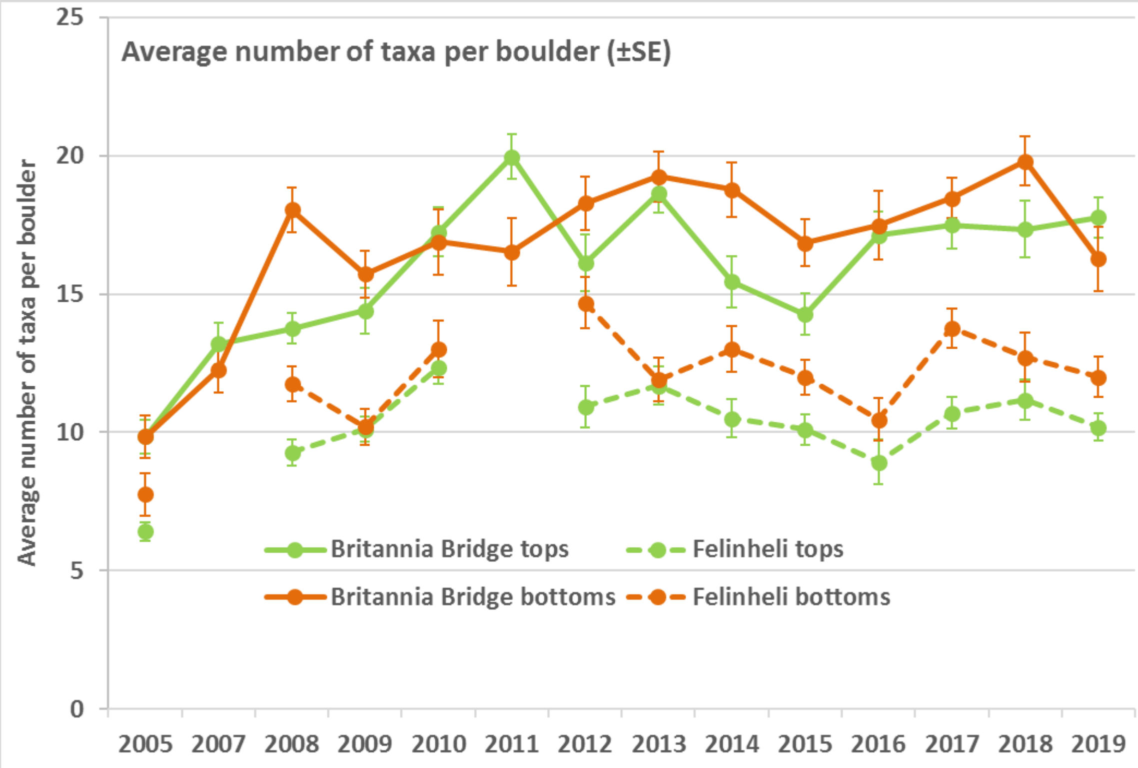
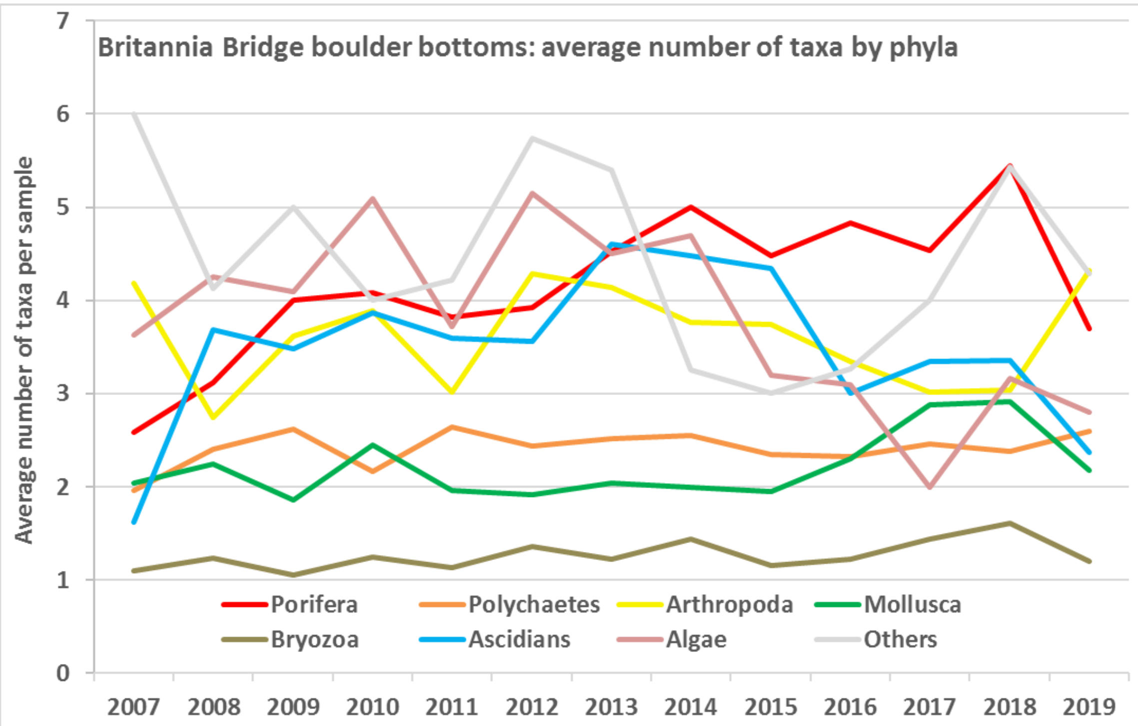


Figure 8. Annual fluctuations in average number of taxa per sample, by phyla, for Britannia Bridge boulder bottoms only.



3.2. Community composition

Multivariate analysis of whole community data (boulder tops and boulder bottoms analysed separately) show that the Britannia Bridge and Felinheli boulder communities are very different from each other (as described in previous reports). It also shows that there are significant differences between the community data recorded in different years. ANOSIM (2-way crossed, sites x years, presence/absence data; testing the null hypothesis that communities are not significantly different) finds global test significance of 0.1% for both sites and years. Pairwise tests between years finds probability values range from 0.1% to 0.8%, i.e. the difference between any pair of years is highly significant, for both boulder top communities and boulder bottom communities. More details of the ANOSIM results are given in Appendix 5.

The MDS plots in SIMPER analyses (see Appendix 5) have been used to describe the changes between the periods. They provide some evidence that the early period is influenced by the newness of the study, when protocols and recording forms were in development and there was limited quality assurance. For example, there were fewer records of *Microciona atrasanguinea* and *Hildenbrandia*, and more records of non-calcareous red algal crusts than the later periods. However, a number of other characteristics of the early period are less well explained by known changes in protocols and are likely real differences. These include fewer records of juvenile barnacles, fucoid sporelings, *Aplidium turbinatum, Corella eumyota*, scale worms and *Sabellaria* than the middle and later periods. These species are discussed further in Section 3.3.

Differences between the middle and later periods are topped by the same species listed above, usually with more records in the later period, but other notable species include *Austrominius modestus* (more in the later period) and *Littorina obtusata* (more in the middle period).

While the species mentioned above are at the tops of the SIMPER lists, it is notable that the contribution of individual species to the dissimilarity between the periods is not high. All of the SIMPER lists comprise at least 20 taxa to reach a cumulative 50% dissimilarity.

It is concluded that there was a progressive change in the boulder community data from 2007 to 2013, partly confounded by methodological changes. Then, from 2014 to 2019, the community has been more stable. Figure 10 shows the progressive changes in more detail for Britannia Bridge boulder bottoms. [*Explanatory note*: The bootstrap averaging in Figure 10 is a relatively novel ordination tool available in PRIMER v7 (Clarke and Gorley 2015).

Figure 9 illustrate those differences and also show there has been an apparent progressive change over time at both sites, evident in both boulder top and boulder bottom communities. Further inspection and analysis suggest three periods: *early* (2007-2008), *middle* (2009-2012) and *late* (2013-2019).

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Figure 9. MDS plots of whole community data from boulder tops and boulder bottoms at Britannia Bridge (BB) and Felinheli (FE), 2007 to 2019. Each dot represents 25+ boulders, with similarities calculated from proportional occurrence data for 247 taxa (177 taxa for boulder tops, 208 taxa for boulder bottoms). Blue lines link consecutive years to show progressive change over time. Red dashed lines indicate divide between periods. The Keys to Years and Sites are the same for both plots.

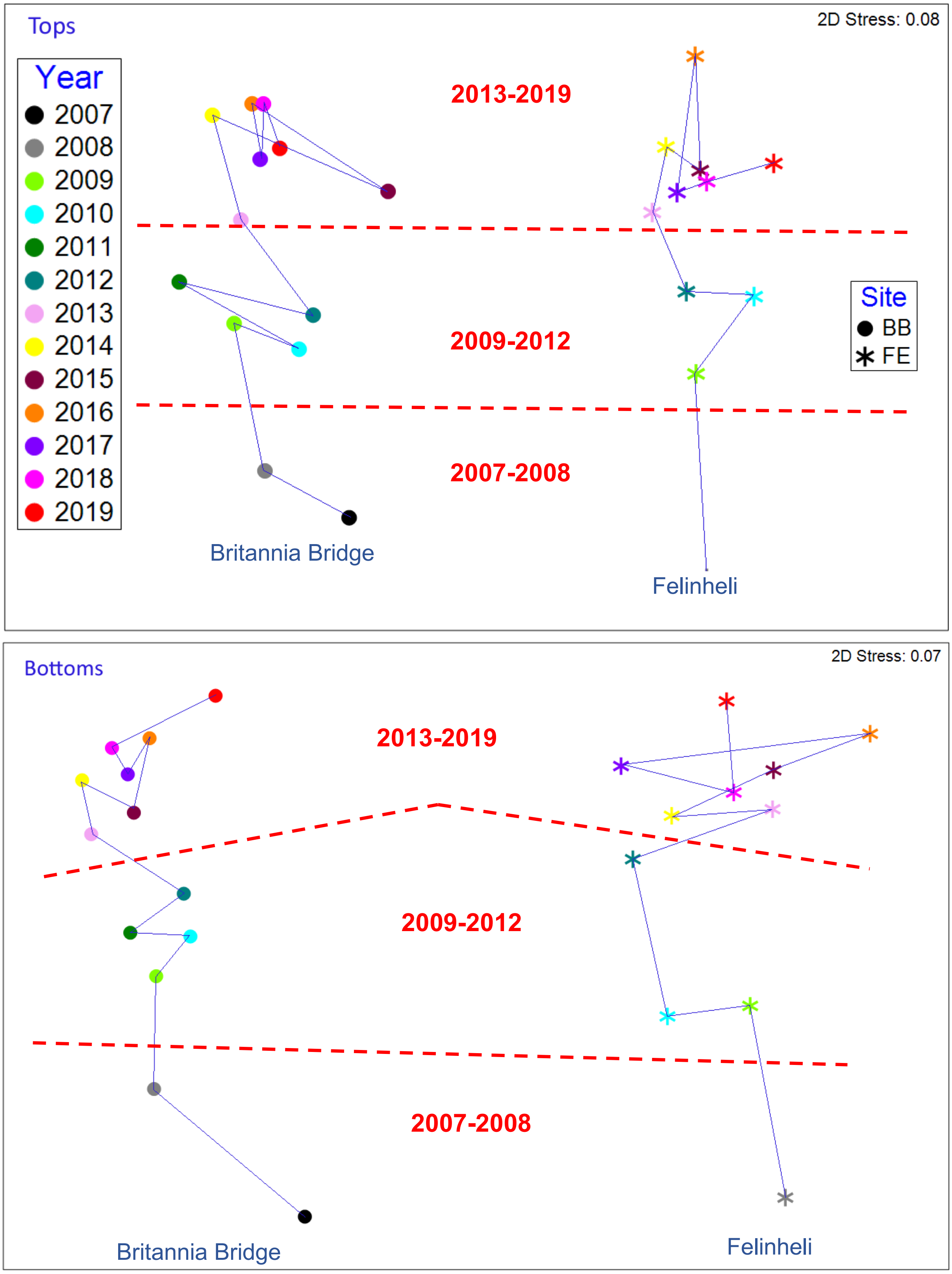

Figure 10. MDS plot of whole community data from boulder bottoms at Britannia Bridge (BB) stations, 2007 to 2019, including bootstrap averages and bootstrap regions, with overlaid trajectory of Years. Derived from presence/absence data for 177 taxa recorded from 25 boulders in each year. See Section 2.2.2 for an explanation of bootstrap averaging.

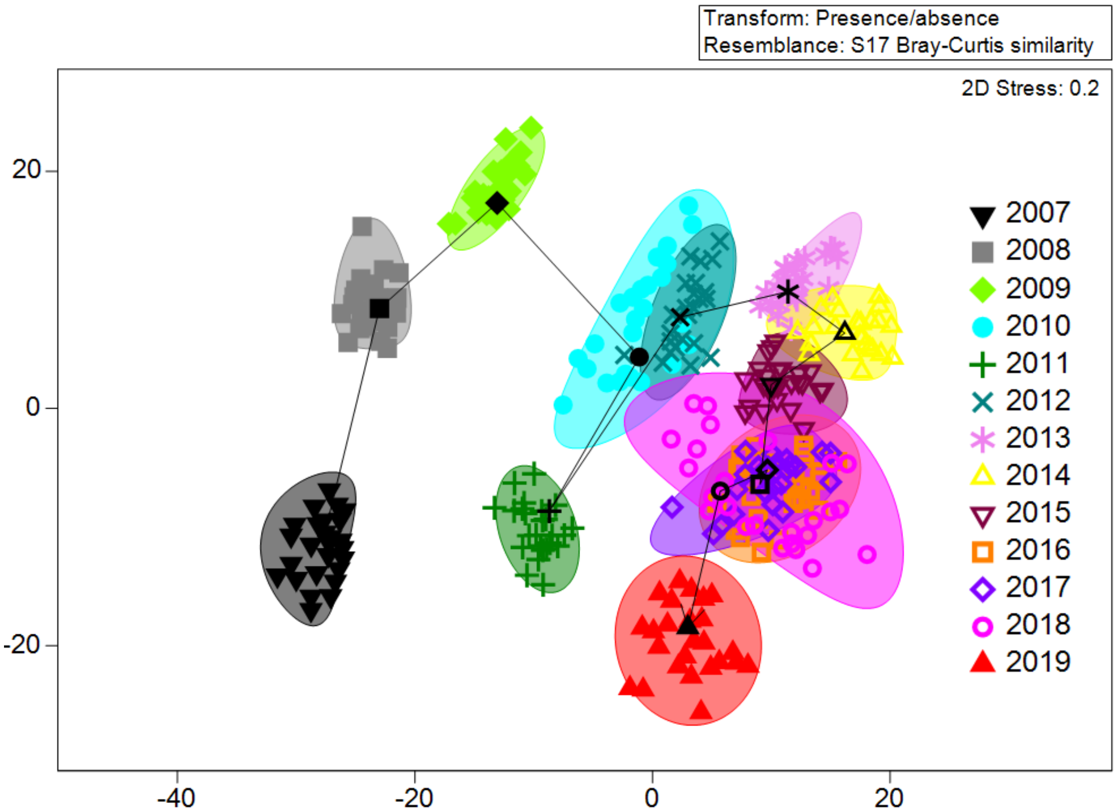

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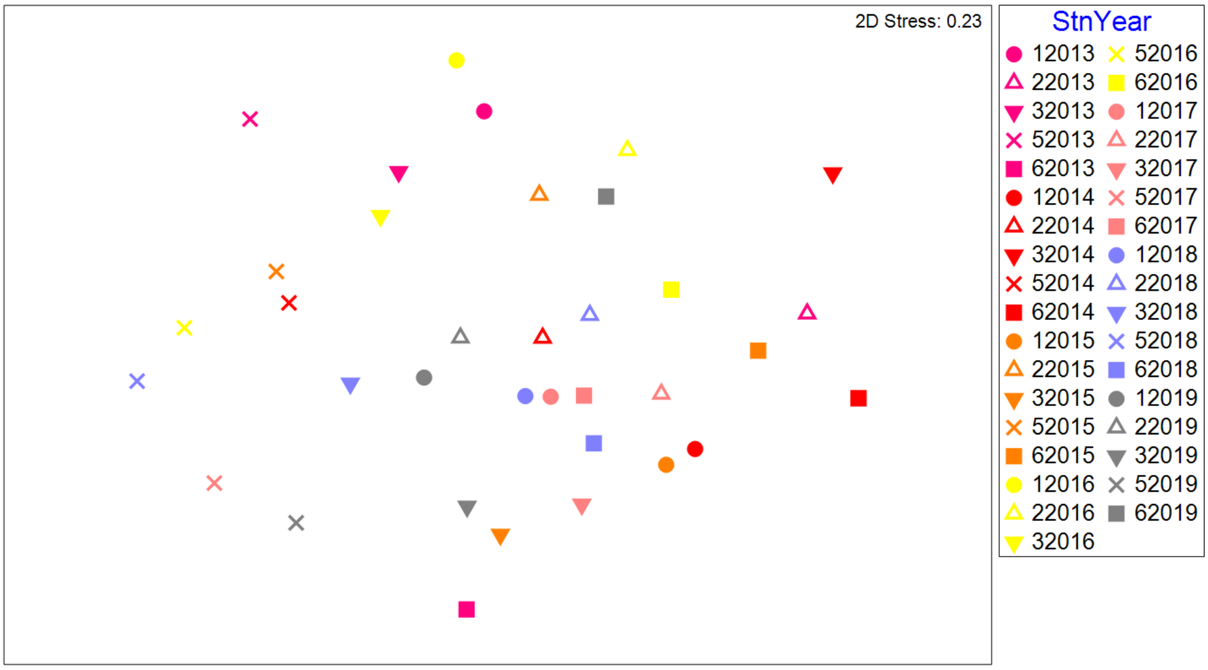
Figure 9 and Figure 10 are dominated by the changes in the period 2007 to 2013. To look in more detail at the community changes in the period 2013 to 2019 further multivariate analyses have been carried out.

The MDS plot in Figure 11 shows similarities between averaged community data (proportional occurrence data) from boulder bottoms in monitoring stations at Felinheli. It confirms a lack of any temporal trends and also shows limited evidence of spatial trends. This is further emphasised by the high 2D stress value of 0.23, which indicates that there is considerable additional variability in the data that cannot be summarised in a 2D plot. The 3D plot (not shown here), with a stress value of 0.16, is an improvement but still shows limited evidence of trends. It is concluded that the 2013-19 data represent a diverse and fairly homogeneous community, with moderate levels of natural fluctuations. The only notable spatial trend is that Station 5 (the X labels in the MDS plot) is significantly different from the other Felinheli stations – characterised by a generally rockier substrata, more boulders and less mud compared to the other Felinheli stations. The samples from Station 6 are also more clustered than the others.

Multivariate analysis of averaged community data for the other three combinations (Felinheli tops, Britannia Bridge bottoms and Britannia Bridge tops, MDS plots not included in this report) show a similar lack of notable spatial or temporal trends and high levels of 2D and 3D stress. There were two exceptions. Firstly, Station 1 at Britannia Bridge is significantly different from the other stations – characterised by more gradually sloping lower shore with muddier substrata under the boulders. Secondly, within the Britannia Bridge boulder bottom data, the samples from 2019 stand out from the other years (also shown in Figure 10). The latter is described in more detail in Section 3.3 for some taxa.

Figure 11. MDS plot of whole community data from boulder bottoms at Felinheli (FE) stations, 2013 to 2019. Each dot represents 5+ boulders, with similarities calculated from proportional occurrence data for 177 individual taxa. The Key identifies each spot by station (first digit) then year (four digits); thus 12013 is station 1 in 2013.



3.3. Individual taxa

Tabulated data in the following sections are percentage occurrences from whole boulders (Britannia Bridge and Felinheli records combined). Each value is calculated from presence / absence data from 50+ boulders (2 sites x 5 stations x 5+ replicates), except 2007 and 2011 (25+ samples) when Britannia Bridge only was surveyed. Coloured data bars (using conditional formatting feature from Excel) have been added to aid visualisation of changes. Example: the sponge *Hymeniacidon perlevis* was recorded as present on 88% (22) of the 25 surveyed boulders in 2007, but only 65% (34) of the 52 surveyed boulders in 2019. This example also highlights one of the differences between the two sites, because *H. perlevis* is less common at Felinheli.

3.3.1 Porifera

Sponges are a major component of the boulder fauna, particularly on the boulder bottoms and particularly at Britannia Bridge. 31 species have been identified, and a similar number of other sponge entities have been recorded using qualifiers of colour and texture. Many sponges are difficult to identify *in situ*, particularly those having an encrusting form, which is common under boulders. Many species are coloured various shades of yellowy brown, so are often assigned to *Porifera (buff)*. The identification skills of the surveyors has improved over the course of the programme, due in particular to training and specimen checking by Jen Jones, a sponge expert who has worked on almost every monitoring survey. However, for the purposes of these analyses the data for some species have been amalgamated into more reliably recorded taxa, e.g. *Porifera (buff)*.

Table 1 shows the annual fluctuations in percentage occurrence of the most frequently occurring sponge taxa. Very few trends are apparent, particularly after the early years once inconsistencies in identifications and protocols had been largely resolved. However, notable reductions between 2018 and 2019 are apparent for some taxa, which explains at least some of the Britannia Bridge species richness reductions described in Section 3.1. The largest reductions are of *Microciona atrasanguinea* and *Halisarca dujardinii*, both of which are well known to all of the surveyors, though *M. atrasanguinea* was less well recognised in the earlier monitoring surveys. Closer inspection of the data confirms that reductions in records of those species occurred at both sites and from boulder tops as well as boulder bottoms. There was no apparent reduction in occurrence of *Hymeniacidon perlevis*. Changes in abundance of other sponges, including many not listed in Table 1, are generally within the range of the previously recorded fluctuations. However, of the 15 sponge taxa recorded in 2018 and 2019, the percentage occurrence of all but two (*Hymeniacidon perlevis* and *Oscarella lobularis*) was lower in 2019.

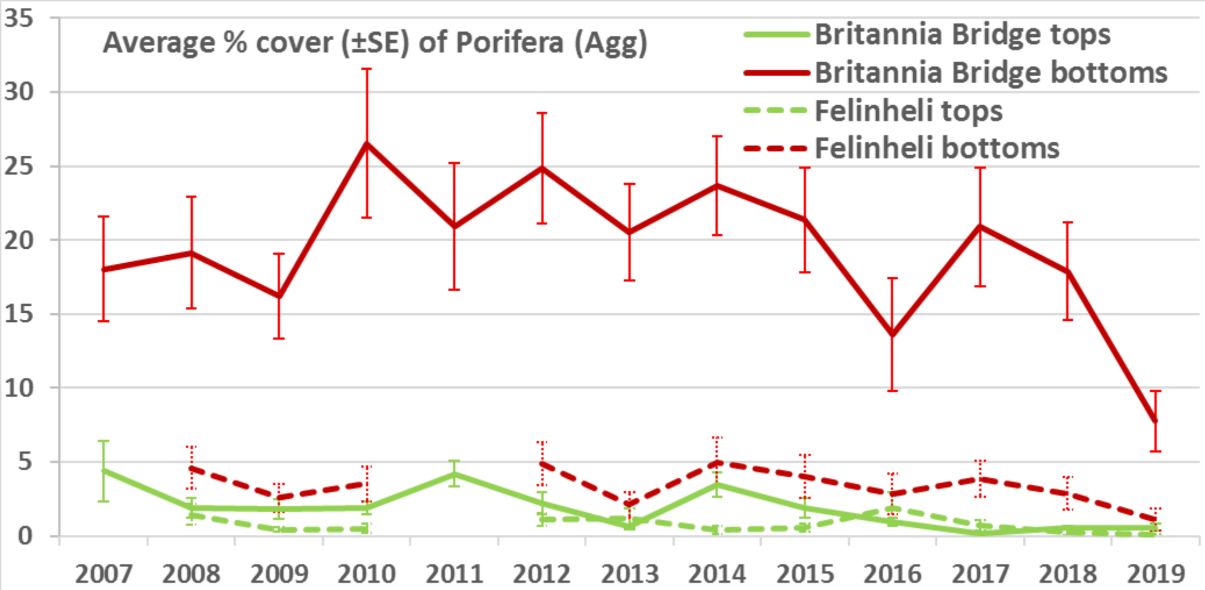
Table 1. Percentage occurrence of the most frequently recorded sponges, across both sites.

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Porifera (buff)	68	29	41	49	76	47	44	43	47	41	52	48	33
Leucosolenia	28	26	41	44	32	44	47	56	62	27	50	46	40
Sycon ciliatum	12	9	11	7	12	10	11	20	11	18	7	19	13
Hymeniacidon perlevis	88	57	48	56	84	68	63	62	64	65	63	59	65
Microciona atrasanguinea	8	1	26	21	48	25	32	44	29	41	48	30	17
Halisarca dujardinii	20	51	54	47	56	53	39	44	35	39	38	52	15

Analysis of percentage cover data for sponges (recorded from each boulder as an aggregate of all sponge species) is shown in Figure 12. This also shows a marked reduction between 2018 and 2019, particularly at Britannia Bridge. The Britannia Bridge reduction is statistically highly significant [T-test on square root transformed percentage cover data (equal variances): n=52, df=50, t=2.85, P(one-tailed)=0.0032]. The Felinheli data has too many zero values for a straightforward parametric test.

Initial assessment of these reductions was concerned that it might be due to a change in survey personnel, as Jen Jones was not available for the 2019 survey. This would have suggested a significant weakness in the methodology. However, it is now clear that the analytical protocols (merging those species that are inconsistently recorded) taken compensated for any reduced species discrimination.

Figure 12. Average percentage cover (± standard error) of all Porifera. Each point is calculated from a minimum of 25 boulders.



3.3.2 Polychaete worms

Frequently occurring polychaetes include mobile scale worms (Polynoidae), the sand-tube forming *Sabellaria* (both *S. alveolata* and *S. spinulosa* have been identified in collected specimens) and the calcareous tube forming keel worm *Spirobranchus* and Spirorbids. Most of these taxa are more abundant under boulders, but *Sabellaria* can be common on boulder tops.

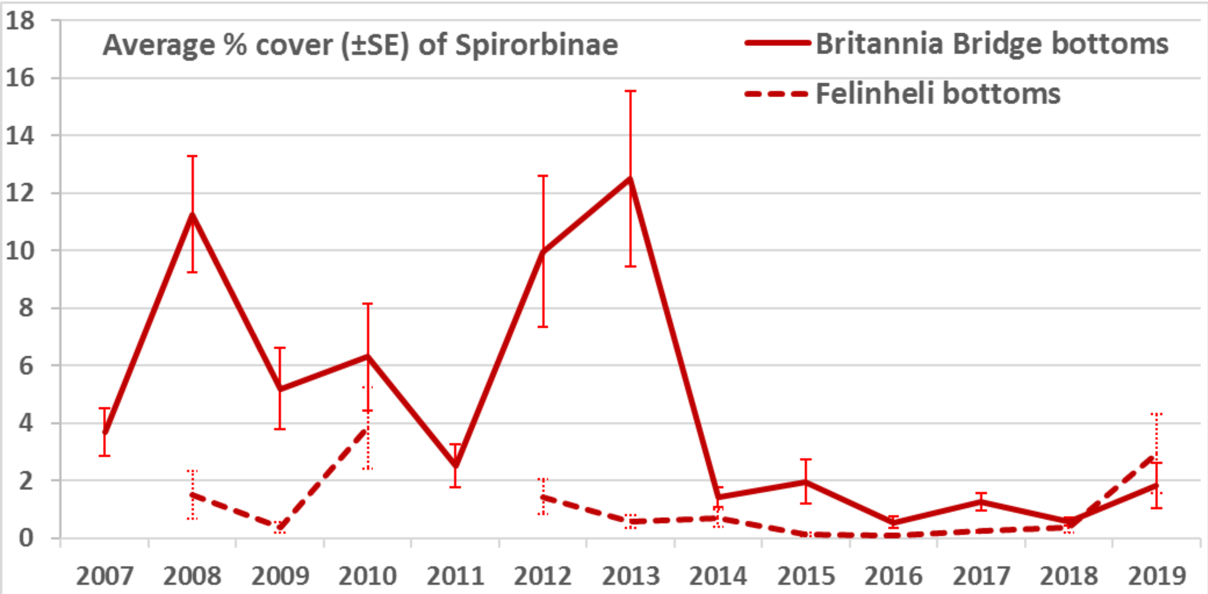
Table 2, which combines the occurrence data from both sites and from boulder tops and bottoms, shows few notable trends. However, it is interesting that scale worms have been recorded less often in recent year. Increases in *Sabellaria* are also notable and are largely from records on boulder tops at Britannia Bridge, particularly monitoring stations at the south west end of that site. Recent records from Station BB1 (furthest south west) give abundances as high as 90% cover on some boulder tops. Current monitoring survey protocols specify only presence/absence recording for *Sabellaria* but surveyors often record percentage cover when it is so conspicuously abundant. For future monitoring it will be appropriate to change the protocol to record percentage cover routinely for this species.

Table 2. Percentage occurrence of the most frequently recorded polychaetes, across both sites.

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Polynoidae	12	32	44	54	64	49	49	52	27	27	38	35	31
Sabellaria	44	13	28	32	76	32	44	51	36	57	61	50	56
Spirobranchus	100	93	82	88	92	81	89	89	95	90	95	91	92
Spirorbinae	88	72	67	86	100	86	79	70	75	63	95	80	77

Percentage cover is routinely recorded for Spirorbids and *Spirobranchus*, though abundances of the latter are usually so low that they are not considered further here. Though often abundant in numbers, the small body size of the former also means that percentage cover is usually low and accuracy of the estimates may be poor. However, Figure 13 suggests that abundance has been much lower since 2014 compared to previous years, particularly at Britannia Bridge. Data from boulder tops shows that abundances are generally lower.

Figure 13. Average percentage cover (± standard error) of Spirorbid worms on boulder bottoms. Each point is calculated from a minimum of 25 boulders.



3.3.3 Barnacles and other crustacea

Four species of barnacles are routinely recorded on the boulders, though *Verruca stroemia* is cryptic and easy to miss. Numerous species of mobile crustacea (amphipods, isopods, prawns, crabs etc.) are also recorded, but only two species are frequent. See Table 3.

- *Verruca stroemia* - it is possible that its apparent absence in 2009 (Table 3), followed by notable increases from 2010, is related to the quality of the recording. However, it has always been listed on the recording form so surveyors should have been looking for it. The notable increase in 2019 contributed to the change in the whole community shown in Figure 10.
- *Other barnacle species* - fluctuations in frequency of occurrence are evident but with no notable trends.
- *Adult barnacle cover* – average percentage cover has fluctuated considerably, particularly at Felinheli (
- Figure 14). At Britannia Bridge there appears to have been a trend of decrease over the course of the monitoring, and a two-way anova comparing Period (early (2007-2011) v late (2014-2019) and Side (tops and bottoms)) finds the difference between the Periods to be statistically highly significant ($p<0.0001$).
- *Juvenile barnacle cover* – large fluctuations particularly at Felinheli (Figure 15) with high abundance in 2016 and 2019, but no apparent trends.
- *Dead barnacle cover* – there has been a notable decline in percentage cover of dead barnacles (Figure 16), particularly at Britannia Bridge. As for adult barnacles, a two-way anova (Period & Side) finds the difference between the Periods to be statistically highly significant ($p<0.0001$).

- *Porcellana platycheles* (hairy porcelain crab) – some fairly large fluctuations in the frequency of their occurrence, but no apparent trends.

Table 3. Percentage occurrence of barnacles and selected other crustacea across both sites.

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Verruca stroemia	16	9		7	20	19	26	25	18	35	27	24	40
Semibalanus balanoides	76	92	59	91	52	85	70	66	82	45	71	61	65
Balanus crenatus	68	59	77	75	100	88	91	92	91	100	93	87	98
Austrominius modestus	60	59	46	54	60	66	74	48	78	67	82	76	88
Porcellana platycheles	52	29	26	33	68	31	40	43	44	37	54	39	44
Carcinus maenas	24	18	16	70	48	49	46	54	27	39	43	30	33

Figure 14. Average percentage cover (± standard error) of adult barnacles. Each point is calculated from a minimum of 25 boulders.

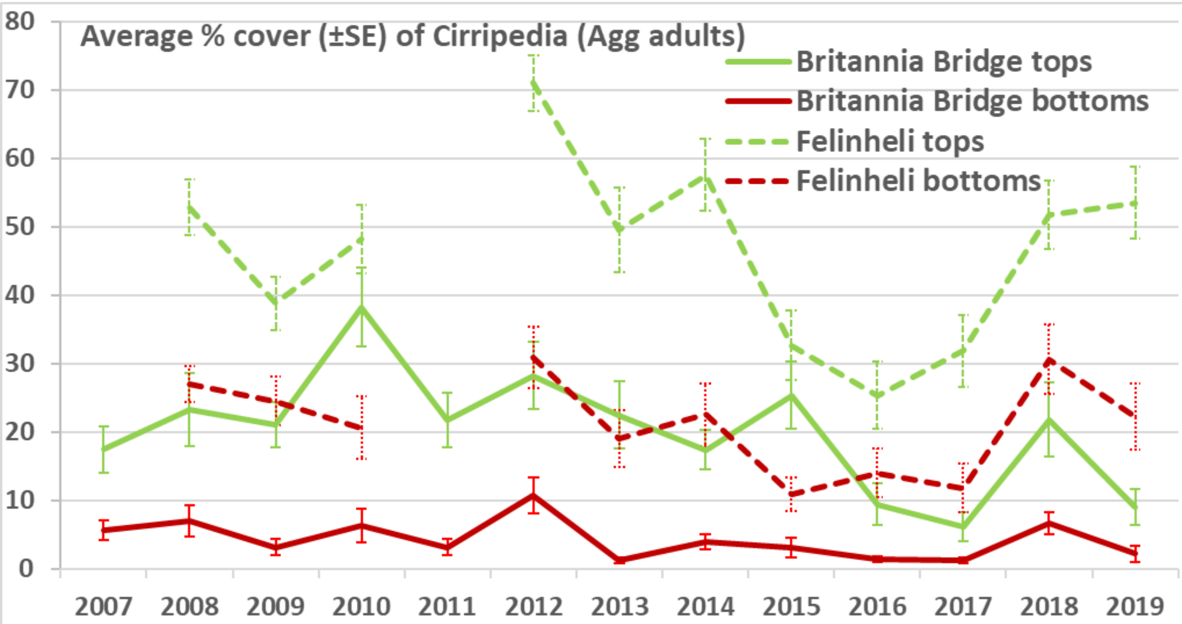


Figure 15. Average percentage cover (± standard error) of juvenile barnacles at Felinheli. Each point is calculated from a minimum of 25 boulders.

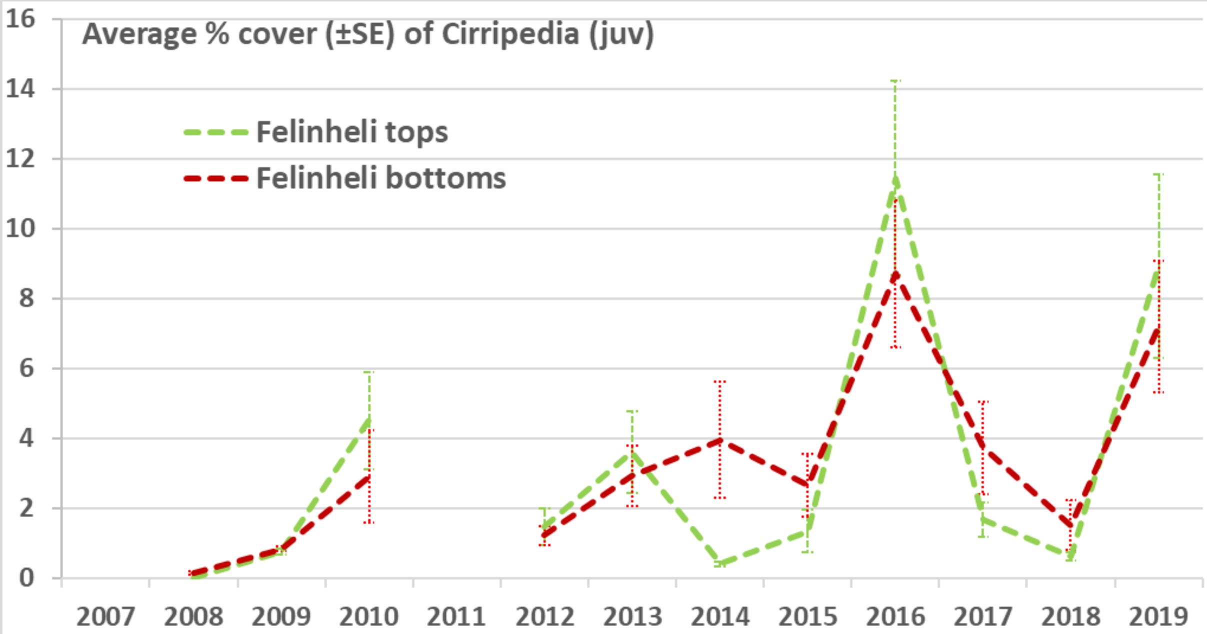
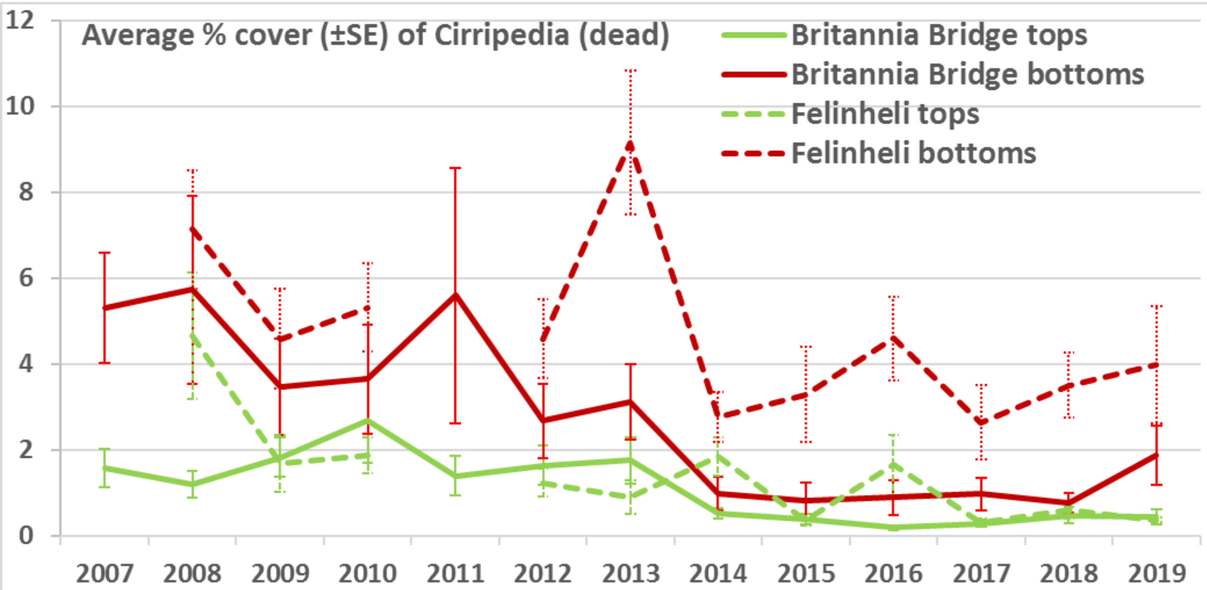


Figure 16. Average percentage cover (± standard error) of dead barnacles. Each point is calculated from a minimum of 25 boulders.



3.3.4 Molluscs

Numerous snails, sea slugs and bivalves have been recorded from the boulder tops and bottoms, but the majority are infrequent. Table 4 shows the frequency of occurrence for six snails and one bivalve. Note: records for the more mobile snails, i.e. the tops shells, littorinids and dogwhelks, may be influenced by environmental conditions.

Fluctuations are shown for all seven taxa, but with known relationships to other factors of interest. 2007 and 2011 stand out for their low abundance of limpets *Patella vulgata* and edible winkles *Littorina littorea*, but this is because those species are more abundant at Felinheli, which was not surveyed in those years.

Table 4. Percentage occurrence of the most frequently recorded snails, across both sites.

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Patella vulgata	20	32	26	30	8	34	21	18	22	12	21	24	29
Sterомphala cineraria	40	47	38	46	24	29	30	23	42	47	54	35	29
Steromphala umbilicalis	40	21	18	7	12	3	7	2	11	12	11	17	8
Littorina littorea		14	11	19		19	12	7	11	12	23	20	29
Littorina obtusata (/fabalis)	72	18	34	75	60	51	44	41	22	12	30	24	15
Nucella lapillus	64	51	38	54	72	47	46	30	31	41	50	48	48
Anomiidae	32	41	49	60	60	59	39	57	45	51	79	69	50

3.3.5 Sea-squirts

Ascidians are a major component of the boulder fauna, particularly on the boulder bottoms and particularly at Britannia Bridge. Over 30 taxa have been recorded, plus a number of entities (particularly Didemnids) that couldn't be identified to species and have been recorded using qualifiers of colour and texture. Table 5 shows the frequency of occurrence for seven taxa, two of which (Polyclinidae and Didemnidae) are combined from a number of individual species that are not easily distinguished.

Table 5. Percentage occurrence of the most frequently occurring sea-squirts, across both sites.

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Clavelina lepadiformis	4	7	16	12	8	12	12	28	13	29	16	30	4
Polyclinidae	4	14	8	25	4	22	12	25	11	10	16	19	12
Aplidium turbinatum		49	66	44	28	46	49	46	38	27	18	30	13
Didemnidae	20	39	36	35	68	44	44	44	49	43	45	54	31
Corella eumyota			3	2	56	53	51	74	56	24	55	2	2
Dendrodoa grossularia	68	43	46	46	72	47	51	41	44	45	46	28	37
Botryllus schlosseri	36	26	18	33	60	14	32	13	22	4	27	13	17

The most conspicuous change has been the dramatic appearance of the invasive solitary ascidian *Corella eumyota* in 2011, followed eight years later by a rapid decline (Figure 17). This species was first recorded in Wales in 2005 (Macleod *et al*. 2016), but its first appearance on the surveyed boulders in the early years of this programme is confused by records (possibly misidentified) of *Ascidiella scabra*.

Less dramatically, the frequency of occurrence of a number of colonial ascidian taxa also increased to a peak in the period 2013-15 and then declined. They include the polyclinid *Aplidium turbinatum* and other polyclinids, *Clavelina lepadiformis* and the didemnids.

Species richness of ascidians at Britannia Bridge (see Figure 8 in Section 3.1) showed a similar increase and then decline. There was no clear pattern of change at Felinheli, where ascidian occurrence and abundance was generally much lower anyway.

The graph in Figure 18 also shows that the percentage cover of colonial ascidians on boulder bottoms at Britannia Bridge increased to a peak in 2013 and then decreased. A one-way anova comparing abundance for three Periods (A (2010-2011), B (2012-2015) and C (2016-2019)) finds the difference between the Periods to be statistically highly significant ($p<0.0001$). There was no obvious trend at Felinheli data, but that data have too many zero values for any meaningful analysis.

The graph in Figure 19, for solitary ascidians is strongly influenced by the abundance of *C. eumyota* and shows that its percentage cover fluctuated more than its frequency of occurrence during the period when it was present.

The solitary species *Dendrodoa grossularia* is notable because it showed relatively little variability in its occurrence. The high values in 2007 and 2011 are because it is more common at Britannia Bridge (Felinheli was not surveyed in those years).

Figure 17. Percentage occurrence of *Corella eumyota*. Each point represents a minimum of 25 boulders.

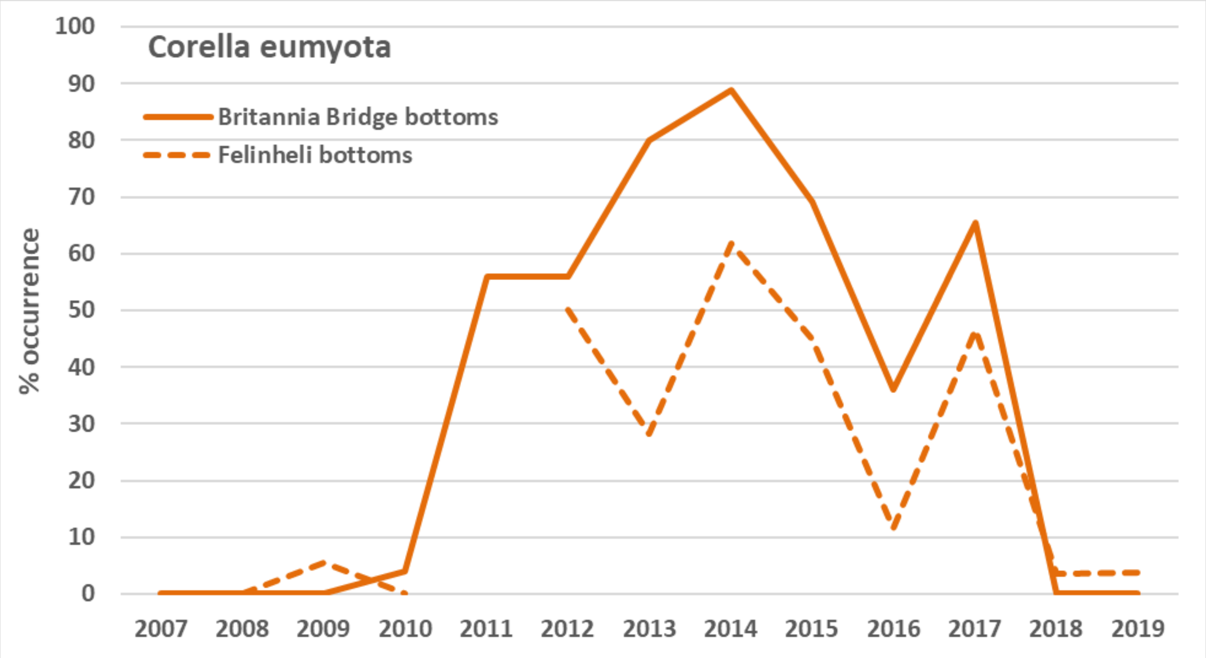


Figure 18. Average percentage cover (± standard error) of colonial ascidians. Each point is calculated from a minimum of 25 boulders.

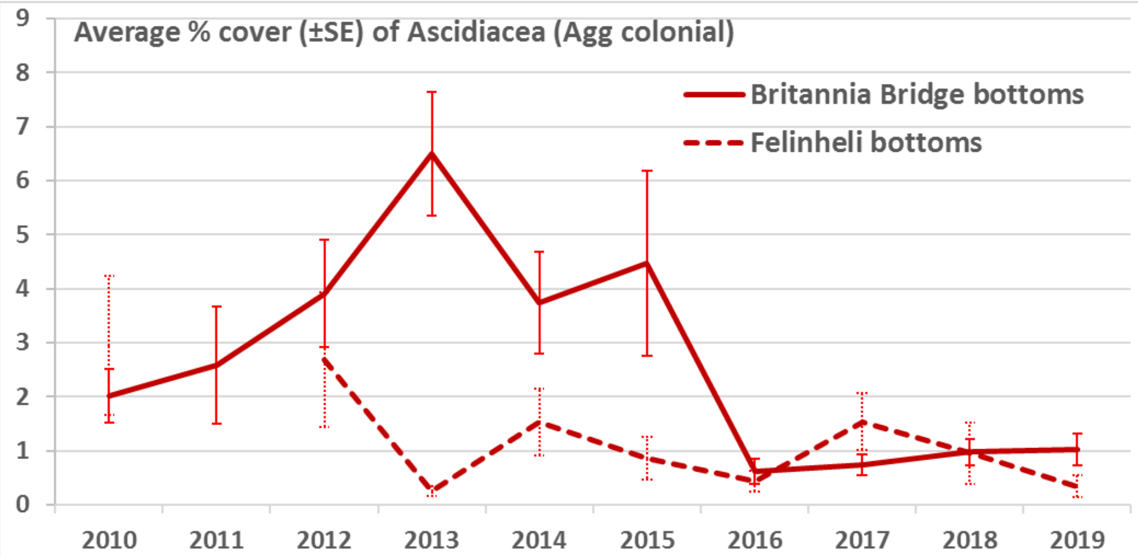
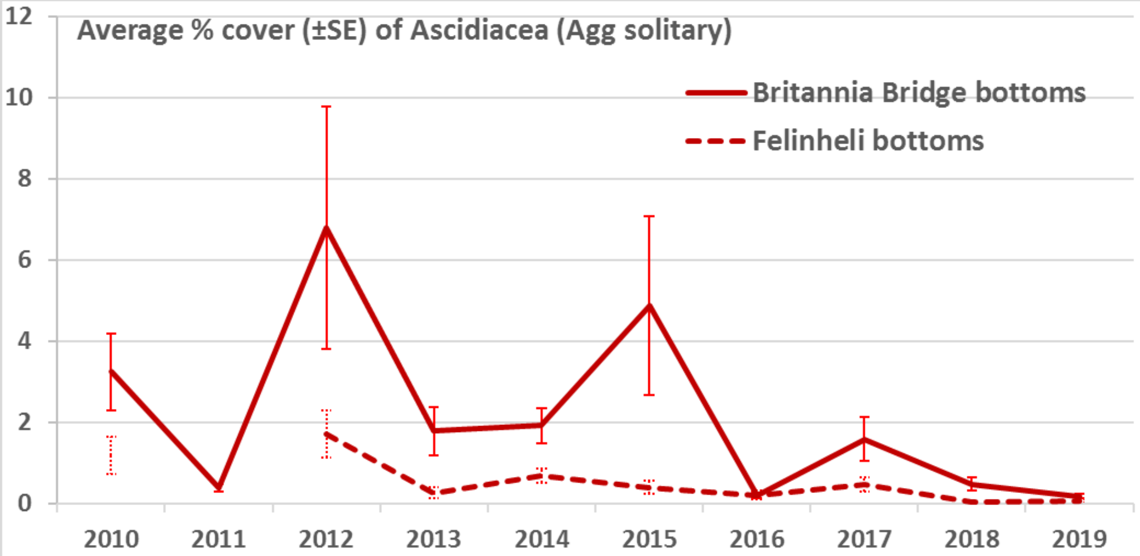


Figure 19. Average percentage cover (± standard error) of solitary ascidians. Each point is calculated from a minimum of 25 boulders.



3.3.6 Other animals

This sub-section includes selected animal taxa from phyla not included above. Table 6 shows the frequency of occurrence for five taxa, from three phyla.

Table 6. Percentage occurrence of selected other invertebrates, across both sites.

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Actinia		13	13	16		22	21	13	25	18	16	17	8
Bryozoa (enc)	80	84	70	86	92	86	88	84	87	78	95	87	90
Amathia		4	3	12		8	2	13	20	6	20	22	15
Asterias rubens		3			32	15	21	5		6	2		2
Ophiothrix fragilis		13	10	18	40	22	19	20	16	20	25	24	37

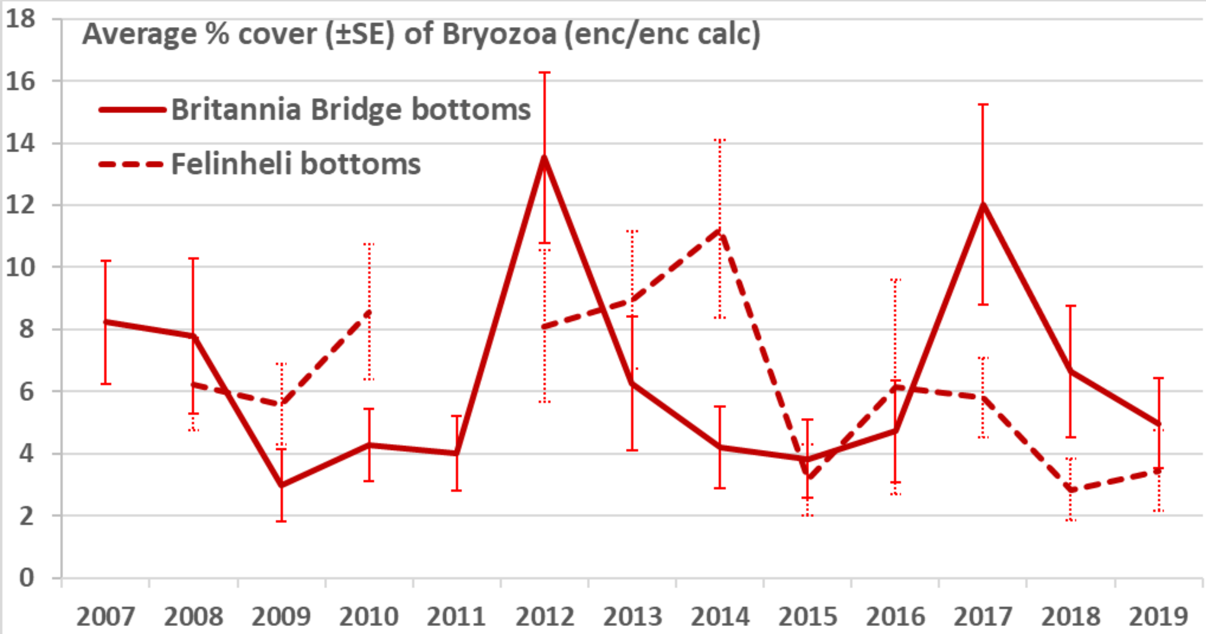
Actinia, primarily comprising the beadlet anemone *Actinia equina*, are frequent at Felinheli but have almost never been recorded from the Britannia Bridge boulders, which explains their absence in Table 6 in 2007 and 2011. Fluctuations are otherwise relatively low.

Encrusting bryozoa are almost ubiquitously present on the undersides of boulders. However,

Figure 20 shows that their average percentage cover fluctuates considerably. Some care needs to be taken when interpreting these data as these crusts are not always easy to see.

The other taxa in Table 6 show large fluctuations in their occurrence, but with no known relationships to other factors of interest.

Figure 20. Average percentage cover (± standard error) of encrusting calcareous bryozoa. Each point is calculated from a minimum of 25 boulders.



3.3.7 Red algae

Various red algae are present as an understorey turf below the fucoid algae on tops of the boulders. Crustose species are also present and are occasionally found on the undersides where some light reaches under the boulder. The relatively high frequency of occurrence of many taxa in 2011 is mainly because they only include data from Britannia Bridge (Felinheli not surveyed in 2011), but it is possible that surveyors selected a higher proportion of boulders at the lower edge of the *Fucus serratus* zone than in other years (see notes on *Laminaria digitata* in the next section).

Table 7 shows the frequency of occurrence for ten taxa, including encrusting taxa.

The relatively high frequency of occurrence of many taxa in 2011 is mainly because they only include data from Britannia Bridge (Felinheli not surveyed in 2011), but it is possible that surveyors selected a higher proportion of boulders at the lower edge of the *Fucus serratus* zone than in other years (see notes on *Laminaria digitata* in the next section).

Table 7. Percentage occurrence of the most frequently occurring red algae, across both sites.

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Ceramium deslongchampsii		4	11	2	28	2	18	30	16	22	34	24	17
Chondrus crispus	92	59	52	58	100	63	79	69	71	69	64	70	69
Corallinaceae (enc)	56	63	51	61	92	59	67	46	47	57	68	54	60
Gelidium	24	8	2	9	4	7	7	5	7	8	18	7	10
Hildenbrandia	4	30	16	58	84	56	86	25	69	61	71	61	85
Lomentaria articulata	4	4	10	7	16	14	14	15	11	12	13	20	4
Membranoptera alata	8	20	18	12	52	14	23	20	15	24	14	28	12
Palmaria palmata		5	10	5	36	10	21	15	7	8	25	26	13
Rhodothamniella floridula	4	4	5	9	8	8	4	21	11	16	16	13	6

Large fluctuations in frequency of occurrence are shown for many of the taxa, but any relationships with environmental factors are currently unknown. The low values in 2007 may be because less time was spent surveying in the first year of the programme.

Figure 21 and Figure 22 show that percentage cover of encrusting coralline algae and red algal turf have fluctuated considerably in some years. No clear trends are apparent, and while the low cover of red algal turf at Britannia Bridge in 2019 appears notable in a one-way anova of abundance with Year (Logit transformed) finds that the differences are not statistically significant (p=0.055). Note: the high average cover values for encrusting coralline algae at Britannia Bridge in 2012 and 2013 were both due to a single boulder with 80% cover.

Figure 21. Average percentage cover (± standard error) of encrusting coralline algae. Each point is calculated from a minimum of 25 boulders.

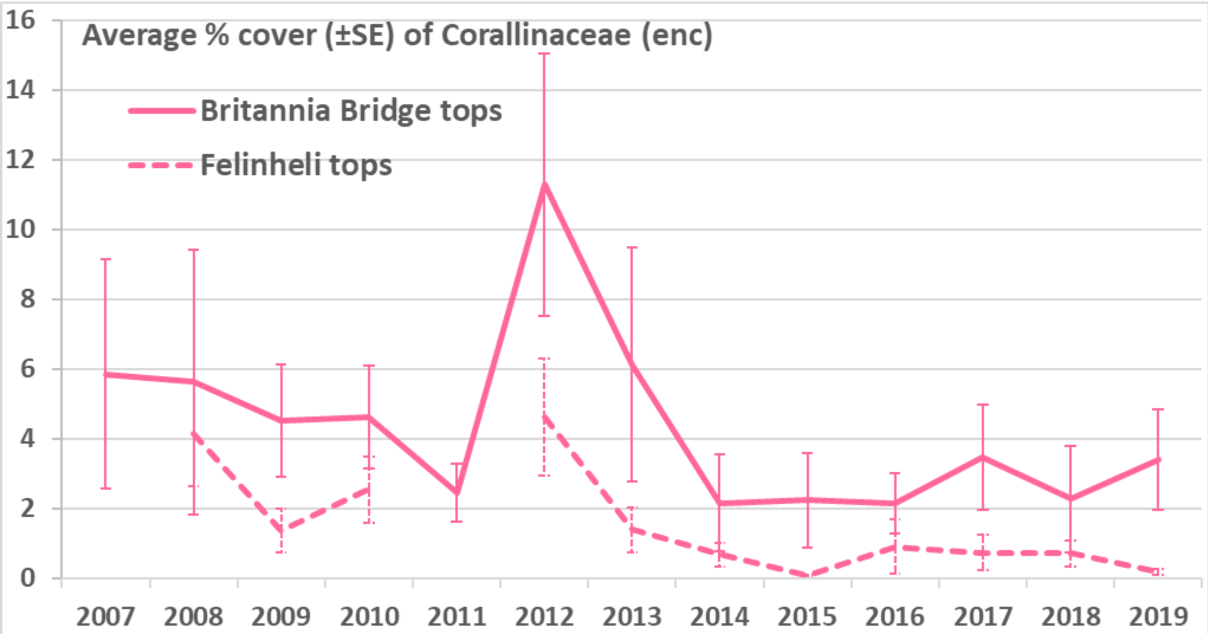
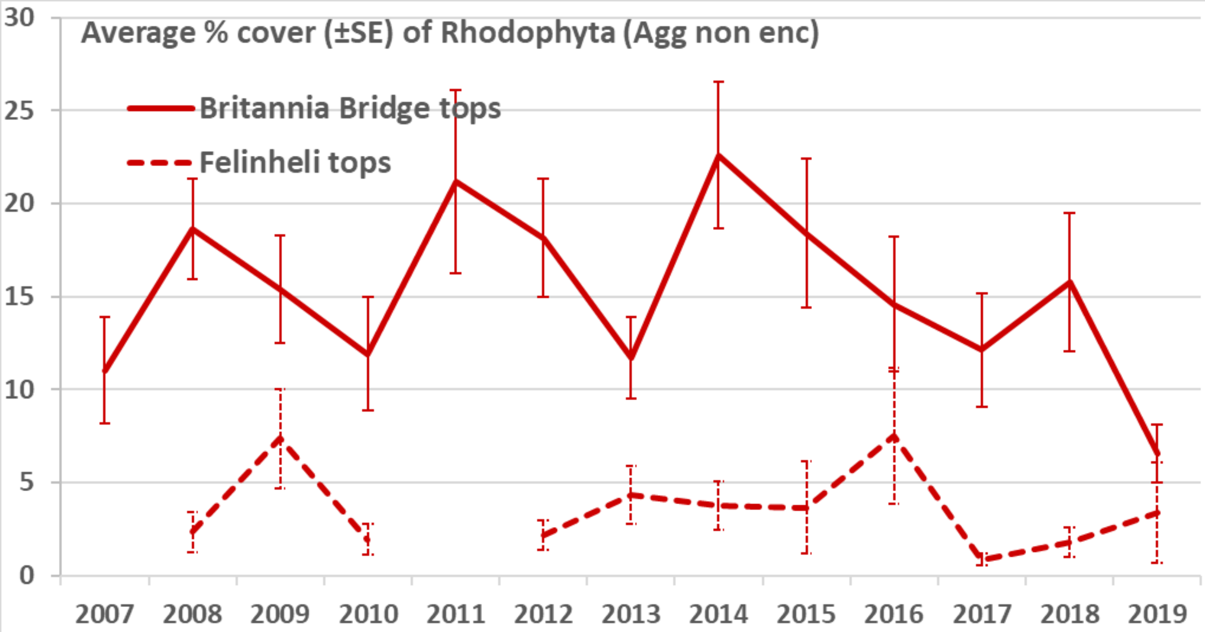


Figure 22. Average percentage cover (± standard error) of red algal turf. Each point is calculated from a minimum of 25 boulders.



3.3.8 Fucoids and other brown algae

The monitored boulder habitat is defined by the presence of *Fucus serratus*, which forms a canopy on the tops of most, but not all, boulders. Other fucoids add to the canopy and kelp is also sometimes present. Other brown algae are present as part of the under storey. Table 8 shows the frequency of occurrence for six selected taxa.

Table 8. Percentage occurrence of the most frequently occurring brown algae at both sites.

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Cladostephus spongiosus		4	5	14	32	25	23	16	16	24	21	20	23
Laminaria digitata		7	8	4	56		21	13	4	8	9	19	8
Fucaceae (sporelings)	24	5	62	60	72	42	79	92	93	92	96	94	85
Ascophyllum nodosum	24	18	15	11	8	22	11	5	16	4	18	11	19
Fucus serratus	100	93	89	96	100	95	100	95	98	88	91	100	98
Fucus vesiculosus	24	11	26	30	4	24	26	21	40	20	30	44	38

The notably high % occurrence of *Laminaria digitata* and low % occurrence of *Fucus vesiculosus* in 2011 suggests that surveyors selected a higher proportion of boulders at the lower edge of the *Fucus serratus* zone than in other years. Counter indications are that the value is exaggerated because it only includes data from Britannia Bridge (Felinheli not surveyed in 2011), that the predicted low tide heights were not especially low during the 2011 survey and that all kelp plants visible in the photographs were sporelings or young – i.e. there may have been an unusually good settlement and growth of young plants within the lower eulittoral that year.

Percentage cover of *Fucus serratus* (

Figure 23) suggests a trend of decreasing cover, by more than a third, at both sites. Spearman rank tests find strongly significant negative correlations ($P<0.0001$) between % cover and year.

No notable trends in percentage cover of *Fucus vesiculosus* are apparent, though fluctuations were large (Figure 24).

Fluctuations in frequency of occurrence are shown for the other taxa, but with no known relationships to factors of interest.

Figure 23. Average percentage cover (± standard error) of *Fucus serratus* (not recorded in some of the earlier years). Each point is calculated from a minimum of 25 boulders. Note: not consistently recorded as % cover in 2008 and 2009.

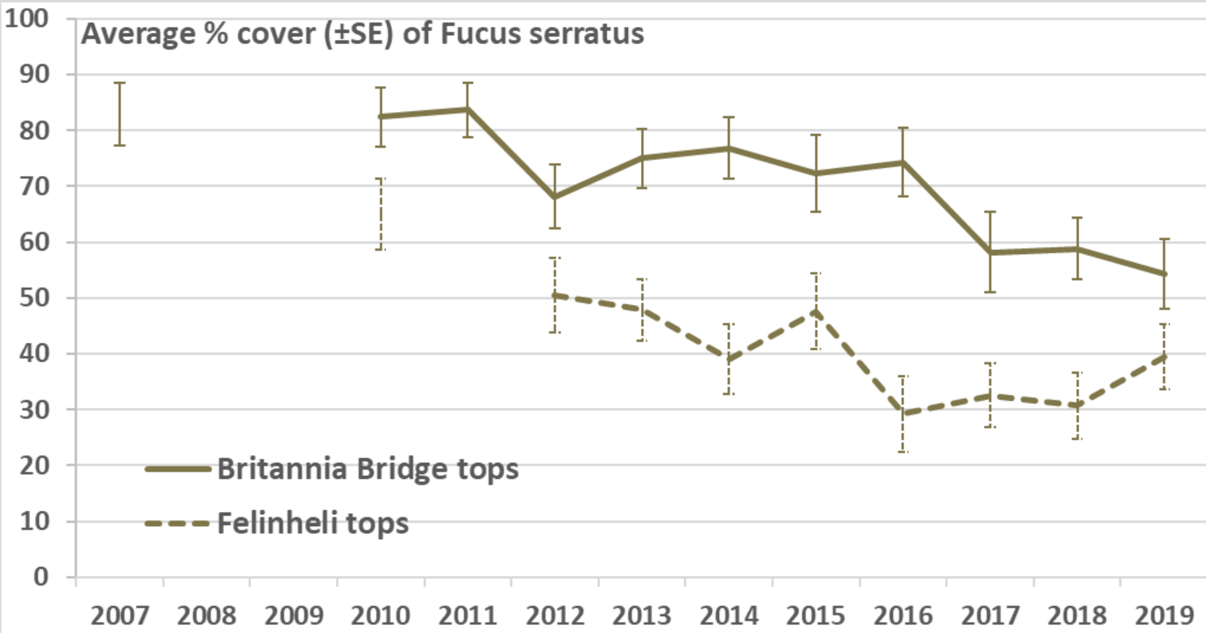
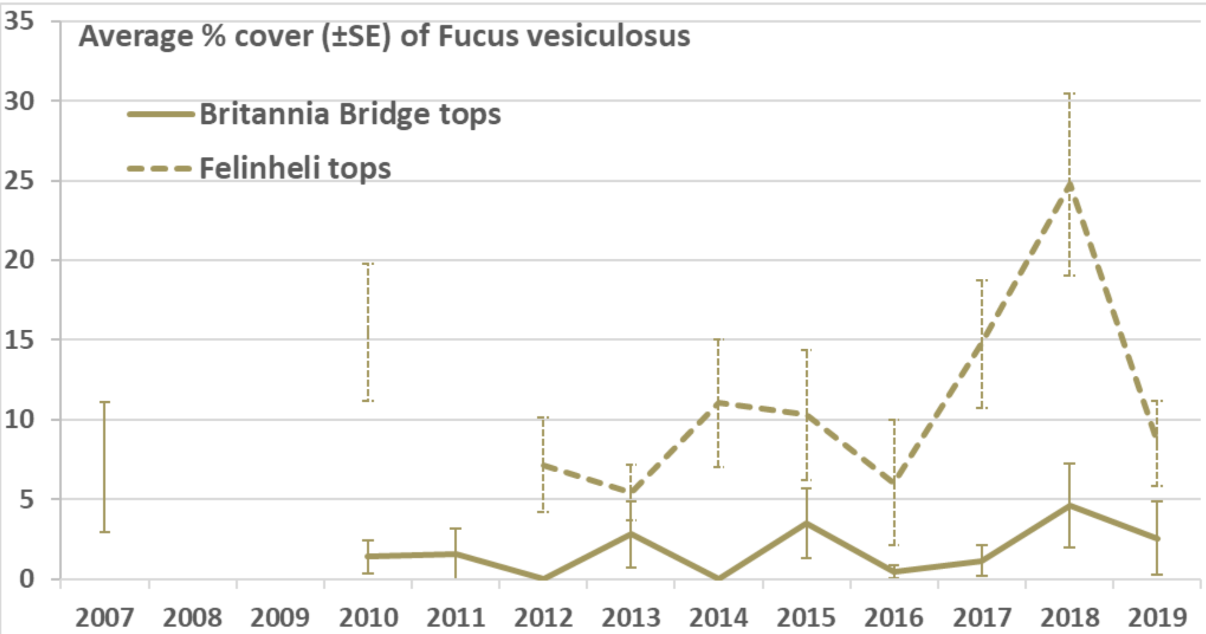


Figure 24. Average percentage cover (± standard error) of *Fucus vesiculosus* (not recorded in some of the earlier years). Each point is calculated from a minimum of 25 boulders. Note: not consistently recorded as % cover in 2008 and 2009



3.3.9 Green algae

Various green algae are present on the tops of some boulders. Table 9 shows the frequency of occurrence for four selected taxa.

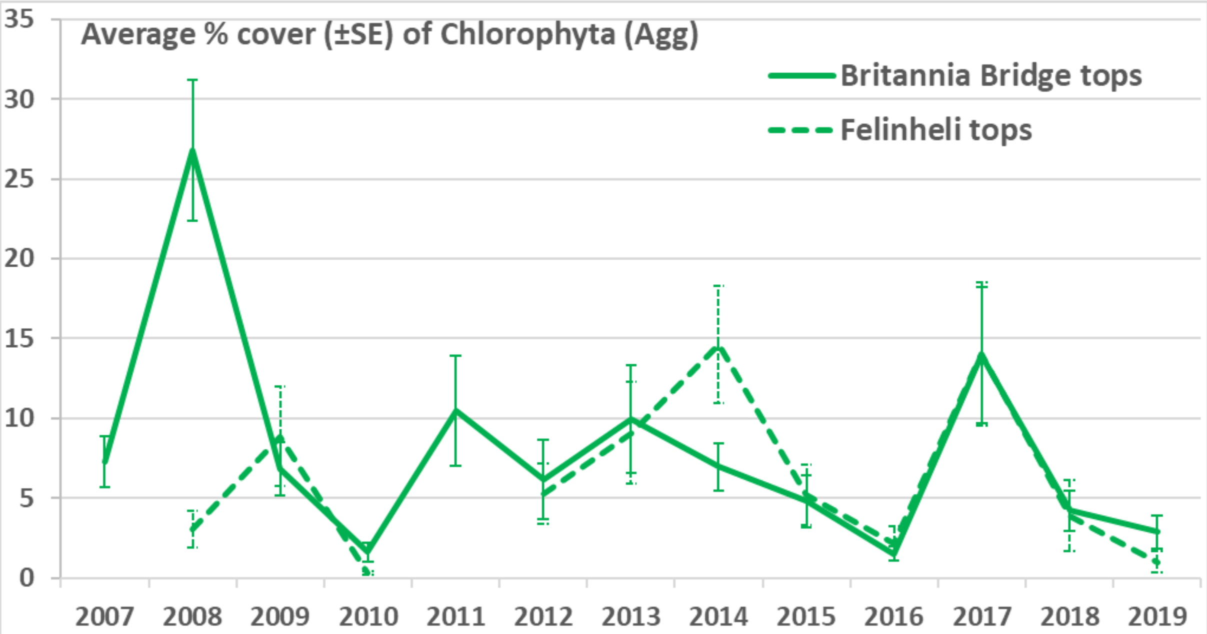
Table 9. Percentage occurrence of the most frequently occurring green algae at both sites.

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Ulva (tubular)	16	8	11	12	20	24	18	48	25	14	25	13	8
Ulva (flat)	76	67	69	56	80	71	77	82	67	67	79	67	56
Chaetomorpha		5	5	12	24	22	5	15	4	6	7	7	12
Cladophora rupestris	40	20	20	30	48	24	19	23	25	35	21	17	35

Large fluctuations in frequency of occurrence are shown for all four taxa, but no trends are evident and any relationships with environmental factors are currently unknown.

Similarly, Figure 25 shows some large fluctuations in percentage cover of green algae, but with no apparent trends of interest.

Figure 25. Average percentage cover (± standard error) of green algae. Each point is calculated from a minimum of 25 boulders.



3.4. Effects of boulder turning

Available data on boulder turning are limited to simple assessments, made by the boulder community surveyors, of whether the boulder had been turned and left upside down by someone in the past. The surveyors make the assessment on the basis of various signs, including the presence of algae and other typical upper boulder taxa on the underside, and *vice versa*. Some signs, like the presence of decaying fucoid algae underneath, are reliable, but the assessment is subjective.

Table 10 shows that average taxonomic richness is lower on boulders that have been assessed as 'turned', at both sites. Analysis of variance shows that the differences between 'turned' and 'unturned' are statistically highly significant ($p<0.0001$)

Table 10. Average taxonomic richness (and standard deviation) for boulders at Britannia Bridge and Felinheli by Turned? (i.e. whether surveyors considered it had been turned).

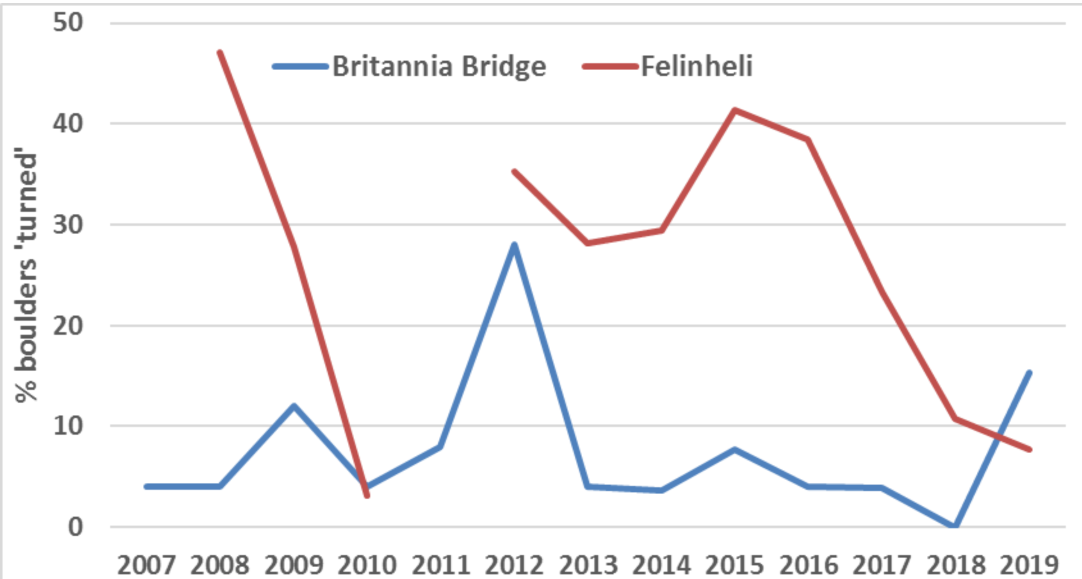
	Britannia Bridge	Felinheli
Unturned	29.1 (7.3)	19.6 (5.4)
Turned	24.8 (6.5)	17.4 (5.5)
Uncertain	22.6 (4.5)	17.8 (6.0)

Multivariate analysis of whole community data also shows the effect of 'turning'. A two-way ANOSIM test (Turned? x Site) gives an R-value of 0.078 and significance level of 3.2% (i.e. statistically significant) for the difference between 'turned' and 'unturned' boulders (see Appendix 5).

A two-way SIMPER analysis (Turned? x Site) shows that a large number of taxa contribute to the community composition differences between 'turned' and 'unturned' boulders (see Appendix 5). The majority occurred less frequently on 'turned' boulders. The most notable taxa include saddle oysters Anomiidae, Porifera (aggregate, but particularly *Hymeniacidon perlevis* and *Halisarca dujardinii*), encrusting coralline algae, flat winkles *Littorina obtusata*, scale worms Polynoidae, *Chondrus crispus*, red algal turf (aggregate), colonial and solitary ascidians (aggregates, but particularly Didemnidae), Spirorbinae and many others.

Figure 26 shows that the percentage of boulders assessed as 'turned' has fluctuated considerably and while it was higher at Felinheli in most years, it was higher at Britannia Bridge in 2010 and 2019. No information on likely related factors is available to compare with these data, but it seems unlikely that they provide good evidence of real trends in boulder turning by bait collectors. It is possible that the assessments of 'turning' are not always inaccurate, but it is also possible that the selection of boulders is not as random as intended. It is difficult not to be influenced, towards or away from, the conspicuously disturbed boulders.

Figure 26. Percentage of surveyed boulders that showed clear signs of having been 'turned' at both sites. A minimum of 25 boulders were surveyed at each site in each year.



4. Discussion and conclusions

4.1. Temporal changes

The most notable results from the analyses are:

Species richness increased over the first four years of the programme, likely due to development of the methodology and the increasing knowledge and familiarity of the surveyors with the species assemblages present. This is to be expected in the early stages of monitoring programmes based on *in situ* recording of epibiota communities and should be taken into account when developing methodological protocols for future programmes (i.e. putting an emphasis on QA/QC procedures, specimen collections and lots of good quality close-up photographs right from the start).

After that initial increase, species richness at Britannia Bridge fluctuated within levels that are considered reasonable for the community and methodology, although there was a notable reduction in 2019, particularly of sponges, which is discussed below.

Species richness at Felinheli has also fluctuated moderately in recent years without any significant trends, but the total number of species recorded in each year appears to have declined. This is also discussed further below.

Multivariate analysis of community composition has shown a progressive change over the course of the programme, with a very similar trajectory at both sites and on both boulder tops and boulder bottoms. The largest changes occurred over the first six years and the communities have remained relatively stable since 2013. However, as mentioned above, some notable changes to boulder bottom communities occurred in 2019. Sponges (see below) were a major contributor to that change, but many other taxa also contributed, so it could be the start of another notable shift. Relationships with environmental factors are not known.

Multiple species, from many phyla, have contributed to the progressive changes in community composition described above, but a few have shown notable changes or trends, including:

Sponges : a statistically significant reduction in the number of species and the percentage cover of sponges on boulder bottoms occurred between 2018 and 2019 at Britannia Bridge. There was also a reduction at Felinheli, but it was not significant. Two commonly occurring species, *Microciona atrasanguinea* and *Halisarca dujardinii*, were particularly affected. No explanation for the reduction is yet known, but it may be no coincidence that recent records from subtidal monitoring in the Menai Strait found a marked reduction in some other sponge taxa in 2019 (NRW pers. comm.).

Spirorbid and Serpulid worms: reduced in abundance since 2014.

Barnacles: the percentage cover of adult barnacles and of dead barnacles both show a significant trend of decrease, at Britannia Bridge, over the course of the programme.

Sea squirts: the dramatic appearance, increase and then disappearance of the invasive solitary ascidian *Corella eumyota*. Also, a statistically significant increase and then decrease in the percentage cover of colonial ascidians at Britannia Bridge.

Fucus serratus: percentage cover of serrated wrack on boulder tops decreased by more than a third at both sites over the course of the programme – a statistically highly significant correlation with year. Interpreting this decline is complicated by the protocol for boulder selection, which attempts to be random but is inherently influenced by the abundance of this wrack. Nevertheless, the apparent decline is a concern and requires further study.

4.2. Impacts and threats

The apparent decline in total species richness at Felinheli is a concern. Surveyors have mentioned that the lower shore habitat at many of the Felinheli monitoring stations appears to have become muddier over the course of the programme and that it has been increasingly difficult to find boulders that fit the criteria for monitoring. Increasing mud and fewer suitable boulders could explain a reduction in overall diversity while maintaining the average species richness. Unfortunately, the monitoring methodology does not provide adequate data (or fixed point photographs) to monitor changes in the lower shore habitat at each station.

The impacts of boulder turning on individual boulders are clearly shown, both *in situ* on the shore and in the monitoring data. Gross effects have been observed on many boulders around Felinheli, particularly where smothered and rotting algae are found under boulders. Conversely, signs of boulder turning were much less common on the shores near Britannia Bridge, likely to be due to more difficult access. The monitoring data further describes reduced species richness and reductions in the occurrence of many species. However, the evidence to demonstrate boulder turning as a significant cause of overall decline in species richness at Felinheli is to some extent subjective, given the confounding effects of increasing mud. The available data are also inadequate for detecting any changes or trends in the rate of boulder turning at either Felinheli or Britannia Bridge. Nevertheless, bait and winkle collection are considered a threat to these communities, because some collectors turn boulders and neglect to turn them back again.

Other potential generic threats to the condition of these communities include water pollution, siltation, dredging and changes to water circulation.

4.3. Methods and protocols

Inconsistency of recording between (and within) surveyors is a constant concern in this type of monitoring and inevitably limits the ability to detect real change and can result in apparent changes that are not real. However, it is clear from results like those shown in Figure 10, which clearly separates the records into year groups, that the methodology is sufficient to detect many temporal changes. The importance of continued application of QA/QC procedures is reiterated.

It is recommended that fixed photo point are used to record the state of the mud levels at each site, with the possibility of establishing a method of detecting changes in sediment level.

Developing a method to monitor the levels of boulder turning activity and the possible damage caused by bait and shellfish collection would lead to future opportunities to improve site management.

5. Condition assessment

Britannia Bridge: **Favourable**

A number of changes have occurred in the monitored communities since the programme began in 2007, but recorded changes in species richness, species composition and abundance appear to be within the normal range of natural fluctuations. The apparent notable changes in 2019 requires further study.

Felinheli: **Unfavourable**

Concerns due to impacts of continued boulder turning for bait on species richness and composition. The majority of boulders at this site show evidence of having been repeatedly turned, including the presence of smothered and rotting algae and dead barnacles. It is considered likely that boulder turning was a factor causing the relatively low species richness, compared to Britannia Bridge.

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Appendix 1 Monitoring surveys of lower eulittoral tide-swept boulders in the Menai Strait

BB = Britannia Bridge, FE = Felinheli. 5 (25) = No. of stations (and boulders) surveyed

Year	BB	FE	Start date	End date	Surveyors
2007	5 (25)	0	13 Sep	14 Sep	JJM DPB FDB JMJ KS AL
2008	5 (25)	5 (51)	03 Jun	05 Jun	JJM DPB CMH JMJ VP KS GW KR
2009	5 (25)	5 (36)	22 Jun	25 Jun	JJM FDB JMJ EH GW CD
2010	5 (25)	5 (32)	12 Jul	14 Jul	JJM DPB FDB JMJ DH EH
2011	5 (25)	0	01 Aug	02 Aug	JJM DPB FDB LK GA
2012	5 (25)	5 (34)	05 Jul	07 Jul	JJM DPB CMH JMJ BW LK
2013	5 (25)	5 (32)	24 Jun	26 Jun	JJM DPB FDB JMJ NL RS LK
2014	5 (27)	5 (34)	13 Jul	15 Jul	JJM DPB FDB JMJ LK MD RS
2015	5 (26)	5 (29)	02 Jul	04 Jul	JJM FDB JMJ FW NL EWJ LK
2016	5 (28)	5 (26)	05 Jun	08 Jun	JJM FDB JMJ JDD TK LAJ EWJ LK AS LG
2017	5 (26)	5 (30)	23 Jun	25 Jun	JJM DPB TSM JMJ HR LG KG
2018	5 (26)	5 (28)	13 Jun	17 Jun	JJM DPB FDB JMJ RD SE
2019	5 (26)	5 (26)	02 Jun	05 Jun	JJM DPB FDB JAT KSB LG KR

More details are given in the survey field logs, which are available on request.

Appendix 2 Full list of taxa recorded

Taxonomic names are according to the World Register of Marine Species (WoRMS, http://www.marinespecies.org), updated for this report in 2019. Qualifiers, for some taxa, are given in brackets after the name. Recording method (P = Presence, % = Percentage cover, T% = Total Percentage cover (for aggregate taxa). Total number of records from all boulders (2007 to 2019) is given in brackets. Taxa are sorted in a taxonomic order based on the Species Directory codes of Howson and Picton 1997.

SPONGES
Porifera P (3)
Porifera (enc indet) P (2)
Porifera (white) P (1)
Porifera (orange) P (10)
Porifera (orange enc) P (12)
Porifera (orange thin enc) P (1)
Porifera (buff) P (26)
Porifera (beige encrusting) P (3)
Porifera (Agg) T% (898)
Calcarea (enc) P (1)
Clathrina P (5)
Clathrina coriacea P (17)
Leucosolenia P (329)
Sycon ciliatum P (88)
Leuconia P (17)
Leuconia nivea P (6)
Grantia compressa P (24)
Oscarella lobularis P (5)
Suberites P (2)
Suberites ficus P (1)
Terpios gelatinosus P (1)
Protosuberites denhartogi P (62)
Cliona celata P (6)
Halichondria P (1)
Halichondria (Halichondria) bowerbanki P (63)
Halichondria (Halichondria) panicea P (272)
Hymeniacidon perlevis P (706)
Hymeniacidon kitchingi P (1)
Mycale P (3)
Amphilectus fucorum P (18)
Amphilectus lobatus P (32)
Myxilla P (3)
Myxilla (Myxilla) rosacea P (1)
Hymedesmia (cf. coriacea) P (1)
Hymedesmia (cf. pansa) P (1)
Hymedesmia (Hymedesmia) paupertas P (1)
Ophlitaspongia papilla P (52)
Clathria (Microciona) atrasanguinea P (199)
Haliclona P (5)
Haliclona (Reniera) cinerea P (10)
Haliclona (Haliclona) oculata P (1)
Haliclona (Gellius) rava P (9)
Haliclona (Rhizoniera) rosea P (35)
Dysidea fragilis P (28)
Aplysilla rosea P (1)
Aplysilla sulfurea P (1)
Halisarca dujardinii P (329)
HYDROIDS & ANEMONES
Hydrozoa P (34)
Anthoathecata P (2)
Ectopleura larynx P (3)
Coryne P (1)
Clava multicornis P (3)
Dynamena pumila P (74)
Sertularella polyzonias P (1)
Campanulariidae P (55)
Gonothyraea loveni P (7)
Laomedea flexuosa P (2)
Obelia P (11)
Alcyonium digitatum P (26)
Actiniaria P (16)
Actinia P (4)
Actinia equina P (102)
Actinia fragacea P (2)
Actinia prasina P (2)
Urticina felina P (1)
Metridium dianthus P (13)
Sagartia elegans P (4)
Sagartia troglodytes P (2)
Cereus pedunculatus P (1)
FLAT WORMS
Platyhelminthes P (3)
Fecampia erythrocephala (egg flask) P (96)
Prostheceraeus vittatus P (1)
RIBBON WORMS
Nemertea P (13)
Cerebratulus P (1)
Lineus longissimus P (11)
POLYCHAETE WORMS
Polychaeta P (15)
Polychaeta (tube) P (12)
Polychaeta (soft sand tube) P (32)
Polynoidae P (279)
Eulalia viridis P (11)
Spionidae (tubes) P (8)
Polydora (tubes) P (137)
Cirratulidae P (5)
Sabellaria P (322)
Terebellidae P (1)
Eupolymnia nebulosa P (2)
Sabellidae (tubes) P (4)
Serpulidae P (5)
Hydroides norvegica P (2)
Spirobranchus P (864)
Spirorbinae % (783)
SEA SPIDERS AND MITES
Pycnogonida P (17)
Anoplodactylus pygmaeus P (1)
Pycnogonum litorale P (8)
Halacaridae (mites) P (2)
CRUSTACEA
Cirripedia (juv) % (975)
Cirripedia (dead) % (1294)
Cirripedia (Agg adults) T% (1325)
Verruca stroemia P (169)
Chthamalus montagui P (1)
Semibalanus balanoides P (746)
Balanus balanus P (124)
Balanus crenatus P (1009)
Austrominius modestus P (634)
Amphipoda P (98)
Amphipoda (tubes) P (8)
Gammarus locusta P (1)
Isopoda P (11)
Dynamene bidentata P (1)
Sphaeroma P (12)
Caridea P (2)
Athanas nitescens P (3)
Paguridae P (10)
Pagurus bernhardus P (3)
Galatheidae P (5)
Pisidia longicornis P (54)
Porcellana platycheles P (274)
Brachyura (juv crabs) P (1)
Inachus P (1)
Cancer pagurus P (41)
Cancer pagurus (juv) P (16)
Necora puber P (3)
Carcinus maenas P (142)
Carcinus maenas (juv) P (184)
INSECTS
Anurida maritima P (4)

MOLLUSCA
Polyplacophora P (5)
Lepidochitona cinerea P (41)
Gastropoda P (2)
Gastropoda (eggs) P (4)
Diodora graeca P (1)
Tectura virginea P (2)
Patella vulgata P (192)
Phorcus lineatus P (2)
Steromphala cineraria P (280)
Steromphala umbilicalis P (88)
Calliostoma zizyphinum P (2)
Tricolia pullus P (2)
Littorina littorea P (112)
Littorina obtusata (/fabalis) P (280)
Littorina saxatilis P (8)
Onoba semicostata P (5)
Trivia arctica P (1)
Trivia monacha P (20)
Lamellaria perspicua P (2)
Nucella lapillus P (392)
Nucella lapillus (eggs) P (277)
Buccinum undatum P (22)
Buccinum undatum (juv) P (15)
Tritia incrassata P (9)
Nudibranchia P (1)
Nudibranchia (eggs) P (1)
Goniodoris castanea P (3)
Acanthodoris pilosa P (1)
Onchidoris bilamellata P (7)
Onchidoris muricata P (2)
Rostanga rubra P (3)
Doris pseudoargus P (5)
Flabellina P (1)
Fjordia browni P (1)
Facelina bostoniensis P (1)
Facelina auriculata P (5)
Aeolidia papillosa P (2)
Aeolidiella alderi P (2)
Aeolidiella glauca P (4)
Bivalvia P (1)
Mytilus edulis P (61)
Musculus discors P (1)
Musculus subpictus P (7)
Modiolula phaseolina P (1)
Ostrea chilensis P (2)
Ostrea edulis P (1)
Chlamys P (1)
Mimachlamys varia P (4)
Anomiidae P (385)
Heteranomia squamula P (8)
Venerupis corrugata P (2)
Sphenia binghami P (1)
Hiatella arctica P (37)
BRYOZOA
Bryozoa (enc calc) % (355)
Cyclostomatida P (3)
Crisia P (2)
Crisia denticulata P (2)
Alcyonidium P (15)
Alcyonidium (polyoum / gelatinosum) P (2)
Alcyonidium diaphanum P (20)
Alcyonidium gelatinosum P (13)
Alcyonidium hirsutum P (1)
Alcyonidioides mytili P (79)
Flustrellidra hispida P (3)
Nolella pusilla P (1)
Amathia citrina P (7)
Amathia gracilis P (1)
Amathia imbricata P (66)
Amathia pustulosa P (10)
Aeteidae (creeping) P (1)
Electra pilosa P (9)
Scrupocellaria scruposa P (41)
Bugulina flabellata P (1)
Bugulina fulva P (17)
Crisularia plumosa P (5)
ECHINODERMS
Asterias rubens P (42)
Ophiothrix fragilis P (138)
Amphipholis squamata P (19)
Psammechinus miliaris P (3)
SEA SQUIRTS
Ascidiacea P (4)
Ascidiacea (Agg colonial) T% (365)
Ascidiacea (Agg solitary) T% (454)
Clavelina lepadiformis P (107)
Polyclinidae P (17)
Polyclinum aurantium P (58)
Morchellium argus P (37)
Aplidium elegans P (1)
Aplidium turbinatum P (297)
Aplidium P (4)
Aplidium (2-spot) P (1)
Aplidium densum P (1)
Aplidium nordmanni P (24)
Aplidium proliferum P (12)
Aplidium punctum P (9)
Didemnidae P (57)
Didemnidae (sandy) P (2)
Didemnidae (transparent) P (129)
Didemnidae (white) P (40)
Didemnidae (yellow) P (3)
Didemnidae (orange) P (2)
Didemnidae (peach) P (2)
Didemnidae (light pink) P (10)
Didemnidae (salmon) P (3)
Didemnidae (purple) P (1)
Didemnidae (brown) P (11)
Didemnidae (white walled) P (7)
Didemnidae (speckled white) P (4)
Didemnum maculosum P (117)
Diplosoma listerianum P (17)
Lissoclinum perforatum P (3)
Ciona intestinalis P (1)
Perophora listeri P (47)
Corella P (10)
Corella eumyota P (208)
Ascidiella aspersa P (5)
Ascidiella scabra P (70)
Dendrodoa grossularia P (450)
Distomus variolosus P (1)
Botryllus schlosseri P (158)
Botrylloides violaceus P (1)
Botrylloides (brown) P (2)
Botrylloides leachii P (44)
Molgula P (11)
FISH
Teleostei P (1)
Teleostei (eggs) P (1)
Anguilla anguilla P (1)
Entelurus aequoreus P (1)
Nerophis lumbriciformis P (5)
Blenniidae P (1)
Lipophrys pholis P (19)
Lipophrys pholis (eggs) P (3)
Pholis gunnellus P (22)
OTHER ENCRUSTING PLANTS
Other plant (Agg enc) T% (663)
RED ALGAE
Rhodophyta P (3)
Rhodophyta (sporelings) P (6)
Rhodophyta (dk.enc) P (332)
Rhodophyta (fil) P (21)
Rhodophyta (fuzz) P (1)
Rhodophyta (Agg non enc) T% (630)
Porphyra P (7)
Rhodothamniella floridula P (68)
Gelidium P (1)
Gelidium (thin like crinale) P (8)
Gelidium crinale P (14)
Gelidium pusillum P (38)
Palmaria palmata P (93)
Dumontia contorta P (11)
Hildenbrandia P (505)
Corallinaceae (enc) % (489)
Gracilariaceae P (1)
Gracilaria gracilis P (8)
Gymnogongrus griffithsiae P (3)
Phyllophora pseudoceranoides P (36)
Erythrodermis traillii P (2)
Mastocarpus stellatus P (55)
Mastocarpus stellatus (Petrocelis) P (6)
Chondrus crispus P (508)
Calliblepharis jubata P (1)
Cystoclonium purpureum P (49)
Rhodophyllis divaricata P (1)
Rhodymenia delicatula P (2)

Rhodymenia pseudopalmata P (3)
Lomentaria articulata P (76)
Lomentaria clavellosa P (1)
Antithamnionella ternifolia P (1)
Aglaothamnion P (2)
Ceramium P (34)
Ceramium botryocarpum P (8)
Ceramium deslongchampsii P (109)
Ceramium virgatum P (42)
Ceramium pallidum P (8)
Halurus flosculosus P (3)
Plumaria plumosa P (2)
Acrosorium ciliolatum P (1)
Cryptopleura ramosa P (4)
Delesseria sanguinea P (1)
Hypoglossum hypoglossoides P (3)
Membranoptera alata P (134)
Haraldiophyllum bonnemaisonii P (2)
Nitophyllum punctatum P (1)
Phycodrys rubens P (5)
Dasysiphonia japonica P (4)
Osmundea (sporelings) P (2)
Osmundea oederi P (1)
Osmundea hybrida P (2)
Osmundea pinnatifida P (2)
Osmundea truncata P (2)
Polysiphonia P (6)
Polysiphonia atlantica P (2)
Polysiphonia elongata P (3)
Melanothamnus harveyi P (2)
Vertebrata fucoides P (29)
Polysiphonia stricta P (37)
Rhodomela confervoides P (5)

BROWN ALGAE

Phaeophyceae (enc) P (1)
Phaeophyceae (fil) P (15)
Phaeophyceae (bristly brown) P (15)
Ectocarpaceae P (3)
Pylaiella littoralis P (4)
Ralfsia P (10)
Elachista fucicola P (1)
Sphacelaria P (16)
Sphacelaria fusca P (8)
Protohalopteris radicans P (1)
Sphacelaria rigidula P (3)
Halopteris scoparia P (1)
Cladostephus spongiosus P (118)
Dictyota dichotoma P (7)
Laminaria (sporelings) P (41)
Laminaria digitata P (33)
Saccharina latissima P (2)
Fucaceae (sporelings) P (498)
Ascophyllum nodosum P (101)
Fucus serratus % (709)
Fucus spiralis P (1)
Fucus vesiculosus % (193)
Sargassum muticum P (2)

GREEN ALGAE

Chlorophyta (enc) P (5)
Chlorophyta (fil) P (10)
Chlorophyta (Agg) T% (615)
Ulva (tubular) P (126)
Ulva flexuosa P (2)
Ulva intestinalis P (3)
Ulva prolifera P (1)
Ulva (flat) P (510)
Ulva rigida P (3)
Chaetomorpha P (11)
Chaetomorpha linum P (41)
Chaetomorpha melagonium P (15)
Cladophora P (37)
Cladophora albida P (4)
Cladophora rupestris P (186)
Bryopsis hypnoides P (1)
Bryopsis plumosa P (5)

LICHENS

Verrucaria P (68)

Appendix 3 Database structure

The boulder data are stored in an Access database. A summary of the main data tables and fields is given below:

FullData

Field name	Description
EntCode	Taxonomic code for each entity (=taxon + qualifier), based on Species Directory, e.g. Hymeniacidon perlevis = C005230 and Corallinaceae (enc) = ZM03840.51
Sample	Sample code. Year+Site+Stn+Side+Rep(+QArepeat), e.g. 09F3Tb = 2009, Felinheli, Stn3, Top, rep b
Method	P (=Present) or % (=Percentage). The actual method used for this entity in this sample. Not necessarily the default method given in the TaxaList table.
Abundance	A numeric value from 0.01 to 100. If Method = % then Abundance is percentage cover. If Method = P, then Abundance can only be 1 (=Present) or 0.01 (=Trace).

TaxaList

Field name	Description
Entity	Accepted name for the taxon, based on WoRMS, plus qualifier
EntCode	Taxonomic code for each entity (=taxon + qualifier): as in Fulldata table
AnalysisEntity	Fairly reliable taxonomic entity for use in analyses where identification of Entity is not always reliable
AphiaID	Code for taxon name from WoRMS online database
Authority	Taxonomic authority from WoRMS online database
Kingdom -> Species	Multiple fields – taxonomic classification, from WoRMS online database
Current	Whether the entity is in current use in the monitoring programme. Some aggregate taxa are no longer recorded.
OnRecordingForm	Tags entities that are listed on the recording form
Method	Default survey method: P (=Presence), % (=Percentage cover), TP (=Presence of aggregate taxa), T% (Percentage cover of aggregate taxa)
TemporalAnalysis	Tags entities to include in temporal analysis. Excluded taxa are those that are very inconsistently recorded.
AnalysisRichness	Tags entities to include in analysis of taxonomic richness. Excludes aggregate taxa, tubes (e.g. polychaetes), eggs and juvenile stages, and taxa not strictly associated with the defined habitat (e.g. very mobile crabs and fish occasionally sheltering under boulders)

Samples

Field name	Description
Sample	Sample code, as in Fulldata table
Year	2005 to 2019
Site	BB (=Britannia Bridge) or FE (=Felinheli)
Stn	1 to 5 (at BB), 1 to 6 (at FE, no stn4)
Side	T (=top of boulder) or B (=bottom of boulder)
Rep	Replicate, from a to s
Boulder	Boulder code. Same as Sample but without Side, e.g. 09F3b = 2009, Felinheli, Stn3, rep b
QA-repeat	1 or 2, where 2 is a repeated sample by another surveyor, for quality control

Boulders

Field name	Description
Boulder	Boulder code., as in Sample table
Surveyors	Initials of surveyors
Date	Date survey carried out
Start time	Time survey started on boulder
Mins	Minutes taken to survey boulder (total for both sides)
Conditions	Environmental conditions during survey
Length	Length (centimetres) of boulder
Width	Width (centimetres) of boulder
Substrata underneath	List of main substratum types under boulder (e.g. R = rock, C = cobble, S = sand, M = mud)
Anoxia?	Whether a black anoxic patch was present on the underside (Y, N or %)
Turned?	Whether surveyors considered boulder had been turned (Y, N or ?)

Appendix 4 Results of an exercise to assess consistency of recording

As part of a QA/QC exercise, on the last day of the 2010 survey (16th July) a series of repeat surveys were carried out on three boulders at Britannia Bridge. The selected boulders were in the same shore zone (lower shore *Fucus serratus*) as the main monitoring sites, half way between monitoring station BB2 and BB5 (see Figure 2). The three boulders were spaced approximately 15m apart; close enough for ease of moving between them, but far enough that surveyors would not disturb (hear!) each other. The boulders are labelled E (east), M (middle) and W (west) (although on the field sheets they are labelled North, Middle and South).

Each boulder was surveyed five times – three times fully by the three most experienced surveyors and twice by the less experienced assistants who recorded only selected key and aggregate taxa. The survey methodology and recording form was the same as in the main monitoring survey but the boulders were only turned once – i.e. the top surfaces were recorded first by all of the surveyors in rotation; then the boulders were turned over and the bottom surfaces were recorded by all of the surveyors in rotation.

All three boulders lay on a substratum of stones and muddy gravel, with no signs of anoxia and no indications that they had been recently turned. The sizes of the boulders were:

Boulder E: 36 x 36 cm

Boulder M: 27 x 29 cm

Boulder W: 29 x 46 cm

Repeated surveys of the same boulders inevitably resulted in certain species being surveyed differently by the surveyors: Fucoid canopy (mainly *Fucus serratus*) thrown back by the first surveyor, mobile crustacea (particularly *Porcellana platycheles* and *Carcinus maenas*) crawling away and mobile gastropods (particularly dogwhelks and littorinids) falling off the boulders. Many of the analyses have therefore excluded these species.

Table 11 shows that there were substantial inconsistencies in the estimates of percentage cover for most of the selected taxa. Some taxa were recorded more consistently than others, but statistical analysis shows that the variance is mostly many times the value of the mean. Detailed inspection of the data shows that individual surveyors tended to record higher or lower values for certain species, but the majority of the variation is not explained by such biases or by the level of experience of the surveyors.

Table 11. Boulder Trials at Britannia Bridge in 2010. Range in percentage cover of selected easily identified taxa on tops and bottoms of boulders, recorded by 5 surveyors (experienced and inexperienced). Boulder tops = Top, Boulder bottoms = Bot. E, M & W identify the 3 boulders. Values in **bold** indicate particularly wide ranges (i.e. very inconsistent).

Boulder Top / Bottom	**Top**	**Top**	**Top**	**Bot**	**Bot**	**Bot**
Boulder ID	**E**	**M**	**W**	**E**	**M**	**W**
Porifera [Agg]	**2 - 15**	2 - 8	**<1 - 12**	**20 - 60**	7 - 10	**15 - 40**
Pomatoceros	0 - <1	0 - <1	0 - <1	0	0 - <1	0 - <1
Spirorbidae	**0 - 15**	<1	0 - <1	**5 - 35**	3 - 6	5 - 15
Cirripedia (juv)	<1 - 3	**0 - 5**	0 - 3	0 - <1	0 - <1	0 - <1
Cirripedia (dead) [Agg]	<1 - 5	**1 - 10**	<1 - 5	<1 - 3	<1 - 3	<1 - 2
Cirripedia (live) [Agg]	**2 - 15**	**8 - 40**	**3 - 40**	<1 - 1	<1 - 2	<1 - 3
Bryozoa (calcareous enc on rock)	<1 - 3	<1 - 1	0 - <1	0 - 5	**2 - 20**	**1 - 15**
Ascidiacea (colonial) [Agg]	0	0	0	<1 - 3	<1	0 - <1
Ascidiacea (solitary) [Agg]	<1 - 1	1 - 2	<1 - 1	10 - 30	**5 - 25**	10 - 20
Corallinaceae (enc)	**<1 - 5**	**0 - 5**	0 - 1	0	0 - <1	0
Rhodophycota (non enc) [Agg]	**30 - 70**	**5 - 25**	15 - 25	0 - 2	0 - <1	0 - <1
Chromophycota (non enc) [Agg]	**<1 - 15**	**<1 - 20**	**<1 - 30**	0	0	0
Chlorophycota [Agg]	**<1 - 10**	<1 - 2	**7 - 30**	0 - <1	0 - <1	0 - <1
Other plant enc (enc) [Agg]	1 - 5	2 - 5	0 - <1	0 - <1	0 - <1	0 - 1

SIMPER analysis in PRIMER finds that the taxa contributing most to the between-boulder differences were Chlorophycota, Rhodophycota (non enc) and Chromophycota (non enc) for the boulder tops and Porifera, Bryozoa (calcareous enc on rock) and Spirorbinae for the boulder bottoms.

Table 12 shows that very few species were consistently recorded as present or absent by all three experienced surveyors on all three boulders. The only five species that were consistently recorded were *Grantia compressa*, *Hymeniacidon perlevis*, *Sidnyum turbinatum*, *Dendrodoa grossularia* and *Ulva*. Some of those that were inconsistently recorded are mobile species, so might have been lost between surveys.

SIMPER analysis in PRIMER shows that no individual species contributed very highly to the between-boulder differences for the boulder bottoms, but that the differences were made up of contributions from a large number of species.

Table 12. Boulder trials at Britannia Bridge in 2010. Number of records of most frequently recorded species on tops and bottoms of boulders, recorded by 3 experienced surveyors. Thus, a value of 0 or 3 indicates consistent recording. 1s and 2s are in **bold** to highlight inconsistency of recording. Header labels as in Table 11.

Boulder Top / Bottom	**Top**	**Top**	**Top**	**Bot**	**Bot**	**Bot**
Boulder ID	**E**	**M**	**W**	**E**	**M**	**W**
Clathrina coriacea	0	0	0	**1**	0	**1**
Leucosolenia	0	0	0	3	3	**2**
Grantia compressa	0	0	0	0	3	0
Halichondria panicea	0	**1**	**1**	3	3	3
Hymeniacidon perlevis	3	3	3	3	3	3
Ophlitaspongia papilla	0	0	0	**2**	0	0
Microciona atrasanguinea	0	0	0	**1**	0	3
Polynoidae (scale worms)	0	0	0	**2**	**1**	3
Sabellaria	3	3	3	0	**1**	**1**
Verruca stroemia	0	0	0	**2**	**1**	**1**
Semibalanus balanoides	**2**	**2**	**2**	0	0	0
Balanus crenatus	**2**	3	**2**	**2**	3	3
Amphipoda	**2**	0	**1**	0	**1**	0
Porcellana platycheles	0	0	0	**2**	**1**	3
Carcinus maenas (juvs)	**2**	**1**	3	**1**	**2**	**2**
Gibbula cineraria	0	0	**2**	3	3	3
Gibbula umbilicalis	**1**	**1**	**1**	0	0	0
Littorina obtusata (/mariae)	**2**	**2**	3	3	**1**	3
Nucella lapillus (eggs)	0	0	0	3	**2**	3
Nucella lapillus	3	3	3	**2**	3	3
Anomiidae	0	0	0	3	**2**	3
Sidnyum turbinatum	0	0	0	3	3	0
Didemnum maculosum	0	0	0	**2**	0	3
Ascidiella scabra	0	0	0	**2**	0	**1**
Dendrodoa grossularia	3	3	3	3	3	3
Botryllus schlosseri	0	0	0	3	0	**1**
Rhodophycota (dk red enc)	**1**	**2**	**1**	0	0	0
Gelidium crinale	0	**2**	0	0	**1**	**1**
Hildenbrandia	3	3	3	**1**	**2**	**1**
Mastocarpus stellatus	**1**	**1**	**1**	0	0	0
Chondrus crispus	**2**	**2**	3	**1**	**1**	**1**
Membranoptera alata	**2**	0	0	0	0	**1**
Cladostephus spongiosus	**1**	**1**	**2**	0	0	0
Fucaceae (sporelings)	**1**	**1**	**1**	0	0	0
Ulva	3	3	3	0	0	0
Chaetomorpha melagonium	**2**	0	**2**	0	**1**	**1**
Cladophora rupestris	3	3	3	**1**	0	**1**

Total No. of spp recorded by all 3 surveyors [and range for individual surveyors]	32 [18 – 25]	28 [17 – 21]	33 [19 – 25]	33 [20 – 24]	29 [16 – 22]	38 [22 – 27]
No. of spp (excl. fucoids & mobile spp) recorded by all 3 surveyors [and range]	26 [15 – 20]	23 [15 – 17]	24 [15 – 16]	27 [17 – 20]	21 [14 – 16]	27 [14 – 19]

Appendix 5 Multivariate analyses results

More detailed results from multivariate analyses summarised in Section 3.

ANOSIM: Site x Year, Boulder Tops

Analysis of Similarities (see Section 3.2, page 11)
Two-Way Crossed – Site x Year
Data – Bray-Curtis similarities derived from presence/absence data for 251 taxa
Factors: Site (unordered): BB, FE. Year (ordered): 2007 to 2019

Tests for differences between unordered Site groups (across all Year groups)
Global Test
Sample statistic (Average R): 0.399
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from a large number)
Number of permuted statistics greater than or equal to Average R: 0

Tests for differences between ordered Year groups (across all Site groups)
Global Test
Sample statistic (Average R): 0.207
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from a large number)
Number of permuted statistics greater than or equal to Average R: 0

<u>Pairwise Tests</u>

Groups	R Statistic	Significance Level %
2007, 2008	0.187	0.1
2007, 2009	0.397	0.1
2007, 2010	0.271	0.1
2007, 2012	0.29	0.1
2007, 2013	0.529	0.1
2007, 2014	0.596	0.1
2007, 2015	0.457	0.1
2007, 2016	0.617	0.1
2007, 2017	0.577	0.1
2007, 2018	0.68	0.1
2007, 2019	0.598	0.1
2008, 2009	0.325	0.1
2008, 2010	0.3	0.1
2008, 2011	0.416	0.1
2008, 2012	0.252	0.1
2008, 2013	0.385	0.1
2008, 2014	0.501	0.1
2008, 2015	0.398	0.1
2008, 2016	0.494	0.1
2008, 2017	0.418	0.1
2008, 2018	0.466	0.1
2008, 2019	0.415	0.1
2009, 2010	0.252	0.1
2009, 2011	0.488	0.1
2009, 2012	0.191	0.1
2009, 2013	0.237	0.1
2009, 2014	0.256	0.1
2009, 2015	0.254	0.1
2009, 2016	0.32	0.1
2009, 2017	0.279	0.1
2009, 2018	0.316	0.1
2009, 2019	0.301	0.1
2010, 2011	0.316	0.1
2010, 2012	0.141	0.1
2010, 2013	0.209	0.1
2010, 2014	0.307	0.1
2010, 2015	0.204	0.1
2010, 2016	0.315	0.1
2010, 2017	0.254	0.1
2010, 2018	0.334	0.1
2010, 2019	0.251	0.1
2011, 2012	0.343	0.1
2011, 2013	0.268	0.1
2011, 2014	0.463	0.1
2011, 2015	0.384	0.1
2011, 2016	0.437	0.1
2011, 2017	0.406	0.1
2011, 2018	0.43	0.1
2011, 2019	0.433	0.1
2012, 2013	0.189	0.1
2012, 2014	0.32	0.1
2012, 2015	0.202	0.1
2012, 2016	0.313	0.1
2012, 2017	0.287	0.1
2012, 2018	0.307	0.1
2012, 2019	0.284	0.1
2013, 2014	0.209	0.1
2013, 2015	0.098	0.2
2013, 2016	0.148	0.1
2013, 2017	0.123	0.1
2013, 2018	0.11	0.1
2013, 2019	0.119	0.1
2014, 2015	0.117	0.1
2014, 2016	0.152	0.1
2014, 2017	0.084	0.1
2014, 2018	0.101	0.1
2014, 2019	0.213	0.1
2015, 2016	0.083	0.1
2015, 2017	0.068	0.1
2015, 2018	0.079	0.1
2015, 2019	0.082	0.1
2016, 2017	0.117	0.1
2016, 2018	0.104	0.1
2016, 2019	0.092	0.1
2017, 2018	0.061	0.1
2017, 2019	0.1	0.1
2018, 2019	0.093	0.1

ANOSIM: Site x Year, Boulder Bottoms

Analysis of Similarities (see Section 3.2, page 11)
Two-Way Crossed – Site x Year
Data – Bray-Curtis similarities derived from presence/absence data for 251 taxa
Factors: Site (unordered): BB, FE. Year (ordered): 2007 to 2019

Tests for differences between unordered Site groups (across all Year groups)
Global Test
Sample statistic (Average R): 0.339
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from a large number)
Number of permuted statistics greater than or equal to Average R: 0

Tests for differences between ordered Year groups (across all Site groups)
Global Test
Sample statistic (Average R): 0.151
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from a large number)
Number of permuted statistics greater than or equal to Average R: 0

Pairwise Tests

Groups	R Statistic	Significance Level %	Groups	R Statistic	Significance Level %	Groups	R Statistic	Significance Level %
2007, 2008	0.255	0.1	2009, 2013	0.181	0.1	2012, 2016	0.17	0.1
2007, 2009	0.38	0.1	2009, 2014	0.167	0.1	2012, 2017	0.123	0.1
2007, 2010	0.258	0.1	2009, 2015	0.139	0.1	2012, 2018	0.138	0.1
2007, 2012	0.306	0.1	2009, 2016	0.153	0.1	2012, 2019	0.168	0.1
2007, 2013	0.481	0.1	2009, 2017	0.198	0.1	2013, 2014	0.08	0.1
2007, 2014	0.519	0.1	2009, 2018	0.138	0.1	2013, 2015	0.055	0.4
2007, 2015	0.415	0.1	2009, 2019	0.195	0.1	2013, 2016	0.117	0.1
2007, 2016	0.342	0.1	2010, 2011	0.168	0.1	2013, 2017	0.144	0.1
2007, 2017	0.44	0.1	2010, 2012	0.098	0.1	2013, 2018	0.134	0.1
2007, 2018	0.454	0.1	2010, 2013	0.16	0.1	2013, 2019	0.146	0.1
2007, 2019	0.289	0.1	2010, 2014	0.193	0.1	2014, 2015	0.042	0.8
2008, 2009	0.194	0.1	2010, 2015	0.17	0.1	2014, 2016	0.116	0.1
2008, 2010	0.163	0.1	2010, 2016	0.193	0.1	2014, 2017	0.104	0.1
2008, 2011	0.229	0.1	2010, 2017	0.18	0.1	2014, 2018	0.123	0.1
2008, 2012	0.213	0.1	2010, 2018	0.137	0.1	2014, 2019	0.193	0.1
2008, 2013	0.322	0.1	2010, 2019	0.173	0.1	2015, 2016	0.098	0.1
2008, 2014	0.405	0.1	2011, 2012	0.133	0.1	2015, 2017	0.094	0.1
2008, 2015	0.346	0.1	2011, 2013	0.175	0.1	2015, 2018	0.1	0.1
2008, 2016	0.384	0.1	2011, 2014	0.228	0.1	2015, 2019	0.134	0.1
2008, 2017	0.327	0.1	2011, 2015	0.24	0.1	2016, 2017	0.173	0.1
2008, 2018	0.332	0.1	2011, 2016	0.215	0.1	2016, 2018	0.067	0.2
2008, 2019	0.326	0.1	2011, 2017	0.273	0.1	2016, 2019	0.081	0.1
2009, 2010	0.057	0.2	2011, 2018	0.287	0.1	2017, 2018	0.103	0.1
2009, 2011	0.295	0.1	2011, 2019	0.245	0.1	2017, 2019	0.16	0.1
2009, 2012	0.12	0.1	2012, 2013	0.074	0.1	2018, 2019	0.077	0.1
			2012, 2014	0.099	0.1			
			2012, 2015	0.101	0.1			

SIMPER: Site x Year, Boulder Tops

Similarity Percentages - species contributions (see Section 3.2, page 14)
Two-Way Analysis – Site x Year
Data – presence/absence data for 251 taxa
Analysis parameters: S17 Bray-Curtis similarity; Cut off for low contributions: 70.00%
Factor Groups: Period (Early = 2007 & 2008, Middle = 2009-2012, Late = 2013-2019) x Site (BB, FE)
Results from comparisons between Periods only:

Early & Middle - Average dissimilarity = 30.32

	Group Early	Group Middle				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Cirripedia (juv)	0.03	0.68	2.26	1.90	7.44	7.44
Fucaceae (sporelings)	0.13	0.56	1.46	1.96	4.80	12.24
Balanus crenatus	0.40	0.75	1.21	2.06	3.98	16.22
Littorina obtusata (/fabalis)	0.33	0.49	1.09	1.43	3.60	19.82
Hildenbrandia	0.20	0.41	0.92	1.34	3.04	22.86
Rhodophyta (dk.enc)	0.60	0.71	0.76	1.31	2.51	25.37
Spirobranchus	0.58	0.42	0.71	1.42	2.34	27.71
Carcinus maenas	0.09	0.24	0.70	1.66	2.31	30.02
Ceramium	0.25	0.04	0.69	0.93	2.28	32.30
Semibalanus balanoides	0.80	0.71	0.64	1.48	2.11	34.41
Bryozoa (enc)	0.28	0.33	0.63	1.33	2.09	36.50
Sabellaria	0.19	0.33	0.62	1.27	2.03	38.53
Fucus vesiculosus	0.12	0.19	0.58	1.36	1.91	40.43
Cladostephus spongiosus	0.03	0.17	0.57	1.16	1.88	42.31
Chaetomorpha	0.01	0.15	0.55	2.31	1.83	44.14
Ulva (flat)	0.70	0.65	0.54	1.30	1.78	45.92
Mastocarpus stellatus	0.05	0.14	0.53	0.79	1.76	47.68
Corallinaceae (enc)	0.58	0.62	0.51	1.40	1.68	49.36
Steromphala umbilicalis	0.22	0.06	0.49	1.30	1.62	50.98
Membranoptera alata	0.19	0.21	0.47	1.05	1.54	52.52
Austrominius modestus	0.51	0.50	0.45	1.78	1.49	54.02
Dendrodoa grossularia	0.31	0.34	0.44	1.16	1.44	55.46
Laminaria digitata	0.06	0.12	0.43	0.84	1.42	56.87
Cirripedia (dead)	0.85	0.96	0.41	1.68	1.34	58.22
Aplidium turbinatum	0.07	0.09	0.40	1.59	1.32	59.53
Chondrus crispus	0.70	0.65	0.38	1.01	1.26	60.79
Fucus serratus	0.89	0.93	0.37	0.99	1.22	62.01
Palmaria palmata	0.05	0.13	0.36	1.14	1.19	63.19
Spirorbinae	0.64	0.51	0.31	0.89	1.04	64.23
Cladophora rupestris	0.32	0.28	0.31	1.30	1.03	65.26
Ceramium deslongchampsii	0.04	0.09	0.31	1.09	1.02	66.28
Rhodothamniella floridula	0.03	0.08	0.30	2.00	1.00	67.28
Ulva (tubular)	0.11	0.14	0.30	1.30	0.98	68.26
Gelidium	0.12	0.05	0.29	0.99	0.97	69.22
Phyllophora pseudoceranoïdes	0.01	0.07	0.29	0.52	0.96	70.18

Early & Late - Average dissimilarity = 36.14

	Group Early	Group Later				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Cirripedia (juv)	0.03	0.94	3.16	4.29	8.74	8.74
Fucaceae (sporelings)	0.13	0.88	2.68	3.18	7.40	16.14
Rhodophyta (dk.enc)	0.60	0.07	1.91	2.20	5.28	21.43
Balanus crenatus	0.40	0.81	1.47	3.79	4.06	25.49
Hildenbrandia	0.20	0.58	1.42	2.05	3.94	29.43
Sabellaria	0.19	0.48	1.18	1.97	3.26	32.68
Semibalanus balanoides	0.80	0.61	0.95	1.42	2.62	35.30
Littorina obtusata (/fabalis)	0.33	0.22	0.84	1.15	2.34	37.64
Spirorbinae	0.64	0.34	0.81	2.12	2.24	39.87
Ceramium deslongchampsii	0.04	0.24	0.79	1.45	2.18	42.05
Spirobranchus	0.58	0.38	0.77	1.62	2.12	44.18
Fucus vesiculosus	0.12	0.29	0.75	1.06	2.09	46.27
Cladostephus spongiosus	0.03	0.21	0.75	1.46	2.09	48.35
Ceramium	0.25	0.04	0.73	1.03	2.03	50.38
Austrominius modestus	0.51	0.68	0.70	1.29	1.94	52.32
Corallinaceae (enc)	0.58	0.53	0.56	1.49	1.56	53.88
Bryozoa (enc)	0.28	0.22	0.52	1.11	1.44	55.32
Verruca stroemia	0.03	0.15	0.52	1.12	1.44	56.76
Steromphala umbilicalis	0.22	0.05	0.51	1.70	1.41	58.17
Palmaria palmata	0.05	0.17	0.50	1.09	1.39	59.56
Polychaeta (tube)	0.02	0.17	0.48	1.18	1.32	60.88
Membranoptera alata	0.19	0.20	0.46	1.01	1.27	62.15
Carcinus maenas	0.09	0.19	0.44	1.36	1.23	63.38
Rhodothamniella floridula	0.03	0.13	0.44	1.13	1.21	64.59
Ulva (tubular)	0.11	0.20	0.43	0.87	1.18	65.77
Ulva (flat)	0.70	0.68	0.42	1.21	1.16	66.93
Aplidium turbinatum	0.07	0.05	0.42	1.11	1.15	68.08
Lomentaria articulata	0.05	0.14	0.40	1.06	1.10	69.18
Laminaria digitata	0.06	0.12	0.36	1.02	0.99	70.16

Middle & Late - Average dissimilarity = 27.85

	Group Middle	Group Later				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Rhodophyta (dk.enc)	0.71	0.07	2.04	2.43	7.34	7.34
Fucaceae (sporelings)	0.56	0.88	1.04	2.08	3.75	11.09
Littorina obtusata (/fabalis)	0.49	0.22	0.97	1.41	3.49	14.57
Hildenbrandia	0.41	0.58	0.96	1.55	3.45	18.03
Cirripedia (juv)	0.68	0.94	0.79	1.12	2.84	20.86
Semibalanus balanoides	0.71	0.61	0.79	1.48	2.83	23.70
Austrominius modestus	0.50	0.68	0.72	1.22	2.57	26.27
Sabellaria	0.33	0.48	0.65	1.51	2.33	28.60
Carcinus maenas	0.24	0.19	0.57	1.57	2.03	30.63
Spirorbinae	0.51	0.34	0.56	1.52	2.00	32.63
Ceramium deslongchampsii	0.09	0.24	0.51	1.13	1.84	34.47
Bryozoa (enc)	0.33	0.22	0.51	1.34	1.84	36.31
Spirobranchus	0.42	0.38	0.49	1.71	1.77	38.08
Mastocarpus stellatus	0.14	0.04	0.46	0.85	1.66	39.74
Ulva (flat)	0.65	0.68	0.46	1.24	1.65	41.39

Corallinaceae (enc)	0.62	0.53	0.46	1.29	1.64	43.03
Balanus crenatus	0.75	0.81	0.45	1.21	1.63	44.66
Polychaeta (tube)	0.05	0.17	0.41	1.11	1.47	46.13
Dendrodoa grossularia	0.34	0.18	0.41	0.99	1.45	47.58
Ulva (tubular)	0.14	0.20	0.40	1.14	1.45	49.04
Chondrus crispus	0.65	0.68	0.37	0.97	1.32	50.35
Fucus vesiculosus	0.19	0.29	0.37	1.03	1.31	51.67
Verruca stroemia	0.04	0.15	0.35	0.86	1.26	52.92
Cirripedia (dead)	0.96	0.91	0.33	1.50	1.19	54.11
Palmaria palmata	0.13	0.17	0.33	1.09	1.19	55.30
Laminaria digitata	0.12	0.12	0.32	0.86	1.15	56.45
Hymeniacidon perlevis	0.56	0.47	0.31	1.30	1.12	57.57
Halisarca dujardinii	0.12	0.05	0.31	1.03	1.12	58.69
Patella vulgata	0.24	0.18	0.31	0.91	1.11	59.79
Cladostephus spongiosus	0.17	0.21	0.31	1.07	1.10	60.90
Amphipoda	0.10	0.05	0.31	0.97	1.10	62.00
Nucella lapillus	0.15	0.17	0.30	1.31	1.09	63.09
Phyllophora pseudoceranoïdes	0.07	0.06	0.29	0.79	1.04	64.13
Chaetomorpha	0.15	0.08	0.28	1.12	1.01	65.14
Alcyonidioides mytili	0.03	0.09	0.27	1.23	0.98	66.12
Verrucaria	0.05	0.10	0.27	0.88	0.98	67.11
Cladophora rupestris	0.28	0.25	0.27	1.05	0.96	68.06
Aplidium turbinatum	0.09	0.05	0.25	1.19	0.91	68.98
Rhodothamniella floridula	0.08	0.13	0.25	1.14	0.89	69.86
Ascophyllum nodosum	0.13	0.10	0.23	1.43	0.82	70.68

SIMPER: Site x Year, Boulder Bottoms

Similarity Percentages - species contributions (see Section 3.2, page 14)
Two-Way Analysis – Site x Year
Data – presence/absence data for 251 taxa
Analysis parameters: S17 Bray-Curtis similarity; Cut off for low contributions: 70.00%
Factor Groups: Period (Early = 2007 & 2008, Middle = 2009-2012, Late = 2013-2019) x Site (BB, FE)
Results for Periods Early v Middle and Middle v Later only:

Early & Middle - Average dissimilarity = 28.60

Species	Group Early Av.Abund	Group Middle Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Cirripedia (juv)	0.13	0.58	1.41	1.46	4.91	4.91
Rhodophyta (dk.enc)	0.53	0.20	1.05	1.37	3.66	8.57
Aplidium turbinatum	0.34	0.49	0.97	1.03	3.41	11.98
Clathria (Microciona) atrasanguinea	0.04	0.28	0.86	1.68	3.00	14.97
Polynoidae	0.29	0.52	0.81	1.31	2.84	17.82
Corella eumyota	0.00	0.25	0.77	0.95	2.68	20.50
Anomiidae	0.38	0.57	0.72	1.54	2.52	23.02
Semibalanus balanoides	0.55	0.41	0.64	1.56	2.24	25.26
Balanus crenatus	0.52	0.72	0.64	1.70	2.22	27.49
Ascidiella scabra	0.21	0.22	0.63	0.97	2.20	29.69
Leucosolenia	0.33	0.44	0.61	1.13	2.13	31.82
Botryllus schlosseri	0.33	0.26	0.60	1.47	2.10	33.92
Nucella lapillus (eggs)	0.30	0.36	0.55	1.50	1.94	35.86
Didemnidae	0.33	0.43	0.53	1.10	1.85	37.71
Carcinus maenas	0.15	0.32	0.53	1.31	1.85	39.56
Halisarca dujardinii	0.36	0.49	0.52	1.30	1.82	41.38
Hildenbrandia	0.11	0.22	0.50	1.35	1.74	43.12
Corallinaceae (enc)	0.29	0.18	0.48	2.03	1.68	44.81
Spirorbinae	0.71	0.81	0.47	1.40	1.65	46.45
Spirobranchus	0.88	0.78	0.44	1.27	1.53	47.98
Ulva (flat)	0.19	0.07	0.42	1.47	1.46	49.45
Dynamena pumila	0.13	0.03	0.39	1.85	1.37	50.81
Chondrus crispus	0.16	0.10	0.37	2.02	1.30	52.11
Porifera (buff)	0.47	0.53	0.36	2.90	1.25	53.37
Polyclinidae	0.05	0.16	0.35	1.38	1.22	54.58
Porifera	0.06	0.15	0.34	1.39	1.18	55.77
Austrominius modestus	0.29	0.21	0.33	1.53	1.16	56.93
Ophiothrix fragilis	0.07	0.16	0.33	0.79	1.16	58.08
Nucella lapillus	0.56	0.44	0.33	1.92	1.14	59.22
Dendrodoa grossularia	0.59	0.52	0.31	1.44	1.09	60.31
Steromphala umbilicalis	0.13	0.04	0.30	1.89	1.04	61.35
Hymeniacidon perlevis	0.62	0.53	0.30	2.61	1.04	62.39
Fucus serratus	0.16	0.09	0.29	0.92	1.01	63.41
Bryozoa (enc)	0.76	0.78	0.28	1.90	1.00	64.40
Fecampia erythrocephala (egg flask)	0.08	0.07	0.27	1.32	0.95	65.35
Steromphala cineraria	0.36	0.30	0.27	1.51	0.94	66.30
Porcellana platycheles	0.44	0.38	0.27	1.41	0.93	67.23
Clavelina lepadiformis	0.06	0.13	0.26	1.29	0.92	68.15
Asterias rubens	0.01	0.07	0.24	0.77	0.85	68.99
Botrylloides	0.14	0.08	0.24	1.56	0.83	69.82
Balanus balanus	0.12	0.09	0.23	1.18	0.81	70.63

Early & Late - Average dissimilarity = 34.87

Species	Group Early Av.Abund	Group Late Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Cirripedia (juv)	0.13	0.85	2.12	2.96	6.09	6.09
Rhodophyta (dk.enc)	0.53	0.01	1.64	2.00	4.70	10.79
Corella eumyota	0.00	0.39	1.22	1.34	3.48	14.28
Clathria (Microciona) atrasanguinea	0.04	0.34	1.02	2.15	2.94	17.22
Balanus crenatus	0.52	0.82	0.96	1.64	2.76	19.98
Aplidium turbinatum	0.34	0.33	0.95	1.30	2.74	22.71
Semibalanus balanoides	0.55	0.31	0.94	3.32	2.69	25.40
Anomiidae	0.38	0.56	0.77	1.40	2.19	27.60
Didemnidae	0.33	0.44	0.72	1.40	2.06	29.66
Leucosolenia	0.33	0.47	0.71	1.33	2.04	31.70
Nucella lapillus (eggs)	0.30	0.40	0.69	1.32	1.98	33.68
Hildenbrandia	0.11	0.32	0.65	1.13	1.85	35.53
Halisarca dujardinii	0.36	0.36	0.60	1.39	1.71	37.25
Corallinaceae (enc)	0.29	0.11	0.57	1.72	1.64	38.88
Polynoidae	0.29	0.37	0.56	1.48	1.62	40.50
Ascidiella scabra	0.21	0.00	0.56	1.10	1.60	42.10
Clavelina lepadiformis	0.06	0.19	0.54	1.27	1.56	43.66
Nucella lapillus	0.56	0.37	0.53	1.77	1.51	45.17
Botryllus schlosseri	0.33	0.18	0.52	1.20	1.49	46.67
Protosuberites denhartogi	0.00	0.15	0.51	1.49	1.47	48.13
Austrominius modestus	0.29	0.33	0.47	1.47	1.35	49.49
Spirorbinae	0.71	0.73	0.45	1.20	1.29	50.78
Ophiothrix fragilis	0.07	0.22	0.44	1.23	1.26	52.04
Ulva (flat)	0.19	0.05	0.43	1.40	1.24	53.28
Carcinus maenas	0.15	0.26	0.42	1.60	1.21	54.49
Dendrodoa grossularia	0.59	0.41	0.42	1.31	1.21	55.70
Verruca stroemia	0.13	0.21	0.42	1.01	1.20	56.90
Campanulariidae	0.00	0.12	0.42	0.94	1.19	58.09
Fecampia erythrocephala (egg flask)	0.08	0.18	0.41	1.39	1.17	59.26
Balanus balanus	0.12	0.15	0.39	1.93	1.12	60.38
Steromphala cineraria	0.36	0.33	0.39	1.54	1.11	61.50
Porcellana platycheles	0.44	0.45	0.38	1.50	1.09	62.59
Porifera (buff)	0.47	0.45	0.37	1.52	1.07	63.65
Dynamena pumila	0.13	0.04	0.36	1.58	1.04	64.70
Polychaeta (tube)	0.05	0.20	0.36	1.25	1.04	65.73
Bryozoa (enc)	0.76	0.85	0.35	1.46	1.01	66.74
Chondrus crispus	0.16	0.08	0.33	1.65	0.96	67.70
Fucus serratus	0.16	0.10	0.30	0.87	0.86	68.55
Ophlitaspongia papilla	0.01	0.09	0.30	1.12	0.85	69.40
Botrylloides	0.14	0.04	0.28	1.41	0.81	70.21

Middle & Late - Average dissimilarity = 27.26

Species	Group Middle Av.Abund	Group Late Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Corella eumyota	0.25	0.39	0.94	1.34	3.44	3.44
Cirripedia (juv)	0.58	0.85	0.76	1.19	2.79	6.23
Aplidium turbinatum	0.49	0.33	0.75	1.60	2.77	9.00
Ascidiella scabra	0.22	0.00	0.64	1.13	2.35	11.35
Halisarca dujardinii	0.49	0.36	0.60	1.51	2.22	13.57
Rhodophyta (dk.enc)	0.20	0.01	0.57	1.28	2.11	15.67
Nucella lapillus (eggs)	0.36	0.40	0.56	1.49	2.04	17.71
Hildenbrandia	0.22	0.32	0.54	1.04	1.98	19.69
Anomiidae	0.57	0.56	0.47	1.42	1.73	21.42
Polynoidae	0.52	0.37	0.47	1.46	1.73	23.14
Semibalanus balanoides	0.41	0.31	0.46	1.24	1.69	24.84
Verruca stroemia	0.08	0.21	0.46	1.06	1.67	26.51
Leucosolenia	0.44	0.47	0.44	1.23	1.62	28.13
Spirobranchus	0.78	0.87	0.43	1.28	1.57	29.70
Carcinus maenas	0.32	0.26	0.42	1.54	1.55	31.25
Spirorbinae	0.81	0.73	0.41	0.89	1.50	32.75
Balanus balanus	0.09	0.15	0.41	1.43	1.49	34.24
Protosuberites denhartogi	0.02	0.15	0.40	1.35	1.46	35.70
Clathria (Microciona) atrasanguinea	0.28	0.34	0.40	1.51	1.45	37.15
Didemnidae	0.43	0.44	0.39	1.51	1.44	38.59
Austrominius modestus	0.21	0.33	0.39	0.91	1.43	40.02
Balanus crenatus	0.72	0.82	0.38	1.07	1.41	41.43
Polychaeta (tube)	0.07	0.20	0.38	1.10	1.38	42.81
Porifera	0.15	0.02	0.37	1.55	1.37	44.18
Ophiothrix fragilis	0.16	0.22	0.37	1.39	1.35	45.54
Botryllus schlosseri	0.26	0.18	0.37	1.08	1.35	46.89
Clavelina lepadiformis	0.13	0.19	0.36	1.31	1.33	48.22
Fecampia erythrocephala (egg flask)	0.07	0.18	0.35	1.36	1.30	49.52
Dendrodoa grossularia	0.52	0.41	0.35	1.24	1.30	50.82
Campanulariidae	0.00	0.12	0.35	0.90	1.29	52.11
Hymeniacidon perlevis	0.53	0.57	0.34	1.79	1.26	53.38
Bryozoa (enc)	0.78	0.85	0.34	1.59	1.26	54.64
Porcellana platycheles	0.38	0.45	0.33	1.42	1.22	55.86
Steromphala cineraria	0.30	0.33	0.33	1.36	1.22	57.08
Nucella lapillus	0.44	0.37	0.31	1.35	1.13	58.22
Porifera (buff)	0.53	0.45	0.28	1.58	1.03	59.24
Corallinaceae (enc)	0.18	0.11	0.28	1.33	1.01	60.25
Polyclinidae	0.16	0.14	0.26	1.43	0.96	61.21
Amathia	0.06	0.11	0.25	1.14	0.92	62.14
Perophora listeri	0.05	0.09	0.24	0.97	0.87	63.01
Littorina obtusata (/fabalis)	0.14	0.08	0.24	1.52	0.86	63.87
Chondrus crispus	0.10	0.08	0.23	1.47	0.85	64.72
Pisidia longicornis	0.10	0.07	0.23	1.80	0.83	65.55
Cancer pagurus	0.11	0.07	0.22	1.57	0.82	66.37
Asterias rubens	0.07	0.05	0.22	0.91	0.80	67.17
Scrupocellaria scruposa	0.03	0.09	0.22	0.87	0.80	67.97
Alcyonidioides mytili	0.05	0.07	0.22	0.91	0.79	68.76
Sycon ciliatum	0.11	0.14	0.21	1.03	0.79	69.55
Hiatella arctica	0.02	0.08	0.20	1.10	0.75	70.30

ANOSIM: Turned? x Site

Analysis of Similarities (see Section 3.4, page 30)
Two-Way Crossed – Turned? x Site
Data – Bray-Curtis similarities derived from presence/absence data for 258 taxa
Factors: Turned? (unordered): N, Y; Site (unordered): BB, FE.

Tests for differences between unordered Turned? Groups (across all Site groups)
Global Test
Sample statistic (Average R): 0.078
Significance level of sample statistic: 3.2%
Number of permutations: 999 (Random sample from a large number)
Number of permuted statistics greater than or equal to Average R: 31

Tests for differences between unordered Site groups (across all Turned? groups)
Global Test
Sample statistic (Average R): 0.403
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from a large number)
Number of permuted statistics greater than or equal to Average R: 0

SIMPER: Turned? x Site

Similarity Percentages - species contributions (see Section 3.4, page 30)
Two-Way Analysis – Turned? x Site
Data – presence/absence data for 258 taxa
Analysis parameters: S17 Bray-Curtis similarity; Cut off for low contributions: 70.00%
Factor Groups: Turned?: N, Y; Site: BB, FE.
Results for Turned?: N v Y only:

Turned? N v Y. Average dissimilarity = 47.85

Species	Group N Av.Abund	Group Y Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Hildenbrandia	0.54	0.54	0.96	0.94	2.01	2.01
Rhodophyta (dk.enc)	0.33	0.45	0.94	0.91	1.96	3.96
Anomiidae	0.61	0.27	0.93	0.97	1.95	5.91
Nucella lapillus	0.46	0.44	0.91	0.91	1.90	7.81
Other plant (Agg enc)	0.67	0.62	0.90	0.87	1.88	9.69
Carcinus maenas	0.40	0.33	0.90	0.91	1.88	11.57
Porifera (Agg)	0.86	0.53	0.90	0.85	1.87	13.44
Steromphala cineraria	0.38	0.35	0.89	0.90	1.87	15.31
Ulva (flat)	0.72	0.62	0.88	0.85	1.84	17.15
Corallinaceae (enc)	0.61	0.50	0.88	0.86	1.84	18.99
Fucaceae (sporelings)	0.70	0.66	0.87	0.84	1.82	20.81
Halisarca dujardinii	0.46	0.29	0.87	0.90	1.81	22.62
Fucus vesiculosus	0.23	0.39	0.84	0.82	1.76	24.38
Littorina obtusata (/fabalis)	0.38	0.21	0.83	0.85	1.73	26.11
Polynoidae	0.43	0.26	0.83	0.86	1.73	27.84
Chondrus crispus	0.73	0.51	0.82	0.80	1.71	29.54
Patella vulgata	0.21	0.32	0.82	0.80	1.70	31.25
Rhodophyta (Agg non enc)	0.83	0.60	0.81	0.78	1.69	32.94
Nucella lapillus (eggs)	0.40	0.36	0.81	0.83	1.69	34.63
Ascidiacea (Agg colonial)	0.54	0.26	0.80	0.87	1.68	36.31

Didemnidae	0.47	0.27	0.80	0.86	1.67	37.98
Spirorbinae	0.81	0.68	0.79	0.77	1.64	39.63
Ascidiacea (Agg solitary)	0.56	0.28	0.78	0.83	1.62	41.25
Chlorophyta (Agg)	0.82	0.73	0.77	0.74	1.60	42.85
Hymeniacidon perlevis	0.70	0.34	0.76	0.79	1.60	44.45
Bryozoa (enc)	0.89	0.70	0.72	0.70	1.50	45.95
Sabellaria	0.46	0.26	0.72	0.76	1.49	47.44
Austrominius modestus	0.64	0.75	0.71	0.74	1.49	48.93
Polychaeta (tube)	0.24	0.17	0.69	0.71	1.44	50.37
Cirripedia (juv)	0.81	0.74	0.66	0.67	1.38	51.75
Actinia	0.14	0.21	0.64	0.66	1.35	53.10
Aplidium turbinatum	0.41	0.22	0.64	0.71	1.35	54.45
Corella eumyota	0.33	0.18	0.64	0.73	1.33	55.78
Leucosolenia	0.49	0.22	0.61	0.73	1.28	57.06
Littorina littorea	0.14	0.18	0.61	0.63	1.28	58.34
Balanus crenatus	0.87	0.81	0.59	0.60	1.24	59.58
Ulva (tubular)	0.18	0.21	0.59	0.66	1.24	60.82
Porcellana platycheles	0.45	0.20	0.56	0.66	1.18	62.00
Ophiothrix fragilis	0.22	0.11	0.54	0.62	1.13	63.13
Amphipoda	0.13	0.14	0.52	0.57	1.09	64.22
Ascophyllum nodosum	0.13	0.18	0.50	0.58	1.05	65.27
Spirobranchus	0.92	0.81	0.50	0.55	1.04	66.31
Fecampia erythrocephala (egg flask)	0.13	0.16	0.48	0.56	1.01	67.32
Semibalanus balanoides	0.67	0.85	0.47	0.57	0.98	68.30
Clathria (Microciona) atrasanguinea	0.33	0.10	0.45	0.58	0.93	69.23
Dendrodoa grossularia	0.51	0.22	0.44	0.56	0.93	70.16

Appendix 6 Data archive

Data outputs associated with this project are archived in the NRW 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 boulder physical parameters and species data, including validation data, verification data and metadata.

[C] A NBN data file containing the relevant survey details.

[D] A Marine Recorder data file of the surveys for NRW validation purposes.

[F] A full set of images from the surveys, in jpg format.

[G] A full set of GIS files of any spatial data.

Metadata for this project is publicly accessible through Natural Resources Wales' Library Catalogue http://libcat.naturalresources.wales/webview/ (English Version) and http://libcat.naturalresources.wales/cnc/ (Welsh Version) by searching 'Dataset Titles'. The metadata is held as record within Intertidal Monitoring.

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