Impacts of Bait Digging on the Gann: Analysis of Monitoring Data

Report No: 450

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Mae'r Gann, ger Dale, sir Benfro, yn gilfach gymharol gysgodol sy'n agos i fynediad Dyfrffordd Aberdaugleddau. Mae gwastadeddau llaid a gwastadeddau tywod rhynglanwol y Gann, sef 'y Fflatiau', yn gymysgedd cymhleth o gynefinoedd sy'n cwmpasu ardal helaeth o gynefin graean mwdlyd cysgodol o waddodion cymysg arfordirol.

Mae Fflatiau'r Gann yn ardal lle ceir llawer iawn o dyrchu am abwyd. Mae'r pryderon ynghylch effaith gweithgareddau casglu abwyd dwys at ddibenion masnachol a hamdden ar Fflatiau'r Gann yn rhai hirsefydlog, ac maent wedi bod yn destun ffocws o'r newydd dros y blynyddoedd diweddar, yn enwedig gan fod Fflatiau'r Gann oddi mewn i Ardal Cadwraeth Arbennig (ACA) Forol Sir Benfro a Safle o Ddiddordeb Gwyddonol Arbennig (SoDdGA) Dyfrffordd Aberdaugleddau ac maent yn gynefin â blaenoriaeth yn ôl Adran 7 (Deddf yr Amgylchedd (Cymru) 2016). Mae nodwedd y gwastadeddau llaid a gwastadeddau tywod rhynglanwol yn ACA Forol Sir Benfro mewn Cyflwr Anffafriol ar hyn o bryd, a nodir mai achosion dwys o dyrchu am abwyd yn y Gann, a lleoliadau eraill yn nyfrffordd Aberdaugleddau, sy'n rhannol gyfrifol.

Yn dilyn degawdau o ddiffyg rheolaeth dros dyrchu am abwyd, cafodd ardal wirfoddol dim tyrchu ei chreu yn 2015 er mwyn i'r ardal adfer. Cafodd y parth dim tyrchu ei weithredu mewn ardal y bu effaith fawr arni yn flaenorol i'r gorllewin o'r safle, ond ni chafodd yr ochr ddwyreiniol ei chau i dyrchu am abwyd. Yn 2016, cafodd ffiniau'r parth dim tyrchu eu gwerthuso am yr eildro, a chafodd yr ardaloedd caeedig eu newid i ddwy adran ar bob ochr i'r safle. Ymgymerodd Cyfoeth Naturiol Cymru ag ymgyrch monitro wedi'i thargedu yn 2015, 2016 a 2017 i gasglu data ar Fflatiau'r Gann er mwyn gwerthuso a oedd y mesurau rheoli gwirfoddol a weithredir ar y safle wedi bod yn effeithiol.

Mae'r mesurau rheoli hyn yn parhau i fod yn eu lle yn 2020, ond mae arsylwadau'n awgrymu nad ydynt yn effeithiol, a cheir tystiolaeth nad yw'r rheiny sy'n tyrchu am abwyd yn cadw at y parthau. Mae mesurau rheoli ychwanegol wrthi'n cael eu hystyried ar gyfer Fflatiau'r Gann. Nod yr adroddiad hwn felly yw asesu'r data diweddaraf ar gyfer yr ardal er mwyn asesu statws ecolegol cyfredol Fflatiau'r Gann ac adolygu effeithiolrwydd y parthau dim tyrchu gwirfoddol cyfredol.

Nodau allweddol y prosiect oedd gwneud y canlynol:

- **Dadansoddi a dehongli'r** canlyniadau o'r data monitro isfilodol ac arfilaidd a gasglwyd gan Cyfoeth Naturiol Cymru, ynghyd â ffynonellau data eraill, er mwyn asesu statws ecolegol cyfredol isfilod ac arfilod ar Fflatiau'r Gann ar hyd y lle a thros amser.
- **Cymharu dosbarthiad a helaethrwydd cyfredol** rhywogaethau ag adroddiadau hanesyddol er mwyn asesu newidiadau mewn cymunedau biolegol ar draws Fflatiau'r Gann dros amser.
- **Gwerthuso effeithiolrwydd mesurau rheoli,** yn benodol parthau dim tyrchu gwirfoddol a weithredir ar y safle.

I grynhoi, mae cymunedau benthig Fflatiau'r Gann yn gymharol amrywiol. Fodd bynnag, maent wedi'u dominyddu gan rywogaethau oportiwnistaidd, sy'n byw am amser cymharol fyr, y cysylltir hwy yn aml â chynefinoedd lle ceir mwy o aflonyddwch. Ceir achosion cymharol fach o ddatblygiad gorchudd algaidd dwys gan mai ardaloedd cyfyngedig a geir sy'n addas ar gyfer ymlynu iddynt. Mae gwahaniaethau arwahanol yn amlwg rhwng y cymunedau isfilodol ar Fflatiau'r Gann o'u cymharu ag ardaloedd ehangach yn Nyfrfford Aberdaugleddau (sef yr ardaloedd o Fae Angle a Phwllcrochan lle nid oes tyrchu am abwyd yn digwydd). Dylid nodi bod dylanwad dŵr croyw ar draws Fflatiau'r Gann oherwydd ardal o ddŵr sy'n rhedeg o aber afon Gann. Nid oes map manwl gywir o safle'r nant dŵr croyw ar gael, ond gallai hwn fod yn ffactor pwysig sy'n dylanwadu ar y casgliad isfilodol ac arfilaidd ar draws y safle.

Cafodd cymhariaeth hanesyddol ei wneud o gymunedau o ffawna sy'n gysylltiedig â Fflatiau'r Gann er mwyn dod i gasgliad ynglŷn â'r newid hirdymor mewn statws ecolegol. Roedd hyn yn seiliedig yn bennaf ar gymhariaeth o ddata a gyflwynwyd mewn adroddiadau o 1960 a 1992 (Bassindale a Clark, 1960; Edwards *et al.*, 1992) sy'n dyddio nôl i amser cyn y lefelau uchel o weithgarwch tyrchu am abwyd yr arsylwir arno ar hyn o bryd. Yn gyffredinol, mae'r rhywogaethau mwy o faint, sy'n byw'n hirach wedi lleihau, a cheir mwy o rywogaethau oportiwnistaidd, sy'n byw am amser byr, ac sy'n gallu cytrefu ardaloedd o waddod sydd wedi'i aflonyddu. Mae hyn yn arwydd o gynnydd yn y lefelau o aflonyddwch ar draws Fflatiau'r Gann ers y 1960au.

Dylid nodi nad yw'n rhwydd dehongli'r newidiadau hyn oherwydd gwahaniaethau mewn cwmpas gofodol, a dulliau samplu, cofnodi a dadansoddi. Mae effeithiau achosol hefyd yn anodd iawn i'w pennu mewn amgylcheddau morol dynamig lle ceir amrediad o brosesau naturiol a phwysau anthropogenig.

Mae mesurau rheoli gwirfoddol i leihau effaith tyrchu am abwyd wedi'u gweithredu ar Fflatiau'r Gann ers 2015. Yn gyffredinol, nid oes gwahaniaeth ystadegol amlwg yn y cymunedau infertebrat a gofnodwyd naill ai oddi mewn i'r parthau dim tyrchu gwirfoddol, neu'r tu allan iddynt. Nid yw'r prinder gwahaniaethau yn strwythur y gymuned yn syndod o ystyried y ffaith na chydymffurfiwyd â'r parthau hyn. Yn ogystal, mae meintiau bach y samplau a ddefnyddir yn y dadansoddiad eto'n cyfyngu ar y cymariaethau y gellir eu gwneud, ac, yn y pen draw, y casgliadau sy'n deillio ohonynt.

Mae canlyniadau'r dadansoddiad arfilaidd yn dangos bod gwahaniaethau yn nosbarthiad a helaethrwydd rhywogaethau arfilaidd rhwng ardaloedd sydd wedi'u tyrchu'n ddiweddar a'r rheiny lle nad yw hynny wedi digwydd. Er y gallai hyn fod yn arwydd o effaith tyrchu, gallai hefyd adlewyrchu'r ardaloedd o waddod sydd wedi'u targedu gan y rheiny sy'n tyrchu am abwyd, ac felly nid yw'n dystiolaeth bendant.

Yn gyffredinol, mae'r canlyniadau'n dangos y bu symudiad mewn cymunedau ar draws Fflatiau'r Gann ers y 1960au. Mae'r rhywogaethau mwy o faint, sy'n byw'n hirach wedi lleihau yn gyffredinol, ac mae cynnydd wedi bod mewn cymunedau sydd wedi'u dominyddu gan rywogaethau oportiwnistaidd, sy'n byw am amser cymharol fyr, y cysylltir hwy yn aml â chynefinoedd lle ceir mwy o aflonyddwch. Mae'n ymddangos nad yw mesurau rheoli gwirfoddol i leihau effaith gweithgareddau tyrchu am abwyd ar Fflatiau'r Gann wedi bod yn effeithiol, a cheir tystiolaeth sy'n dangos nad yw'r rheiny sy'n tyrchu am abwyd yn cadw at y parthau. Cefnogir hyn gan y data biolegol sy'n dangos nad oes gwahaniaeth amlwg yn yr isfilod a gofnodwyd naill ai oddi mewn i'r parthau dim tyrchu gwirfoddol, neu'r tu allan iddynt, gan gydnabod y data cyfyngedig sydd ar gael.

Er mwyn gwella ein dealltwriaeth o effeithiau tyrchu am abwyd ar Fflatiau'r Gann, argymhellir bod gwaith monitro'n parhau i gael ei wneud i'r hirdymor. Lle mae mesurau rheoli yn eu lle, ac yn enwedig lle caiff unrhyw waith rheoli newydd ei weithredu yn y dyfodol, bydd gwaith monitro'n arbennig o bwysig er mwyn deall effeithiolrwydd y mesurau hyn. Bydd hyn yn helpu i wahaniaethu rhwng achos ac effaith unrhyw newidiadau yr arsylwir arnynt mewn system sy'n ddynamig yn barod.

Executive Summary

The Gann, near Dale, Pembrokeshire, is a relatively sheltered inlet close to the entrance of Milford Haven Waterway. The intertidal mudflats and sandflats of the Gann, ‘The Flats’, are a complex mix of habitats encompassing a large expanse of littoral mixed sediment sheltered muddy gravel habitat.

The Gann Flats is a particularly heavily exploited area for bait digging. Concerns over the impact of intensive commercial and recreational bait collection activities on the Gann Flats are longstanding and have been the subject of renewed focus in recent years, especially as the Gann Flats falls within the Pembrokeshire Marine Special Area of Conservation (SAC), the Milford Haven Waterway Site of Special Scientific Interest (SSSI) and are a Section 7 priority habitat (Environment (Wales) Act 2016). The Intertidal Mudflats and Sandflats feature of the Pembrokeshire Marine SAC is currently in Unfavourable Condition which is attributed, in part, to heavy bait digging at the Gann and other locations in the Milford Haven waterway.

Following decades of unmanaged bait digging, a voluntary no-dig area was created in 2015 to allow recovery of the area. The no-dig zone was implemented in a previously highly impacted area to the west of the site, while the eastern side was not closed to bait digging. In 2016, the boundaries of the voluntary no-dig zone were re-evaluated, and the closed areas changed to two sections either side of the site. Natural Resources Wales (NRW) undertook a targeted monitoring campaign in 2015, 2016 and 2017 to gather data at the Gann Flats to evaluate whether the voluntary management measures implemented at the site had been effective.

These management measures are still in place in 2020, but observations suggest that they are not effective, with evidence showing that bait diggers are not adhering to the zones. Additional management measures for the Gann Flats are being considered. This report therefore aims to assess the most recent data for the area to assess the current ecological status of the Gann Flats and review the effectiveness of the current voluntary no-dig zones.

The key aims of the project were to:

- **Analyse and interpret** the results from the infaunal and epifaunal monitoring data collected by NRW, alongside other sources of data, to assess the current ecological status of infauna and epifauna at the Gann Flats over space and time.
- **Compare the current distribution and abundance** of species with historic reports to assess changes in biological communities across the Gann Flats over time.
- **Evaluate the effectiveness of management measures,** specifically voluntary no-dig zones, implemented at the site.

In summary, the benthic communities of the Gann Flats are relatively diverse. They are, however, dominated by relatively short-lived, opportunistic species that are often associated with more disturbed habitats. There is relatively little development of dense algal cover as there are limited areas suitable for attachment. Distinct differences are apparent between the infaunal communities at the Gann Flats as compared to wider areas within the Milford Haven Waterway (namely non bait dug areas of Angle Bay and Pwllcrochan). It should be noted that there is a freshwater influence across the Gann Flats due to an area of running water from the Gann Estuary. Accurate mapping of the position of the freshwater stream is not available but this could be an important factor influencing the both the infaunal and epifaunal assemblage across the site.

A historic comparison of faunal communities associated with the Gann Flats was undertaken to infer long-term change in ecological status. This was largely based on a comparison of data presented within reports from 1960 and 1992 (Bassindale and Clark, 1960; Edwards *et al.,* 1992) which pre-date the high levels of bait digging activity currently observed. Overall, there has been a general reduction in longer-lived, larger species to more opportunistic, short lived species which are readily able to colonise areas of disturbed sediment. This is indicative of increased levels of disturbance across the Gann Flats since the 1960s.

It should be noted that interpretation of these changes is not straightforward due to differences in spatial coverage, sampling approaches, recording and analytical methods. Causal effects are also very difficult to determine in dynamic marine environments where a range of natural processes and anthropogenic pressures occur.

Voluntary management measures to reduce the impact of bait digging activities have been implemented at the Gann Flats since 2015. Overall, there is no statistically distinguishable difference in the invertebrate communities recorded either within or outside of the voluntary no-dig zones. The lack of differences in community structure is unsurprising given the observed lack of adherence to these zones. In addition, the sample sizes used within the analysis are small which again limits the comparisons that can be made and ultimately the conclusions that can be derived.

The results of the epifaunal analysis indicate differences in the distribution and abundance of epifaunal species between areas that have and have not experienced recent digging. While this may indicate an impact of digging, it could also reflect the areas of sediment targeted by bait diggers and is therefore not conclusive.

Overall, the results show that there has been a shift in communities across the Gann Flats since the 1960s. There has been a general reduction in longer-lived, larger species and an increase in communities dominated by relatively short-lived, opportunistic species that are often associated with more disturbed habitats. Voluntary management measures to reduce the impact of bait digging activities at the Gann Flats appear to have been ineffective with evidence showing that bait diggers are not adhering to the zones. This is supported by the biological data which show there is no distinguishable difference in the infauna recorded either within or outside of the voluntary no-dig zones, while recognising the limited amount of data available.

It is recommended that to improve our understanding of the effects of bait digging at Gann Flats, monitoring continues to be undertaken over the long term. Where management measures are in place, especially any new management implemented in the future, monitoring will be especially important to understand the effectiveness of these measures. This will help to distinguish the cause and effect of any changes that are observed in what is already a dynamic system.

1. Introduction

The Gann, near Dale, Pembrokeshire, is a relatively sheltered inlet close to the entrance of Milford Haven Waterway (Figure 1). Extensive saltmarsh dominates the upper shore giving way to mudflats and sandflats lower down, fringed by intertidal rocky shore communities and saline lagoon habitat. The intertidal mudflats and sandflats of the Gann Flats are a complex mix of habitats encompassing a large expanse of littoral mixed sediment sheltered muddy gravel habitat.

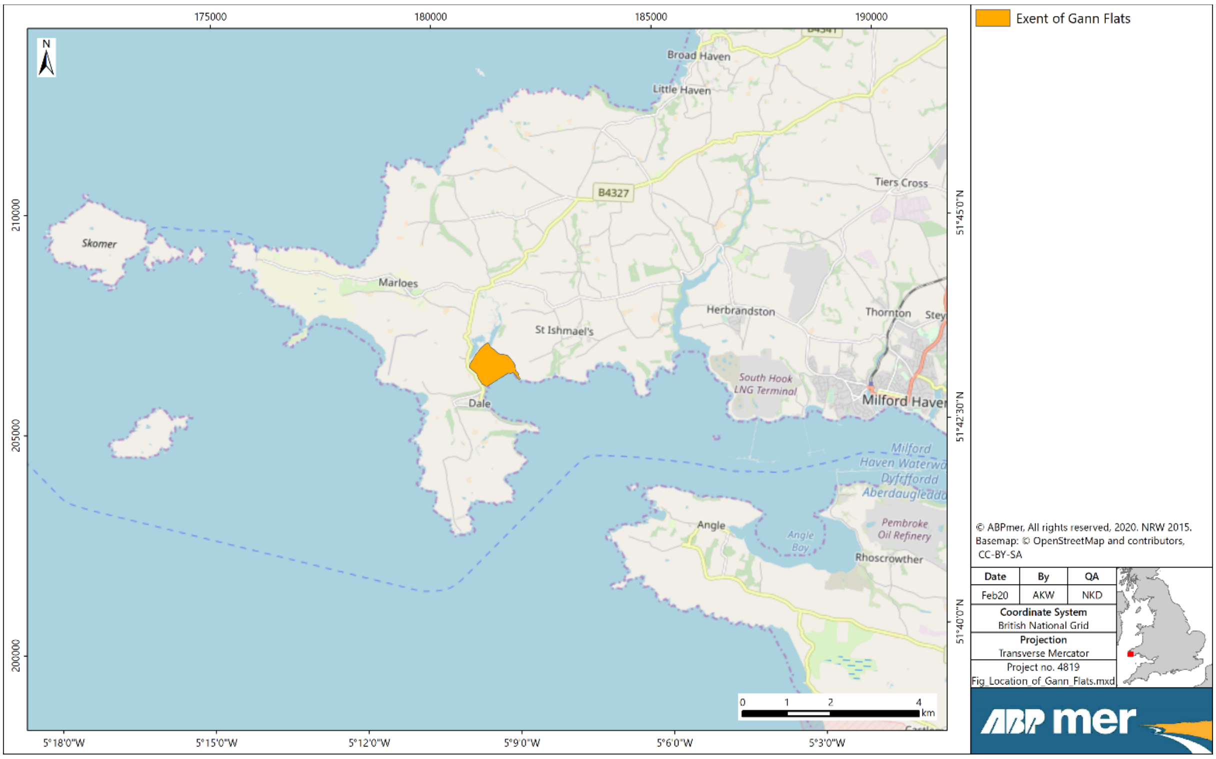


Figure 1: Location of the Gann Flats within the Milford Haven Waterway

The complex mix of muddy gravels at the Gann Flats supports large aggregations of the angling bait species king ragworm Alitta virens (previously named Neanthes virens) with relatively easy access. As such, the Gann Flats is a particularly important and heavily exploited area for bait digging. Concerns over the impact of intensive commercial and recreational bait collection activities on the Gann Flats are longstanding and have been the subject of renewed focus in recent years, especially as the Gann Flats falls within the Pembrokeshire Marine Special Area of Conservation (SAC), the Milford Haven Waterway Site of Special Scientific Interest (SSSI) and are a Section 7 (of the Environment (Wales) Act 2016) priority habitat.

The Intertidal Mudflats and Sandflats feature is currently in Unfavourable Condition in the Pembrokeshire Marine SAC, which is attributed, in part, to heavy bait digging at the Gann and other locations in the Milford Haven waterway. Following decades of unmanaged bait digging, a voluntary no-dig area was created in 2015 to allow recovery of the area, with the aim of trying to reach favourable condition status of the SAC habitats. The no-dig zone was implemented in a previously highly impacted area to the west of the site, while the eastern side was not closed to bait digging. In 2016, the boundaries of the voluntary no-dig zone were re-evaluated, and the closed areas changed to either side of the site (Figure 2). Natural Resources Wales (NRW) undertook a targeted monitoring campaign in 2015, 2016 and 2017 to gather data at the Gann Flats to evaluate whether the voluntary management measures implemented at the site had been effective.

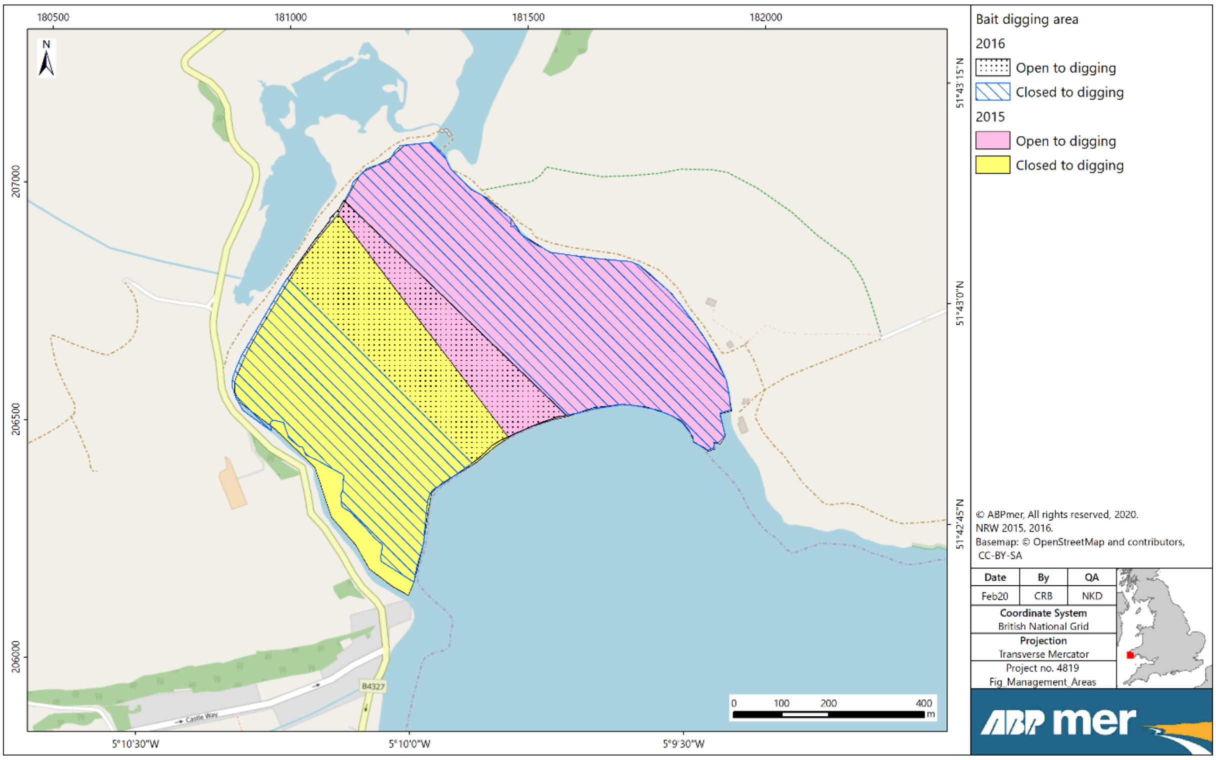


Figure 2: Bait digging management areas for the Gann Flats in 2015 and 2016.

These management measures are still in place in 2020, but observations suggest that they are not effective, with bait diggers not adhering to the zones. Additional, management measures for the Gann Flats are being considered. This report therefore aims to bring together some of the most recent data for the area to assess the current ecological status of the Gann Flats and review the effectiveness of the current voluntary no-dig zones.

Scope and objectives

The key aims of the project were to:

- Analyse and interpret the results from the infaunal and epifaunal monitoring data collected by NRW, alongside other sources of data, to assess the current ecological status of infauna and epifauna at the Gann Flats;
- Compare the current distribution and abundance of species with historic reports to assess changes in biological communities across the Gann Flats through time; and
- Evaluate the effectiveness of management measures, specifically voluntary no-dig zones, implemented at the site.

It is anticipated that the outputs of this review will assist in providing the evidence base upon which future management decisions can be made.

2. Bait Digging Impact

Milford Haven Waterway provides a key area for angling and bait digging activity. Previous reports have found that Gann Flats within Milford Haven Waterway is one of the key sites for bait collection due to dense populations, and target size, of ragworms (*Alitta virens*) and the easy accessibility of the site (Morrell, 2009, Evans *et al.,* 2015). Previous reports have discussed the impact of disturbance caused by bait digging to habitats and species at numerous locations (Farrell, 1996; Fowler, 1999, Watson *et al*., 2007). The evidence indicates that intensive bait digging is having an impact on the benthic communities within the Gann Flats. This section reviews the wider evidence of known impacts caused by bait digging and highlights the specific relevance for the Gann Flats.

Wider evidence

Multiple adverse impacts have been recorded in previous studies as a result of bait digging activities. Bait digging can cause significant modifications to the structure and function of habitats through anthropogenic changes to sediment dynamics and water quality (through increasing the bioavailability of contaminants bound in muddy sediment, particularly where anoxic), and results in direct removal of, or damage to, target and non-target species (Evans *et al.,* 2015).

Changes to habitat structure occur as a result of direct physical disturbance to sediments by diggers. The physical recovery of habitats following disturbance varies according to several factors such as harvesting method, the degree of site exposure and habitat type. Changes to the structure of sheltered, poorly sorted sediment habitats are thought to be most enduring with physical recovery occurring more slowly than in coarse sandy wave exposed areas (Fowler, 1999). Given that the Gann Flats is a sheltered, mixed muddy sediment environment where holes are not typically backfilled, physical recovery of sediment to pre-disturbance distribution is slow.

Fowler (1999) reported that sedentary, long-lived, slow-reproducing species were the most seriously affected, with the recovery of such species after disturbance likely to be lengthy. Common, short-lived species recruit and recover quickly generally in less than 12 months despite evidence of digging leading to a sharp reduction in the total biomass of species recorded in the short term (less than one month after digging).

For example, in a two-year study looking at the impact of bait digging on the infaunal and epifaunal communities of Chichester Harbour, Farrell (1996) noted a significant reduction in density of certain species (*Cerastoderma edule, Neoamphitrite figulus, Harmothoe imbricata* and *Littorina littorea*). *L. littorea* recovered to above pre-disturbance levels in the following year but species such as *C. edule* remained in significantly reduced numbers. Watson *et al*. (2007) found similar results when they simulated bait collection as part of a two-year study into the impacts of bait digging on *A. virens* populations in the Solent. The study demonstrated that four species, *N. figulus*, *H. glabra, C. edule* and *Nephtys hombergii*, were significantly reduced in numbers in dug areas compared to undug areas in both years.

McLusky *et al*. (1983) also assessed the effects of bait digging on the distribution and recovery of species at Blackness, Forth Estuary. They reported recovery of certain smaller short-lived invertebrates, *Peringia ulvae* and *Macoma balthica*, to be fairly swift, with densities indistinguishable from pre-disturbance levels within three weeks. However, there was still evidence of the effects of disturbance to *Arenicola marina* over four months after it had occurred, supporting the conclusion that long-lived, larger and less abundant species suffer significant long-term reductions as a result of bait digging. It should be noted that there is a difference between re-distribution of existing stock and recovery through recruitment. Caution should be exercised when referring to studies such as this, which relate to mobile species or species which translocate easily by minimal wave action, as they often do not distinguish between true recovery via recruitment and redistribution from adjacent areas.

The impacts of bait digging on non-target macrofauna are also well described, with loss or depletion of species through physical damage or habitat change the main result of collection. Bait digging gives rise to highly disturbed or unstable environments which favour short-lived, opportunistic species able to tolerate elevated disturbance levels compared to longer lived, slower growing species typical of undisturbed habitats (Evans *et al.,* 2015, Fowler, 1999).

Overall, bait digging causes significant modifications to the structure and function of habitats. The higher level of disturbance leads to changes in species community composition, which favours smaller short-lived invertebrates such as *Peringia ulvae* and *Macoma balthica*. Long-lived, larger, less motile and less abundant species suffer greater long-term reductions as a result of bait digging. These larger, high biomass species are also functionally important, therefore a reduction in these species can also alter habitat functioning. Additionally, the physical recovery of sediments to the impacts of bait digging in sheltered, mixed muddy sediment environments, such as the Gann Flats, is slow.

Bait digging at the Gann Flats

There is substantial evidence of extensive bait digging across the Gann Flats (Figure 3), and it is acknowledged that local modifications and species level alterations have occurred in areas of the flats where bait digging takes place (Evans *et al*., 2015). Historically, the lugworm *A. marina* was the main bait digging target species of the Gann Flats. More recently this has become *A. virens* given the levels of abundance and relatively high mean weight of this species (Evans *et al*., 2015).

A study by Morrell (2009) assessed the intensity and distribution of bait digging activity across Milford Haven Waterway. Global Positional System (GPS) locations were recorded to provide a detailed quantitative spatial distribution of bait digging activity (Figure 3). The survey was conducted between 2007 and 2008 during which time a total of 26,615 holes associated with bait digging were recorded at the Gann Flats. The report noted, that although the Gann Flats did not have the highest density of ragworm within Milford Haven Waterway, it was the most important site for ragworm bait digging. This was largely due to the ease of access, the still relatively high density and large size of ragworms (average size of 5.5 g wet weight), both of which made it the most exploited area of bait digging.

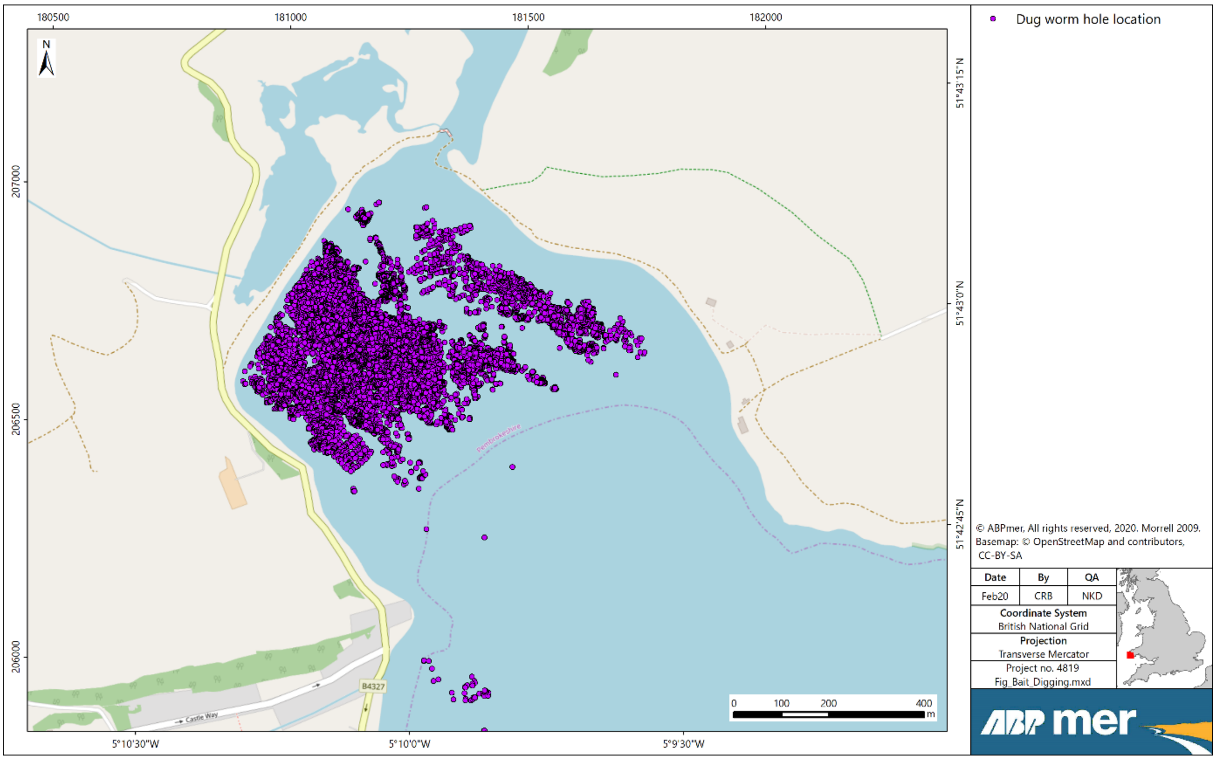


Figure 3: GPS locations of dug 'worm holes' indicating the spatial extent of digging efforts in 2007 and 2008.

Additionally, the report noted that there was a general trend towards intensive digging in the late winter, early spring period, which tailed off towards the summer and autumn.

Available evidence indicates that the most notable impacts on the Gann Flats are the creation of large areas of physically disturbed habitat that support reduced species diversity and favour the proliferation of opportunistic species such as the target *A. virens* (Morrell, 2009; Evans *et al*., 2015). The physical impacts of bait digging in intertidal soft sediments of the Gann Flats are pictured in Figure 4. These are immediately apparent following hand digging activity, however, the long-term implications of this activity on both habitats and species are considerably less clear and require more detailed examination.

Figure 4: Evidence of bait digging on the Gann Flats (Copyright NRW)

This disturbance represents a detrimental impact on the habitat structure and function as well as the benthic assemblage of the Gann Flats mixed muddy gravel habitat. This has resulted in a degradation of designated SAC habitat since designation in 2004 (Evans *et al.,* 2015). These impacts are one of the key drivers behind the move towards the implementation of effective management measures to address the issue of bait digging in this location.

3. Ecological Assessment of the Gann Flats

This section discusses the ecological status of habitats and species within the Gann Flats. Section 3.1 discusses the current ecological status of the Gann Flats based on monitoring which was undertaken by NRW between 2015 and 2017. Chapter 4 compares the current results to historic data to assess changes in biological communities which may be as a result of increased bait digging activities.

3.1. Current ecological status

This section investigates the current ecological status of communities across the Gann Flats, focusing on the distribution of habitats and species present at the site. To assess the current ecological status of communities across the Gann Flats, infauna and epifauna data collected in 2015, 2016 and 2017 have been analysed. These data have also been compared against data from the wider Milford Haven waterway to provide a context for community status.

Methods: Data collection and analysis

Targeted monitoring surveys were undertaken between 2015 and 2017 to assess biological communities within the Gann Flats. The monitoring consisted of two components, epifauna and infauna monitoring.

Epifaunal sampling

Epifaunal samples were collected in 2015 and 2017 across the Gann Flats. Sample locations are shown in Figure 5.

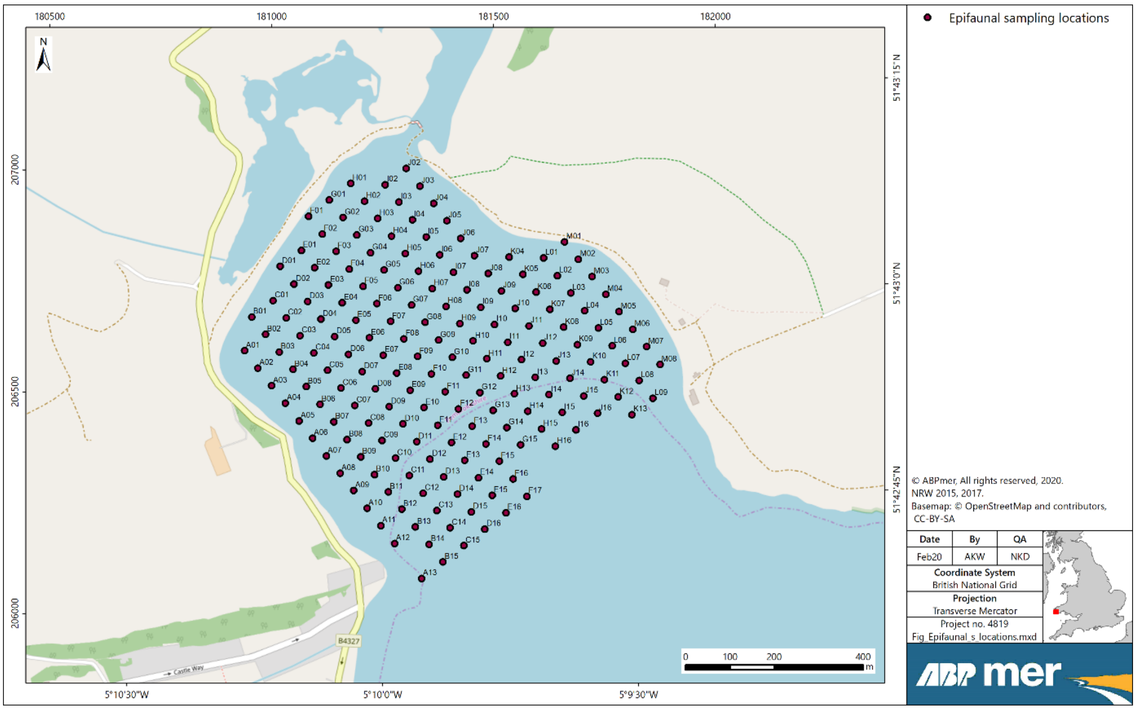


Figure 5: Epifaunal sampling locations within the Gann Flats

A total of 166 records were collected in 2015 and 163 records collected in 2017. All macro-epibenthic organisms were counted individually within a 0.5 x 0.5 m quadrat. Quadrats were sampled along 13 transect lines running down the shore at approximately 60 m spacing.

Additional environmental data was also recorded within each quadrat including sediment type, the presence of running or standing water, and evidence of any bait digging in the immediate area.

Infauna sampling

Infaunal samples were collected in 2015 and 2016 using a 0.01 m² corer and sieved over a 0.5 mm sieve. A total of 40 samples (from within a number of defined station groups) were collected in 2015 and 2016. Sampling was randomised within each station group. Infaunal core sample locations (within each station group) are shown in Figure 6.

In addition to the samples collected within the Gann Flats, sampling was also undertaken at two nearby sites, Pwllcrochan and Angle Bay to act as control sites for assessment of bait digging activities (Figure 7). Infaunal and epifaunal samples were collected at Pwllcrochan and Angle Bay using the methods described above to provide a comparative baseline. Where possible, the samples collected at these two sites were targeted to avoid areas where there was physical evidence of bait digging. Although some bait digging for ragworm and lugworm occur at these two sites this is understood to be much less intensive than at the Gann Flats (Morrell, 2009).

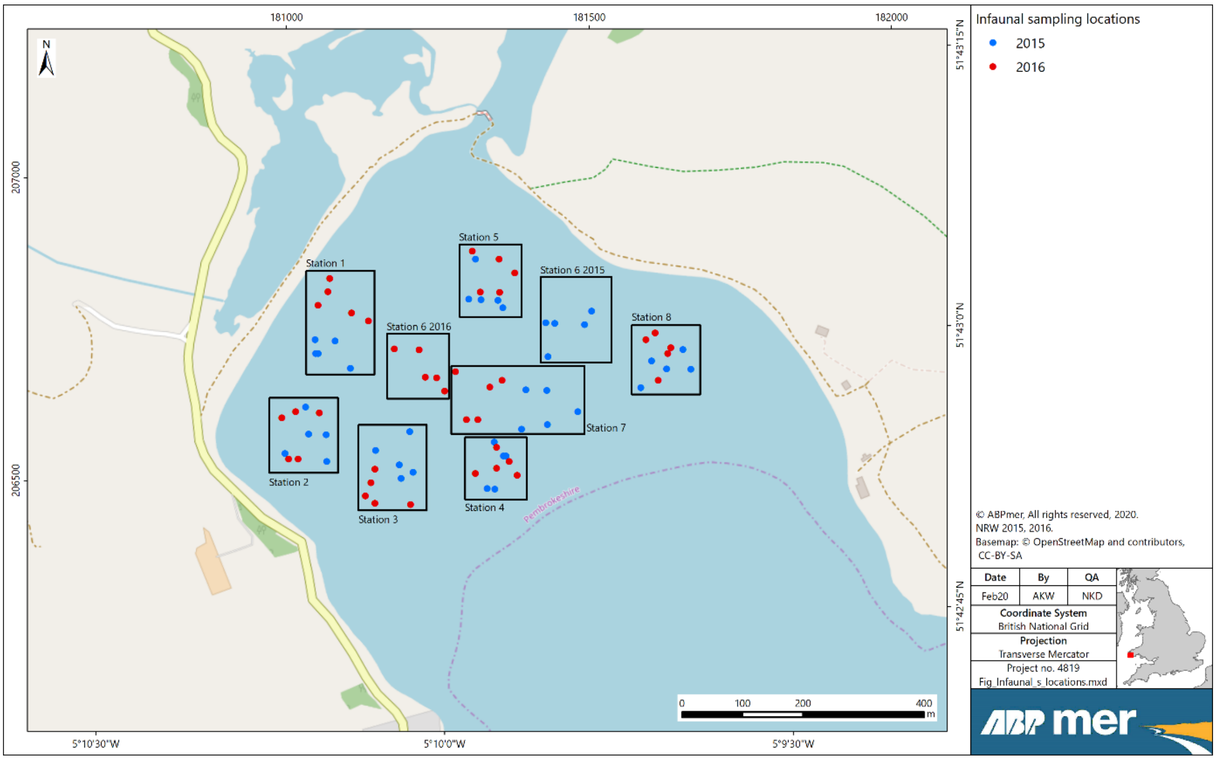


Figure 6:Infaunal sampling locations within the Gann Flats in 2015 and 2016, boxes indicate station locations.

On-going, long-term SAC monitoring is also conducted within Milford Haven Waterway, to analyse changes over temporal and spatial scales in infaunal data and associated environmental variables (sediment granulometry, organic and inorganic sediment chemistry). Five replicate sediment and infaunal samples were collected in 2007, 2012 and 2015 using a 0.1 m² day grab at three sites located within the Gann Flats (G1, G2, G3; Figure 7). These samples were analysed for macrobenthic species composition and Particle Size Analysis (PSA) (summary of monitoring data provided by Matthew Green, 2019, full report in progress) and have been discussed below to provide contextual information for the Gann Flats analysis.

Figure 7: Location of samples collected at Angle Bay and Pwllcrochan, and samples G1-3 of the SAC monitoring.

Sample processing of infaunal data collected in 2015, 2016 and data from the SAC monitoring was carried out by different laboratories. Consequently, there were differences in nomenclature and recording policies for certain taxa that needed to be resolved to make the data comparable between years. Therefore, prior to analysis, and in order to standardise the infaunal data collected from the Gann Flats, Angle Bay and Pwllcrochan between 2015 and 2016, a data truncation exercise was undertaken. The data truncation involved combining the datasets and truncating taxon names where required for consistency, whilst maintaining the most precise quantification and highest taxonomic resolution.

Fauna which were not consistently identified by laboratories such as seaweeds, Ostracoda, Copepoda, Barentsia and Enteropneusta were removed prior to analysis. Additionally, any species listed as ‘fragments’ were also removed prior to analysis. The full results of the data truncation are provided in Appendix A. Data were checked and processed in accordance with the ‘Data Preparation/ Formatting Specification’ provided by NRW. Taxon name checks, against WoRMS (MSBAIS subset), were undertaken during the process to ensure an accepted standardised naming convention was applied and taxonomic information was up to date.

To assess the current ecological status of the Gann Flats a variety of analytical techniques were performed within the PRIMER v7 software package (Clarke and Warwick, 2001). This was undertaken to facilitate a more detailed analysis of the data. Within PRIMER all data were square-root transformed prior to any analysis to down weight the influence of a small number of numerically dominant taxa (Clarke and Warwick, 2001). Transformation is standard practice for this type of analysis to reduce the skew in the data. This is achieved by down weighting high numbers, making the analysis more robust by accounting for the abundance and diversity of communities as a whole, as opposed to showing patterns of highly abundant taxa. A square-root transformation was used as it provided an appropriate strength of transformation for the data values, down weighting numerically dominant species without overly reducing the influence of abundance in the analyses and may have occurred by using, for example, a log transformation.

The DIVERSE component of PRIMER v7 was used to calculate the following diversity indices for each sample: total number of taxa (S) and individuals (N) and Simpsons diversity index (1- ʎ). Simpsons diversity (1- ʎ) index is a dominance index (ranging from 0-1), in the sense that its smallest values correspond to assemblages whose total abundance is dominated by one, or a very few, of the species present and highest values correspond to assemblages with equal numbers of individuals of the species present.

To analyse the intertidal macrobenthic community abundance data collected during 2015 and 2016, the following routines were employed on the samples collected:

- **Hierarchical Cluster Analysis** used on a Bray-Curtis similarity (used to quantify the differences in species populations between two different sites) matrix, groups samples to find and visualise biological similarity between samples, such that samples within a group are more similar to each other than samples in different groups;
- **Similarity Profile Permutation Test (SIMPROF)** to examine whether there is a statistically significant relationship to support the groupings derived from hierarchical cluster analysis;
- **Non-metric Multidimensional Scaling (MDS)** Ordination to further visualise in 2 or 3 dimensions the relationship that exists between samples in multidimensional space. This is achieved by attempting to position the samples to reflect their similarity to each other. The “map” represents community patterns and attempts to position more similar samples closer together to reflect their resemblance, this uses rank order of similarity and is not absolute like cluster analysis;
- **SIMPER analysis** to compare the similarity between groups of samples and taxa identified from the SIMPROF test. This routine identifies the species responsible for within-group similarities or dissimilarities between groups and their contribution to the similarity or dissimilarity; and
- **Analysis of Similarity (ANOSIM)** used to test the null hypothesis (H_0) that there are no (spatial or temporal) differences in community (or sediment)

composition. The results expressed represent the extent of the similarities and differences between pooled data.

- R Statistics approaching zero = very slight differences and therefore a high degree of overlap between the community groups
- R Statistics of 0.2-0.3 = some difference but still with some degree of overlap between the community groups; and
- R Statistics approaching 1 (>0.5) = large differences and therefore only slight overlap between the community groups

- **RELATE and BIO-ENV** used to match two multivariate patterns. The RELATE routine provides a means of testing for correlations between two resemblance rank orders (multivariate patterns) to test for correlations between biological communities and environmental variables (in this case, sediment composition). The BIO-ENV routine is an exploratory tool that matches multivariate patterns so that combinations of variables are considered at ever increasing levels of complexity in order to find the best sub-set of variables that match with the biological patterns.

The AZTI Marine Biotic Index (AMBI) (Borja *et al.,* 2000) describes the sensitivity of a macro benthic community to anthropogenic and natural disturbance. Taxa at the Gann Flats were assigned to one of five AMBI groups ('ecological group' I – V) using the AMBI Workbook Tool (Phillips *et al.*, 2012, 2014). Group I describes the most sensitive taxa to natural or anthropogenic disturbance, and V represent the most opportunistic taxa (i.e. those able to best colonise disturbed environments).

To more accurately assess the sensitivity of benthic communities at the Gann Flats the original data, prior to truncation, was used for AMBI analysis. The original species list was imported into the AMBI workbook, taxa were then matched against the species list within the workbook. Any taxa which did not match were cross checked with synonymised names within the WoRMS database. The outcomes of the taxon match and AMBI scores for each of the taxa are provided in Appendix B. Within the AMBI workbook there is an in-built confidence assessment to highlight the percentage of taxa unassigned to an AMBI group for each sample. Within our results no samples had greater than 0.5% unassigned taxa.

Within the AMBI Workbook Tool a number of criteria also need to be assigned to each sample, such as salinity and sediment type. Due to the freshwater influence at the Gann Flats the salinity regime was considered 'Transitional', in comparison Angle Bay and Pwllcrochan were considered 'Coastal'. PSA results from sampling across the Gann Flats, Angle Bay and Pwllcrochan were used to define the sediment composition.

Particle Size Analysis (PSA) data were standardised to Wentworth (1922) size classes for each survey year for consistency between surveys. Sediment classifications for mean size data at each station were calculated using GRADISTAT (Blott and Pye, 2001). Principal Components Analysis (PCA) was carried out on the sediment data to provide a 2D ordination plot. This routine provides a 'best-fit' two-dimensional ordination of the relationship between samples, based upon environmental variables. PCA was carried out on particle size data where Wentworth size classes were overlaid on the plot as vectors, to show the differences in sediment size between samples and sites. The PCA for the PSA data used untransformed data in Wentworth (1922) size classes.

To support the assessment of ecological status of biological communities at the Gann Flats spatial mapping of species distributions was undertaken using ArcGIS version 10.6.

The results of the analysis are presented in Section 3.2 below. These provide greater insight into the current ecological status of the Gann Flats through the consideration of the relationship between sediment composition and the varying faunal assemblages present.

3.2 Results

This section presents the results of the analysis on the current ecological status of the Gann Flats. The section is structured as follows:

- Section 3.2.1: Sediment Composition: analysis of sediment classification across the Gann Flats;
- Section 3.2.2: Infauna: the current ecological status of infaunal community composition at the Gann Flats; and
- Section 3.2.3: Epifauna: the current ecological status of epifaunal communities at the Gann Flats.

3.2.1 Sediment composition

The Folk (1954) sediment classifications based upon particle size data for each station, are presented in Table 1.

Single samples were collected per station in 2016.

Table 1:Folk (1954) sediment classifications based on particle size data for each station group in each year

Station group	Year	Folk descriptions	Station group	Year	Folk descriptions
Gann Flats 1	2015	Gravelly Muddy Sand Gravelly Sand Muddy Sandy Gravel Sandy Gravel	Gann Flats 1	2016	Gravelly Muddy Sand
Gann Flats 2	2015	Gravelly Muddy Sand Muddy Gravel	Gann Flats 2	2016	Muddy Sandy Gravel

Station group	Year	Folk descriptions	Station group	Year	Folk descriptions
		Muddy Sandy Gravel Sandy Gravel			
Gann Flats 3	2015	Gravelly Mud Gravelly Muddy Sand Muddy Sandy Gravel	Gann Flats 3	2016	Gravelly Muddy Sand
Gann Flats 4	2015	Gravelly Muddy Sand Muddy Sandy Gravel	Gann Flats 4	2016	Gravelly Mud
Gann Flats 5	2015	Muddy Gravel Muddy Sandy Gravel Sandy Gravel	Gann Flats 5	2016	Sandy Gravel
Gann Flats 6	2015	Gravelly Mud Gravelly Muddy Sand Muddy Sandy Gravel	Gann Flats 6	2016	Gravelly Muddy Sand
Gann Flats 7	2015	Gravelly Muddy Sand Gravelly Sand Muddy Gravel	Gann Flats 7	2016	Gravelly Muddy Sand
Gann Flats 8	2015	Muddy Sandy Gravel Gravelly Mud Gravelly Muddy Sand	Gann Flats 8	2016	Gravelly Muddy Sand
Angle Bay	2016	Slightly Gravelly Muddy Sand	Pwllcrochan	2016	Slightly Gravelly Muddy Sand

The Gann Flats stations were predominantly classified as Gravelly Sandy Mud or Muddy Sandy Gravel in both the 2015 and 2016 surveys. A more detailed view of the differences in sediment composition between the surveys can be seen in Appendix D, which presents the proportions of sediment per size class within each sample in each survey year.

Sediment composition was also determined for Angle Bay and Pwllcrochan in 2016 and provides a comparison with the wider Milford Haven Waterway. Both Angle Bay and Pwllcrochan were classified as Slightly Gravelly Muddy Sand.

Additionally, the results of Principal Components Analysis of the combined particle size data for both survey years are presented in Figure 8. It should be noted that PSA data for Angle Bay and Pwllcrochan was only available for 2016.

The two-dimensional axes PC1 and PC2 capture 86.3% of the total variance and as such the plot can be considered as a very good representation of the higher dimensional relationship between stations (Clarke and Warwick, 2001). The majority of samples across the Gann Flats were dominated by coarser sand and gravel fractions than sediments at Angle Bay and Pwllcrochan. These results correspond with those recorded from the ongoing SAC condition analysis which noted that the majority of samples across Milford Haven Waterway were dominated by proportions of silt and finer sand fractions with the exception of samples from the Gann Flats (GF1-3), where sediments were much coarser (Green, 2019).

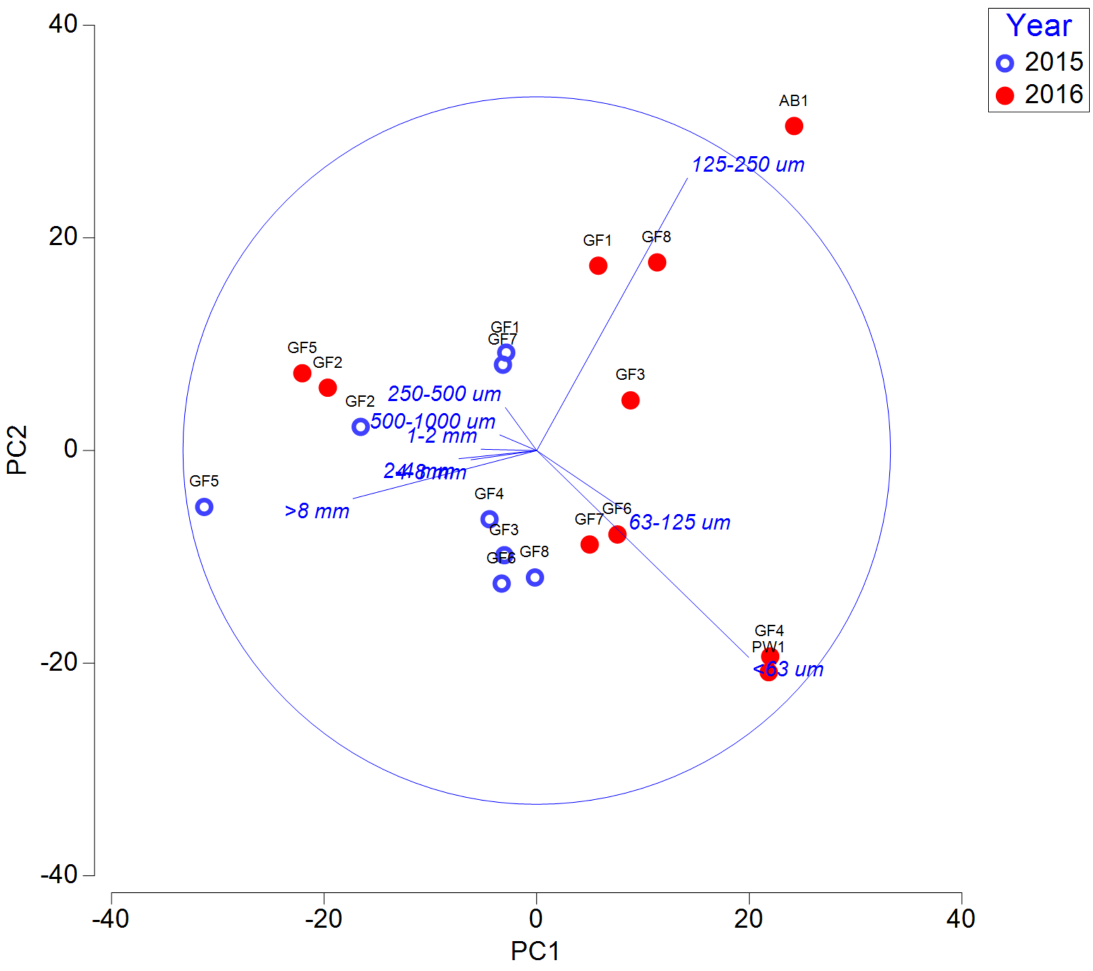


Figure 8: A 2-dimensional PCA ordination of mean untransformed sediment size class contributions from 8 stations at the Gann Flats and 2 stations around Milford Haven Waterway sampled in 2015 (○) and 2016 (●). GF – Gann Flats, AB – Angle Bay, PW – Pwllcrochan

3.2.2 Infauna

A diverse range of fauna were recorded across the Gann Flats with a total of 84 taxa sampled in 2015 and 112 in 2016. Of the 112 taxa recorded in 2016, 57 were also recorded in 2015. *Tubificoides benedii, Pygospio elegans, Melinna palmata* and Nematodes were highly abundant in both surveys.

The abundance, diversity and biomass of taxa recorded in each sample in both 2015 and 2016 are displayed in Figure 9.

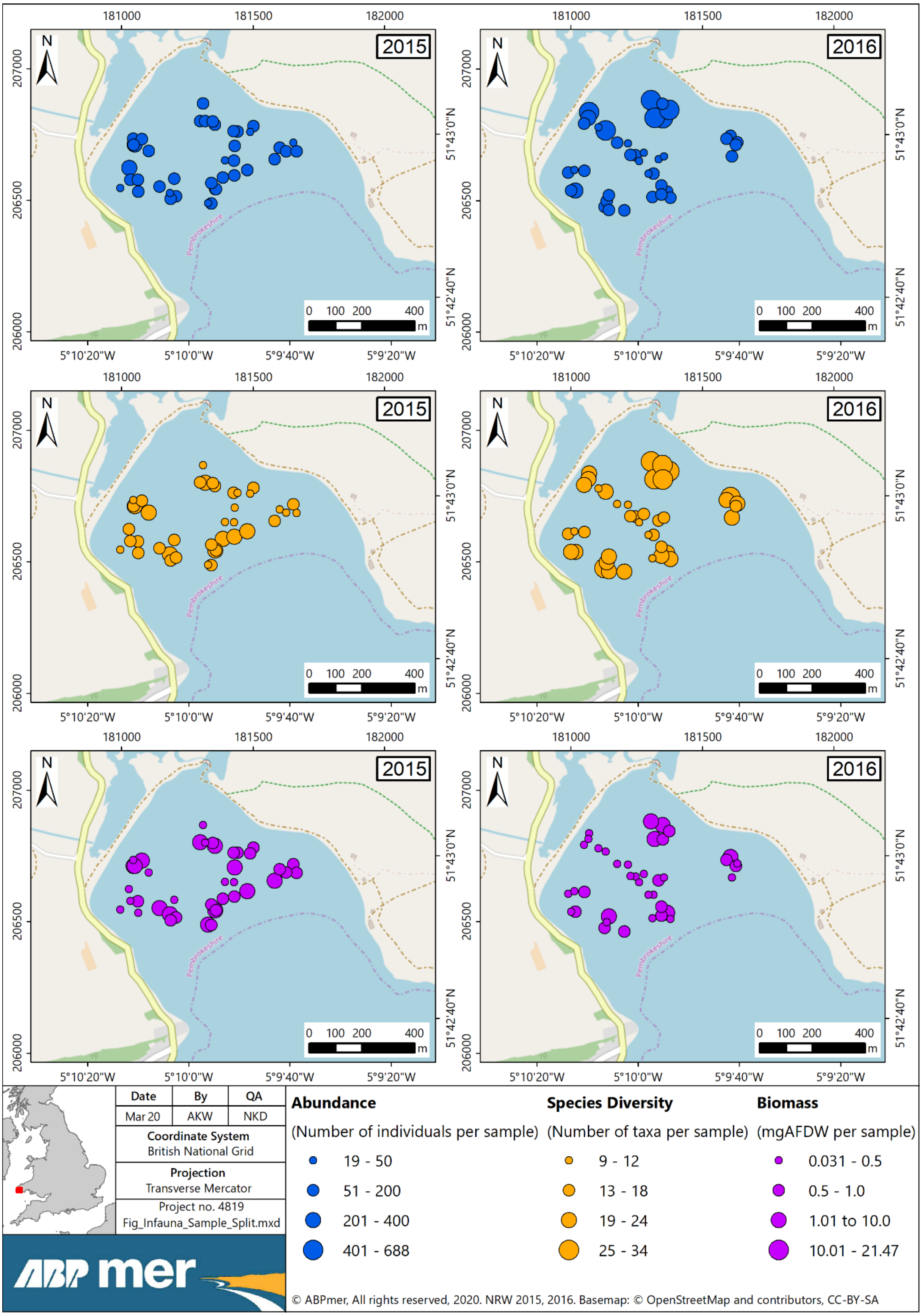


Figure 9: The relative infaunal abundance, species diversity, and biomass sampled at the Gann Flats in 2015 and 2016.

Abundance, diversity and biomass were generally higher in 2016 compared to 2015. The mean number of taxa in each sample on the Gann Flats varied from 7 to 25 in 2015 and 9 to 34 in 2016, with an overall mean of 15 in 2015 and 20 in 2016. In 2015 the mean biomass was 1.38 g, compared to a mean biomass of 0.95 g in 2016.

Abundance generally increased across the Gann Flats between 2015 and 2016, however, abundance decreased at Stations 6 and 7, and marginally at Station 2, with the overall abundance lowest in these three areas. Some of the differences at Stations 6 and 7 may be attributed to relocated sampling areas between 2015 and 2016 (Figure 6). In 2016 the highest average diversity was recorded at Stations 7, 3 and 6 which coincides with the areas of lowest average abundance (Table 2; Figure 10). Diversity was therefore typically highest (and abundance lowest) in the mid shore in the centre of the Gann Flats, all of which were associated with Gravelly Muddy Sand.

In 2015 the highest average biomass was recorded at Stations 3 and 4, on the mid and low shore to the western side of the Gann Flats. In 2016 the average biomass at Station 3 remained the highest but was much greater than in 2015. In comparison, biomass at Station 5 on the upper shore to the eastern side of the Gann Flats was much higher in 2016 than recorded in 2015. Samples within these sites were associated with a range of sediment types, including Gravelly Mud, Gravelly Muddy Sand, Muddy Sandy Gravel, Sandy Gravel (Figure 10, Figure 9). The species contributing most to overall biomass in both 2015 and 2016 were *Cerastoderma edule, Cirriformia tentaculata* and *Melinna palmata*, the distribution of which are shown in Figure 11. When interpreting these results care should be taken as biomass was not directly comparable between years, with biomass not determined for *Actiniaria* in 2015. However, the biomass values were calculated in the same way for all other species between the datasets.

Table 2: Average abundance, biomass and diversity (Simpsons index (1- ʎ) at station groups across the Gann Flats.

Station number	2015 Abund-ance	Biomass	Diversity (1-ʎ)	2016 Abund-ance	Biomass	Diversity (1-ʎ)
Gann Flats 1	182.6	1.085	0.691	331.8	0.279	0.819
Gann Flats 2	132	0.366	0.755	128.6	0.419	0.809
Gann Flats 3	66.6	1.805	0.833	115.2	5.501	0.852
Gann Flats 4	102.4	1.277	0.769	108.6	0.618	0.792
Gann Flats 5	154	0.715	0.763	457.4	2.987	0.808
Gann Flats 6	76.2	0.979	0.731	56.4	0.179	0.838
Gann Flats 7	95.8	0.635	0.821	43.6	0.331	0.876
Gann Flats 8	66	0.752	0.776	105.6	0.696	0.816

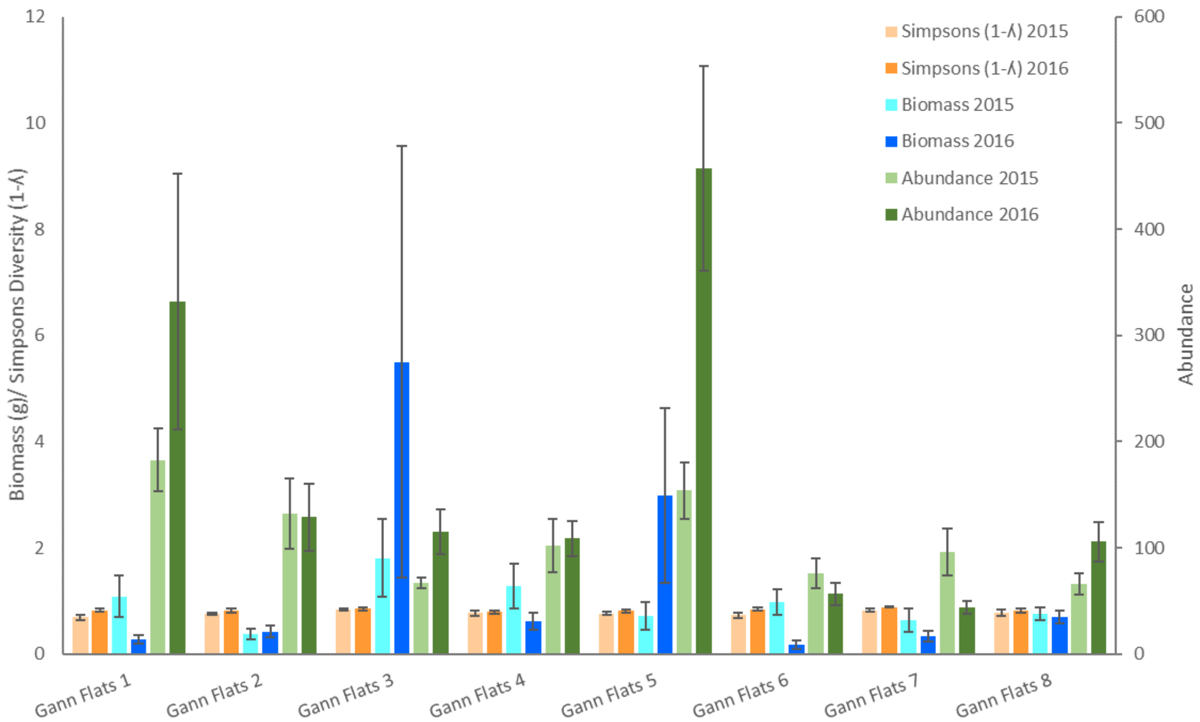


Figure 10:Average biomass (g) and abundance (no. of individuals per sample) and diversity (1- ʎ) sampled at the Gann Flats in 2015 and 2016. Error bars show standard error.

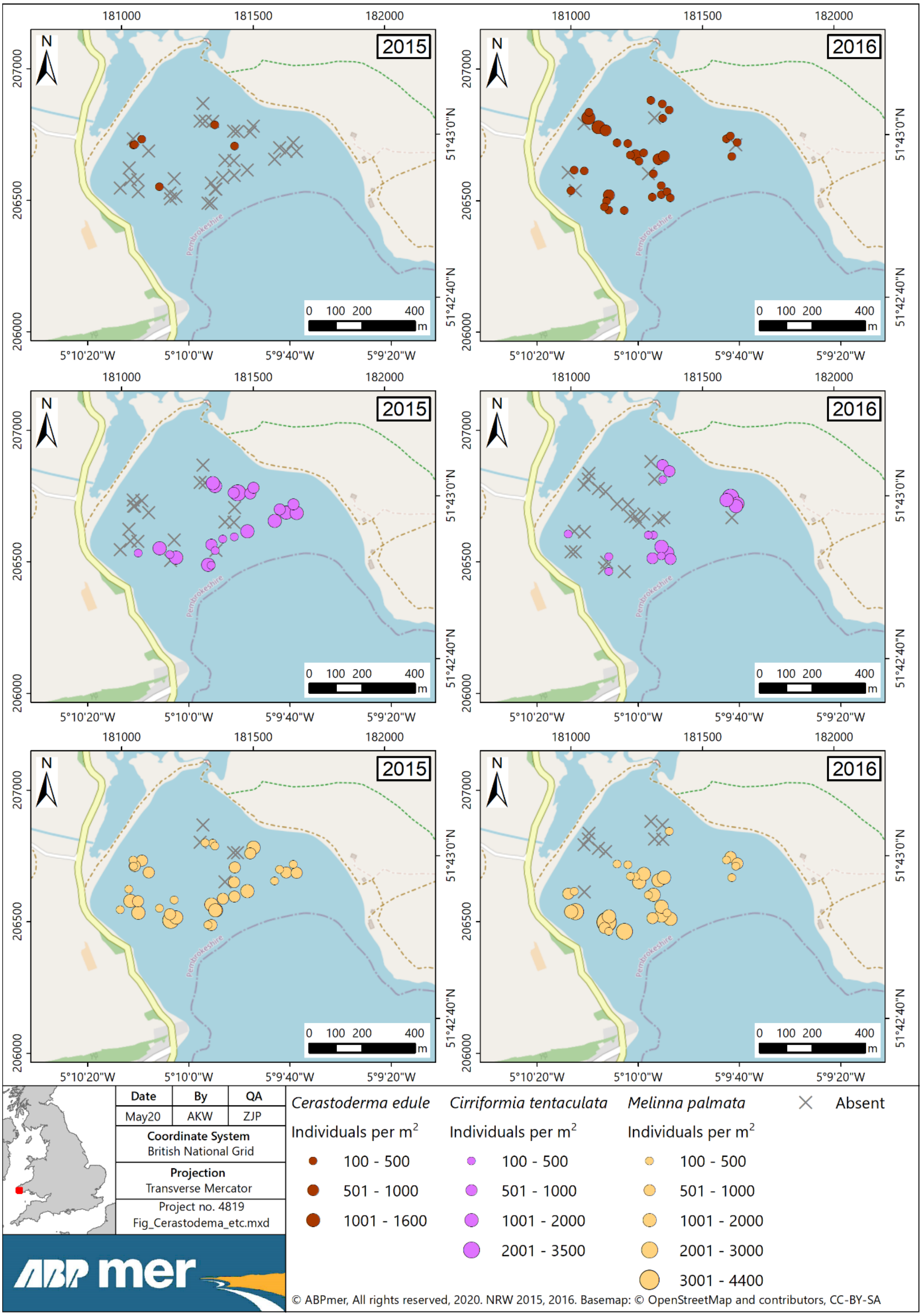


Figure 11:Distribution of Cerastoderma edule, Cirriformia tentaculata and Melinna palmata.

Overall, diversity and biomass were relatively high on the mid and lower shore, outside of the main bait digging area, particularly on the western side of the Gann Flats. This trend was less apparent in species abundance, which was relatively low in the area, however in general abundance was reduced in areas with increased diversity (Figure 9). Abundance, biomass and diversity all increased in 2016 compared to 2015.

Linking faunal data to environmental variables at the Gann Flats

It is well documented that sediment composition is an important factor for determining the distribution of infaunal communities (Cooper *et al.* 2011). In order to determine the strength of this relationship across the Gann Flats, the faunal data were compared with the sediment data using the BEST and RELATE multivariate statistical routines.

The RELATE routine was used to test for correlations between the distribution of biological communities with sediment types. The results of this test demonstrate that there is a significant relationship (Rho = 0.294, $p = 0.001$) between the multivariate patterns observed in the sediment data and in the faunal communities. However, the low Rho value suggests a low level of confidence in the observed pattern.

In order to establish which particle size distributions correlate most strongly with the patterns observed within the faunal communities, the faunal and sediment data were tested using the BIO-ENV BEST routine. The results indicate that the strongest correlation between the multivariate patterns in the sediment and faunal data correspond with the distribution of coarse sand of particle sizes 1-2 mm, and fine and medium sand (0.063-0.125 and 0.125-0.25 mm respectively). A combination of these sediment sizes together account for approximately 36.1% of the observed variation in faunal communities.

Wider spatial context

To provide a comparison to faunal communities in the wider Milford Haven Waterway a comparison between the fauna at the Gann Flats was made with samples collected at nearby sites, Angle Bay and Pwllcrochan.

To assess the richness of species across the Gann Flats in comparison to the wider Milford Haven Waterway, Simpsons diversity indices were calculated, and compared against diversity at Angle Bay and Pwllcrochan. The average diversity at the Gann Flats in 2015 was comparable to that recorded at Angle Bay and Pwllcrochan, $1-\Lambda = 0.767$, $1-\Lambda = 0.801$, and $1-\Lambda = 0.803$ respectively (Simpsons diversity index and K-Dominance plot; Figure 12). However, between 2015 and 2016 there was a slight increase in species richness at the Gann Flats which showed an increase in biodiversity ($1-\Lambda = 0.827$). Diversity in 2016 was higher within the Gann Flats than recorded within the wider area (Angle Bay: $1-\Lambda = 0.745$; Pwllcrochan: $1-\Lambda = 0.726$).

However, it should be noted due to differences in the number of samples between sites there may be a skew in the diversity measure to sites with a higher number of samples. The K-dominance plot (Figure 12) suggests that reductions in K-dominance between 2015 and 2016 were present across both the Gann Flats and the two control stations, Angle Bay and Pwllcrochan. Implying that 2015 to 2016 changes in diversity were wider estuary changes and not necessarily localised or Gann Flat specific effects.

The MDS plot for average invertebrate abundance data at each station is shown in Figure 13. The stress value of 0.2 is reasonable suggesting an adequate two-dimensional representation of relationships between stations, but care should be taken when interpreting this result. The clearest groupings are by year with the points for the same station in each year usually grouping close together, indicating a higher degree of similarity between species communities at each site in each year than between different locations. The plot also shows wider separation between the samples at the Gann Flats compared to both Angle Bay and Pwllcrochan. This plot also shows community change between 2015 and 2016 at all locations, with the direction and scale of shift similar at all sites. The plot therefore supports the K-dominance plot (Figure 12) in suggesting that community changes observed at the Gann Flats between 2015 and 2016 reflect wider changes within the estuary and are not specific to the Gann Flats.

From the MDS it is also interesting to note that there appears to be greater dispersion (more variability in the communities) in 2016 at the Gann Flats, Angle Bay and Pwllcrochan in comparison to 2015. At the Gann Flats this variability is largely due to dispersion between stations at different shore heights with rough groupings of samples on the upper, mid and low shore.

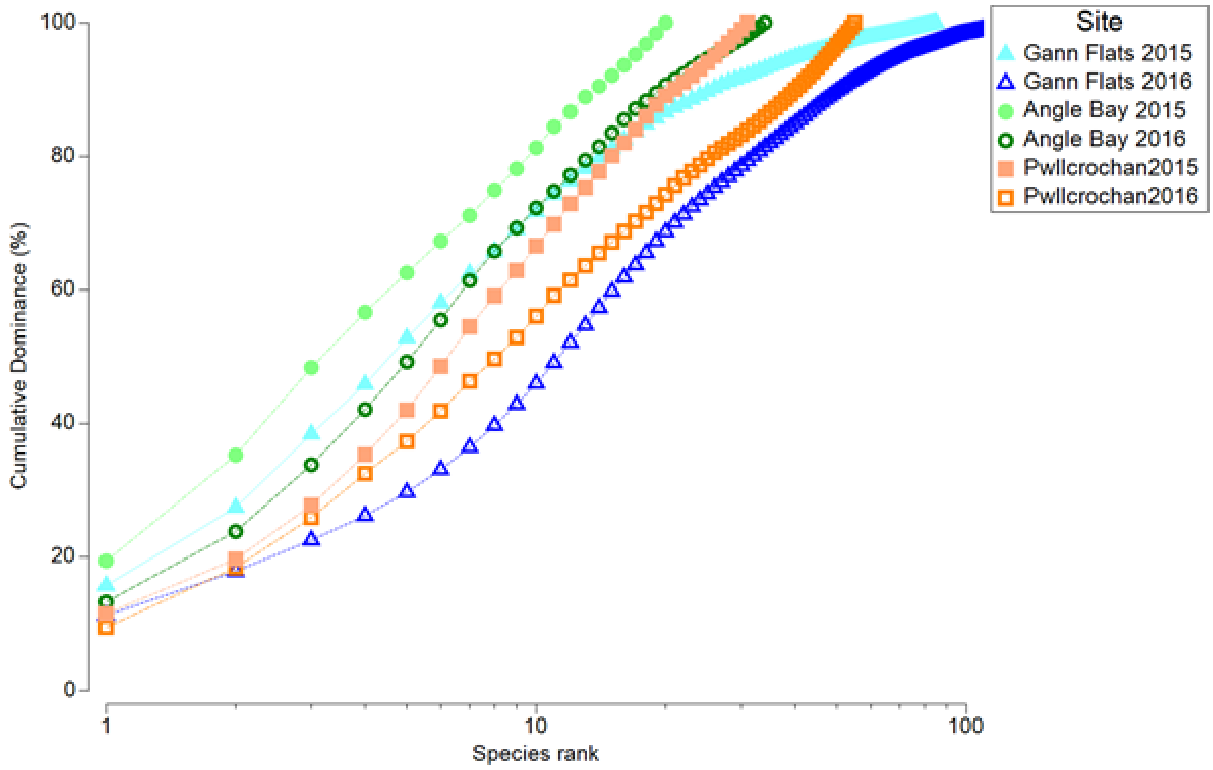


Figure 12: K-Dominance curve for average taxa abundance for stations at the Gann Flats and Angle Bay and Pwllcrochan in the wider Milford Haven Waterway in 2015 and 2016.

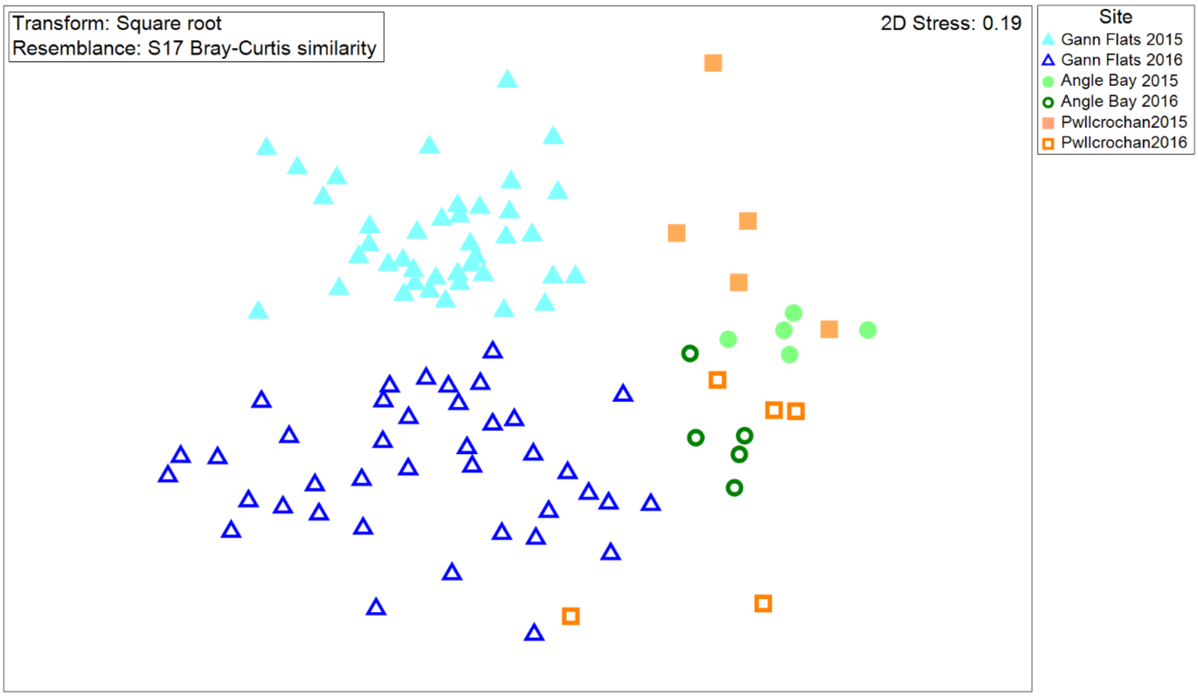


Figure 13: MDS plot of Bray-Curtis Similarity between square-root transformed mean infaunal abundance data (per 0.01 m²)

Multivariate analysis of the infaunal data collected during the 2015 and 2016 surveys was also undertaken to further investigate the current ecological status of the Gann Flats. To visualise the biological similarity between samples collected from the Gann Flats between 2015 and 2016 and to assess the similarity of biological communities at the Gann Flats, Angle Bay and Pwllcrochan a SIMPROF cluster analysis was conducted. A total of six distinct faunal groups were identified within the infaunal abundance dataset, as presented in Figure 14.

The figure shows a group average sorting dendrogram based on square-root transformed averaged abundance data (Bray-Curtis similarity), and the corresponding MDS plot, presented in 2D format. The MDS plot has a low 2D stress (0.1), indicating a representative visualisation of the data points in multidimensional space and as such provides a useful interpretation of the inter-relationships that occur between the communities sampled at the different stations.

The most distinctive groupings were based on sampling year as opposed to specific locations, showing that there is greater similarity within year than between years at all locations; Gann Flats, Pwllcrochan and Angle Bay (Figure 14). However, it does indicate that the biological communities at Pwllcrochan and Angle Bay are different from those at the Gann Flats.

The figure also suggests that there has been a community shift between 2015 and 2016 at all locations. In general, the shift is similar in both direction and scale, however, the trajectory of change varies with sampling area. The stations at Gann Flats 1, 2, 3, 5, Pwllcrochan and Angle Bay all have similar trajectories, however, these differ to those of the communities at the Gann Flats stations 4, 6, 7 and 8.

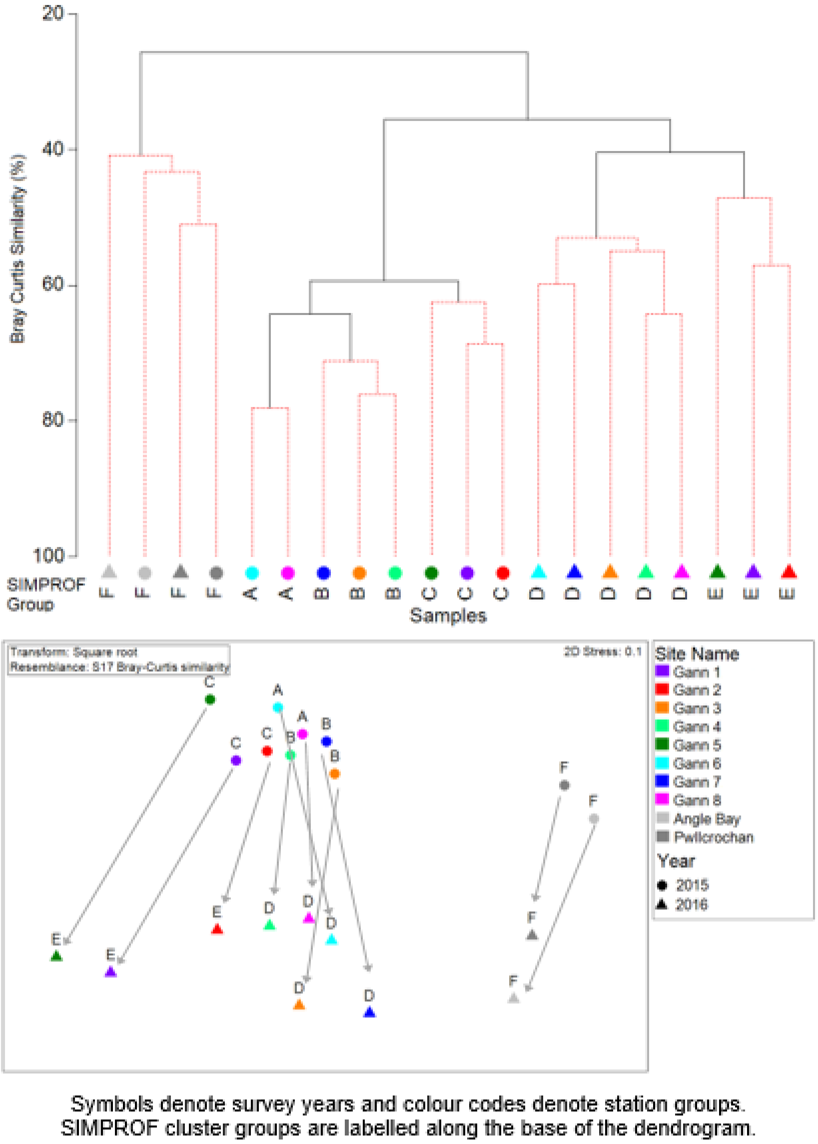


Figure 14: SIMPROF Cluster dendrogram (top) of Bray-Curtis similarity between square-root transformed average station infaunal abundance data for each year and corresponding 2D multidimensional scaling ordination (bottom).

SIMPER analysis was run on the six multivariate groups identified during the SIMPROF analysis to identify the key taxa driving the similarity within the groups, and to further consider why the Gann Flats stations 4, 6, 7 and 8 have a different trajectory to the other sites.

The key findings from the SIMPER analysis (on square-root transformed data) were:

Group A (average group similarity: 78.08%) Group A samples were collected during the 2015 survey from Stations 6 and 8 on the low to mid shore on the eastern side of the Gann Flats. The key characterising species were *T. benedii, Cirriformia tentaculata, Ampharete lindstroemi,* Nereididae sp. and *M. palmata.* Sediment was varied across samples but was comprised of Gravelly Mud, Gravelly Muddy Sand and Muddy Sandy Gravel.

Group B (average group similarity: 72.68%) comprised three sampling stations (Stations 3, 4, and 7) on the mid to low shore to the east of the Gann Flats all collected during the 2015 sampling. The key characterising species were *A. lindstroemi; T. benedii; P. elegans; M. palmata* and Nereididae sp.. A wide range of sediment types were recoded from across these sites including, Gravelly Mud, Gravelly Muddy Sand and Gravelly Sand, as well as Muddy Sandy Gravel and Muddy Gravel.

Group C (average group similarity: 64.40%) comprised three stations (Stations 1, 2, and 5) all on the upper shore of the Gann Flat in 2015. Key characterising species included *T. benedii, P. elegans, A.lindstroemi,* Nereididae sp.*, Mediomastus fragilis* and *Tharyx* sp.. The composition of the sediment's samples from stations within this group were varied consisting of mixed sand and gravel sediments including, Gravelly Muddy Sand, Gravelly Sand, Muddy Sandy Gravel, Sandy Gravel and Muddy Gravel.

Group D (average group similarity: 54.82%) was the largest grouping with five sampling stations (Stations 3,4,6,7, and 8) all from the 2016 monitoring. All areas were within the mid to low shore at the Gann Flats. Key characterising species were *M. palmata, T. benedii, Chaetozone gibber, C. edule* and *Phyllodoce mucosa.* Sediments at stations within this group were comprised of slightly higher amounts of larger sediment classes being predominantly classified as Gravelly Muddy Sand, with some Gravelly Mud.

Group E (average group similarity: 52.23%) Group E comprised of samples from Stations 1,2, and 5 collected from upper shore sites during the 2016 survey. Key characterising species were *T. benedii,* Nematoda sp.*, Capitella* sp., *P. elegans* and *Gammarus* sp.. The predominant sediments recorded at stations within this group were Gravelly Muddy Sand, Muddy Sandy Gravel and Sandy Gravel.

Group F (average group similarity: 43.35%) Group F comprised of samples from Angle Bay and Pwllcrochan in both 2015 and 2016. Key characterising species were *Melinna palmata, Nephtys sp., Chaetozone gibber, and Euclymene oerstedii*.

Sediment data were not available for 2015 but were composed of Slightly Gravelly Muddy Sand at both Pwllcrochan and Angle Bay during the 2016 sampling.

The Gann Flats stations 1, 2, 3 and 5 are generally located on the upper shore. Figure 14 shows that at these sites there was a shift in biological communities between 2015 and 2016 from Group C in 2015 to Group E in 2016. This shift in faunal group was caused by an increase in more opportunistic taxa such as *T. benedii,* Nematoda sp.*, Capitella* sp., and *P. elegans*, compared to *A.lindstroemi,* Nereididae sp.*,* and *M. fragilis* in 2015. Sediments appeared relatively similar at these stations between 2015 and 2016 with the composition of the sediment's consisting of mixed sand, mud and gravel sediments.

In comparison Gann Flat stations 4, 6, 7, and 8 are located on the low to mid shore. The difference in trajectory in the MDS plot suggests that communities on the mid-low shore at the Gann Flats have altered differently to those on the upper shore. The MDS shows a shift from Groups A and B in 2015 to Group D in 2016. This shift was predominantly caused by an increase in the abundance of more sensitive species such as *C. gibber, C. edule and P. mucosa* and a reduction in more opportunistic taxa such as *T. benedii,* from 2015 to 2016. It should also be noted that in 2016 sediments within these sites were comprised of slightly higher amounts of larger sediment classes compared to 2015 being predominantly classified as Gravelly Muddy Sand.

Figure 15 shows the distribution of faunal groups across the Gann Flats following the SIMPROF analysis. Figure 16 shows the K-Dominance curve for average taxa abundance for faunal groups defined following SIMPROF analysis. The plot shows that faunal groups A-C are generally characterised by fewer, highly abundant species.

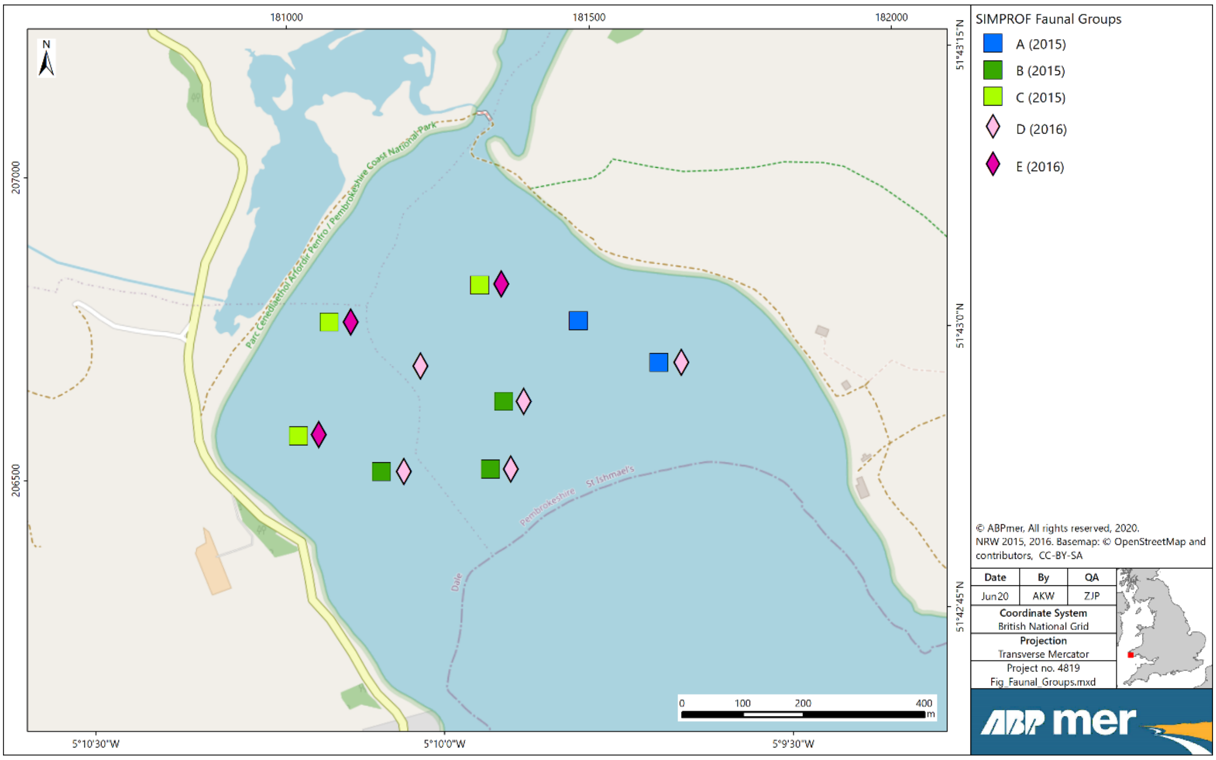


Figure 15: Distribution of faunal groups across the Gann Flats, defined following SIMPROF analysis

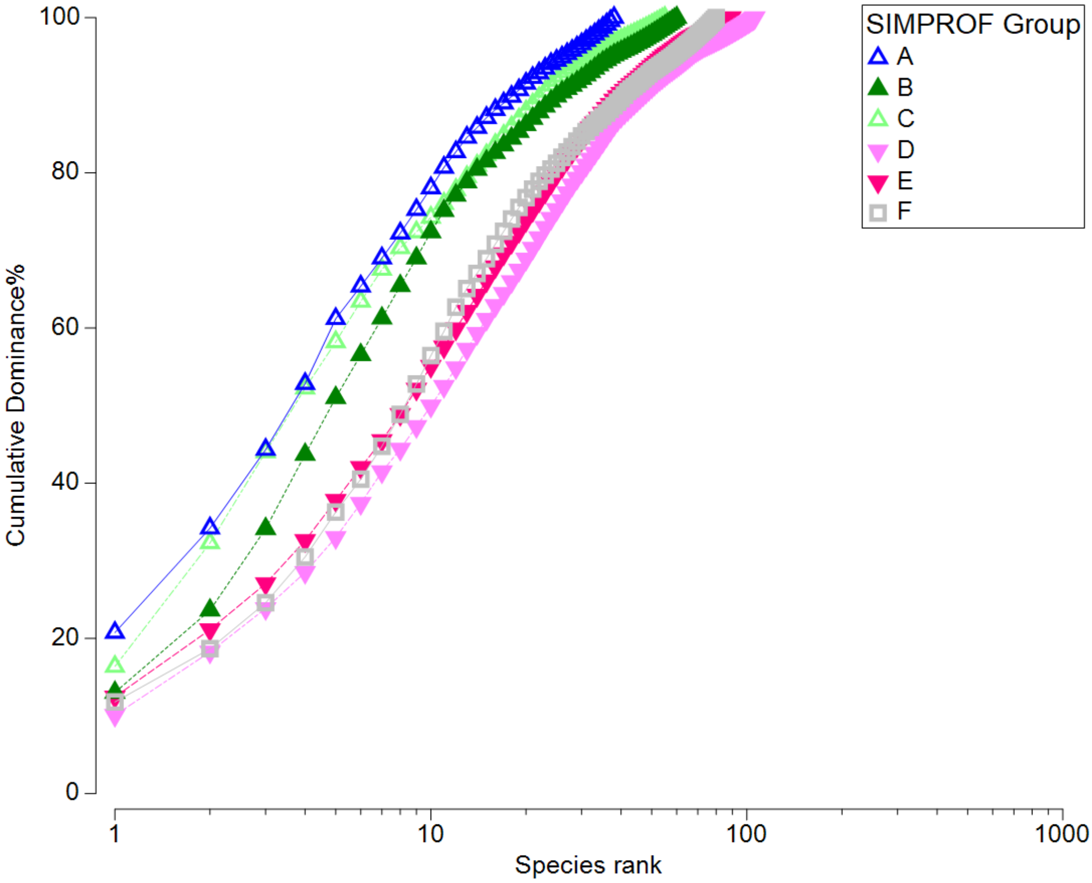


Figure 16: K-Dominance curve for average taxa abundance for faunal groups defined following SIMPROF analysis

To compare the biological communities between the Gann Flats, Pwllcrochan and Angle Bay in both 2015 and 2016 a SIMPER analysis was undertaken (Appendix Table C3). SIMPER analysis identified that the key species leading to dissimilarity were higher abundances of *T. benedii,* Nematoda species*, Capitella* sp.*,* and *P. elegans* at samples across the Gann Flats compared to Angle Bay and Pwllcrochan. These species are generally opportunistic taxa and suggest increased levels of disturbance.

Higher abundance of *A. lindstroemi, C. tentaculata* and Nereididae at the Gann Flats also contributed highly to dissimilarity between Angle Bay and the Gann Flats, in addition to lower abundances of *Nephtys sp*., *P. ulvae* and the cirratulid *Aphelochaeta marioni* at the Gann Flats compared to Angle Bay. Species which contributed most to the dissimilarity between the Gann Flats and Pwllcrochan were higher abundances of *C. tentaculata* and *A. lindstroemi* at the Gann Flats and lower abundances of *Austrominius modestus* and *M. palmata* at the Gann Flats compared to Pwllcrochan. Table 3 shows the abundance of the key species highlighted as contributing to the dissimilarity between sites following SIMPER analysis. Data shows the average abundance of species at each site, prior to square-root transformation.

Table 3: Average abundance of fauna contributing the average dissimilarity between Gann Flat, Angle Bay and Pwllcrochan. Mean Abundance

Species	Gann Flat	Angle Bay	Pwllcrochan
Tubificoides benedii	25.50	0	0.01
Pygospio elegans	7.08	1.59	0.01
Austrominius modestus	0	0.18	4.33
Ampharete lindstroemi agg.	3.06	0	0.69
Cirriformia tentaculata	2.04	0	0.04
Nereididae species (inc. juv.)	1.17	0.01	0
Nephtys species (inc. juv.)	0.07	1.80	1.54
Tharyx Species A	1.99	0	0
Peringia ulvae	0.03	3.17	0.61
Melinna palmata	5.02	6.86	6.25
Kirkegaardia dorsobranchialis	0	0	2.50
Foraminifera	0	2.82	0.01
Nematoda species	2.99	0	0.10
Lanice conchilega	0	0.09	1.10
Chaetozone gibber	1.25	2.07	2.34
Mediomastus fragilis	1.25	0	0.12
Euclymene oerstedii	0	0.85	0.85
Notomastus species	0.67	1.25	0.52
Phyllodoce mucosa	1.08	0.12	0.01
Leucothoe incisa	0.01	0.67	0
Glycera tridactyla	0.55	0	0.01
Tubificoides pseudogaster agg.	0.69	0	0.10
Scoloplos armiger	0.42	0.32	0.22
Cerastoderma edule (inc. juv.)	0.76	1.28	0.32
Capitella species	0.85	0	0
Eteone longa agg.	0.25	0	0.09
Polydora cornuta	0.55	0	0
Gammarus species (inc. juv.)	0.61	0	0
Lumbrineris aniara/cingulata	0.01	0	0.31

To further assess the differences in biological communities between the sites and between years a SIMPER over time was conducted. This assessed the communities at the Gann Flats in 2015 and Gann Flats in 2016, against the control sites of Angle Bay and Pwllcrochan in 2015 and 2016. The full results are presented in Appendix Table C4.

At the Gann Flats between 2015 and 2016 the key changes in biological communities were attributed to increases in the abundance of *T. benedii* and Nematoda, and decreases in the abundances of *A. lindstroemi, P. elegans* and *Nereidiae.* In comparison at Angle Bay and Pwllcrochan the key changes in biological communities between 2015 and 2016 were attributed to increases in *P. ulvae, A. modestus, Foraminifera, C. edule*, and *C. gibber.*

To compare the communities at Gann Flats to the wider Milford Haven waterway the differences in communities at Gann Flats and Angle Bay and Pwllchrochan in 2015 and 2016 were also assessed. The main differences between the sites in 2015 were due to higher abundances of *T. benedii, P. elegans, A. lindstroemi, Nereidiae, and*

Cirriformia tentaculata at Gann Flats. Similarly, in 2016 there were higher abundances of T*. benedii,* and *Nematoda* at Gann Flats than at Angle Bay and Pwllcrochan, however in there were lower abundances of *P. ulvae, A. modestus* and *Forminifera* which were attributing to the difference between sites.

ANOSIM was used to assess if there was an overall difference in communities at the Gann Flats, Angle Bay and Pwllcrochan. The results of the 1-way ANOSIM test between sites and years showed a significant difference between samples across the Gann Flats between 2015 and 2016, between the Gann Flats and Angle Bay in 2015 and 2016 and the Gann Flats and Pwllcrochan in 2015 and 2016 (significance <5%; Appendix C.1). However, there was no significant difference between Angle Bay and Pwllcrochan in either 2015 or 2016. As would be expected from the patterns shown in the MDS plot in Figure 13 the global R statistic of 0.69 shows there are large overall differences between sites when compared to the Gann Flats, the global test significance of 0.1% confirms the significant difference between years and sites.

Disturbance indicators

To assess the level of potential natural or anthropogenic disturbance occurring at the Gann Flats, and to provide a comparison to the nearby sites, Angle Bay and Pwllcrochan, an AMBI assessment was undertaken. AMBI explores the response of soft-bottom communities to natural and man-induced changes in water quality. Although not aimed to specifically assess physical impacts the AMBI assessment can provide an indication of the perceived sensitivity of macrobenthic communities to anthropogenic disturbance by identifying the influence of more opportunistic taxa. Taxa at the Gann Flats were assigned to one of five AMBI groups. Group I describes the most sensitive taxa and V represent the most opportunistic taxa.

Figure 17 shows the distribution of taxa abundance within AMBI sensitivity groups for all of the Gann Flats infaunal samples and provides a comparison for AMBI sensitivity at Angle Bay and Pwllcrochan.

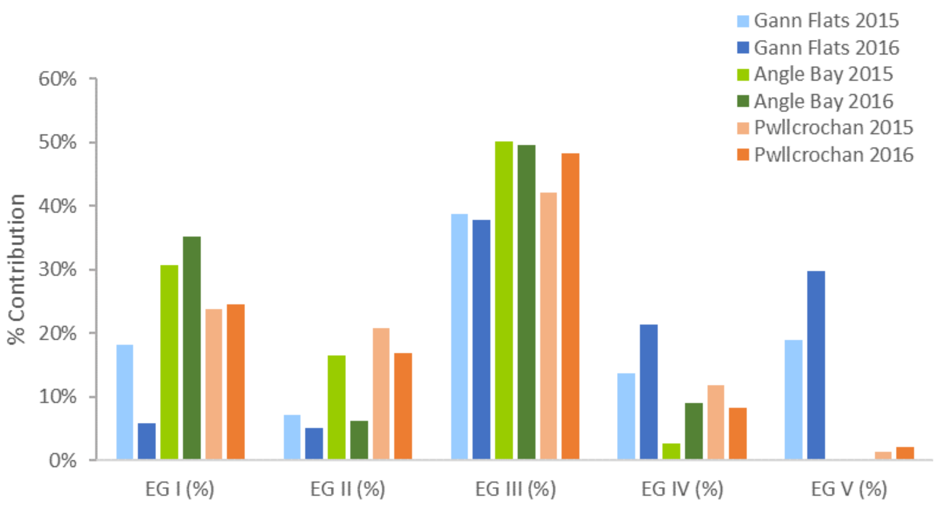
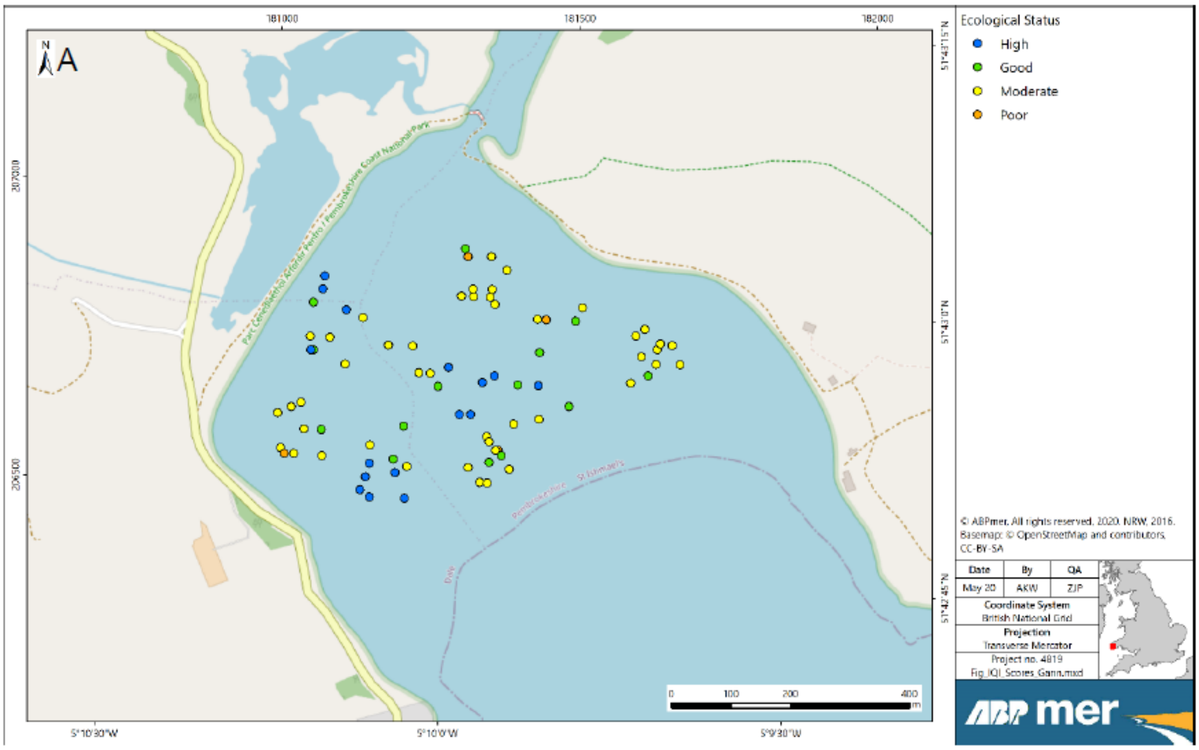


Figure 17: The average percentage contribution of the number of individuals classified into AMBI groups I – V at sampling stations around the Gann Flats, Angle Bay and Pwllcrochan in 2015 and 2016.

Samples at the Gann Flats were generally classified as moderate to good ecological status, with lower Infaunal Quality Index (IQI) scores ranging from 0.35 to 1.06 with an average of 0.63 (moderate status). In comparison, samples at Angle Bay and Pwllcrochan, were generally assessed as having high ecological status within the AMBI assessment with IQI scores ranging from 0.5 to 1.14 with an average IQI of 0.84 (high status). Figure 18 shows the determined ecological status of samples across the Gann Flats, Angle Bay and Pwllcrochan. Within the samples collected from the Gann Flats a notably higher proportion of opportunistic species and lower proportion of sensitive species were recorded in both years compared with other locations. This was even more apparent in 2016 compared to 2015.

Sites with a lower IQI score and therefore assessed as having higher levels of disturbance were generally associated with high abundances of the oligochaete *T. benedii*, a species often associated with nutrient enriched muddy, estuarine sediments. This correlated to the results of the SIMPER analysis above which found that higher abundances of *T. benedii* and *P. elegans* were associated with samples at the Gann Flats compared to the other locations (see multiple tables in Appendix C.2). In comparison *M. palmata* had the highest abundances at Angle Bay and Pwllcrochan.



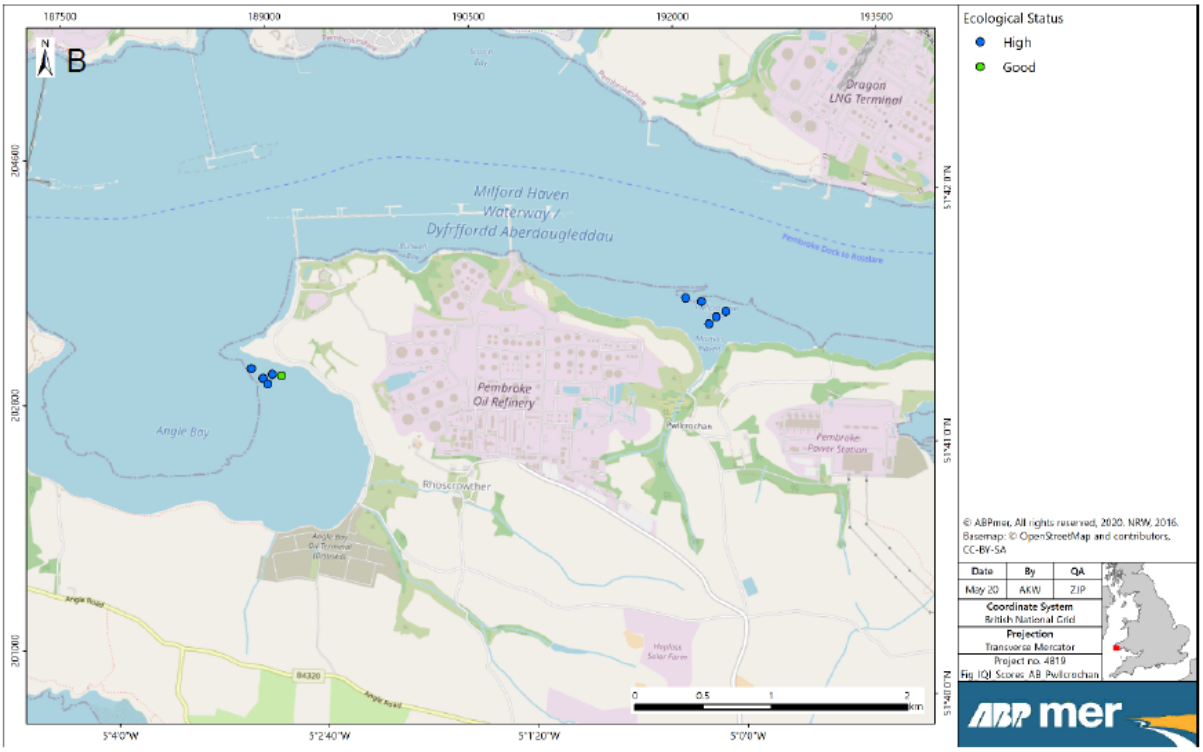


Figure 18: Ecological status of samples collected at the (a) Gann Flats, (b) Angle Bay and Pwllcrochan

3.2.3 Epifauna

Epifaunal surveys were undertaken in 2015 and 2017 to determine the benthic fauna living on the substrate of the Gann Flats, or those species which create casts or moulds on the sediment surface. Physical data including sediment composition, and the presence of running water were also noted to help describe the overall characteristics of the site. Comparable data were not collected for Angle Bay and Pwllcrochan and as such it was not possible to make wider comparisons.

The abundance and diversity of taxa recorded at each station in both 2015 and 2017 are displayed in Figure 19 (epifaunal biomass was not determined). In contrast to the infaunal data, abundance of epifauna decreased in 2017 compared to 2015 with an average abundance of 110 individuals per quadrat in 2017 compared to 153 in 2015.

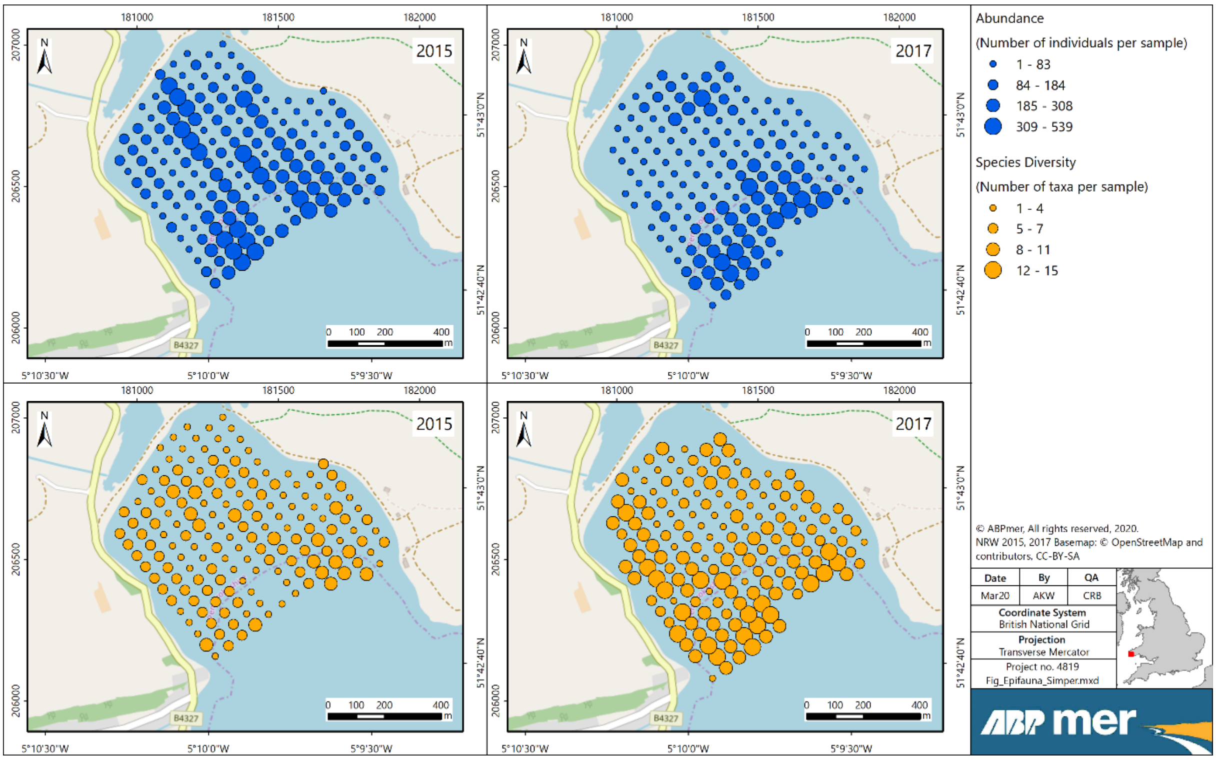


Figure 19: The relative epifaunal abundance and species diversity sampled at the Gann Flats in 2015 and 2017.

Simpsons diversity indices were calculated to inform the richness of epifaunal species across the Gann Flats. Diversity at the Gann Flats in 2015 was lower than in 2017 1-ʎ = 0.380, 1-ʎ = 0.584 respectively (Figure 20). This suggests that in 2017 the epifaunal communities across the Gann Flats had become more species rich with a higher diversity of species forming the epifaunal community. This is supported by the k-dominance curve (Figure 21).

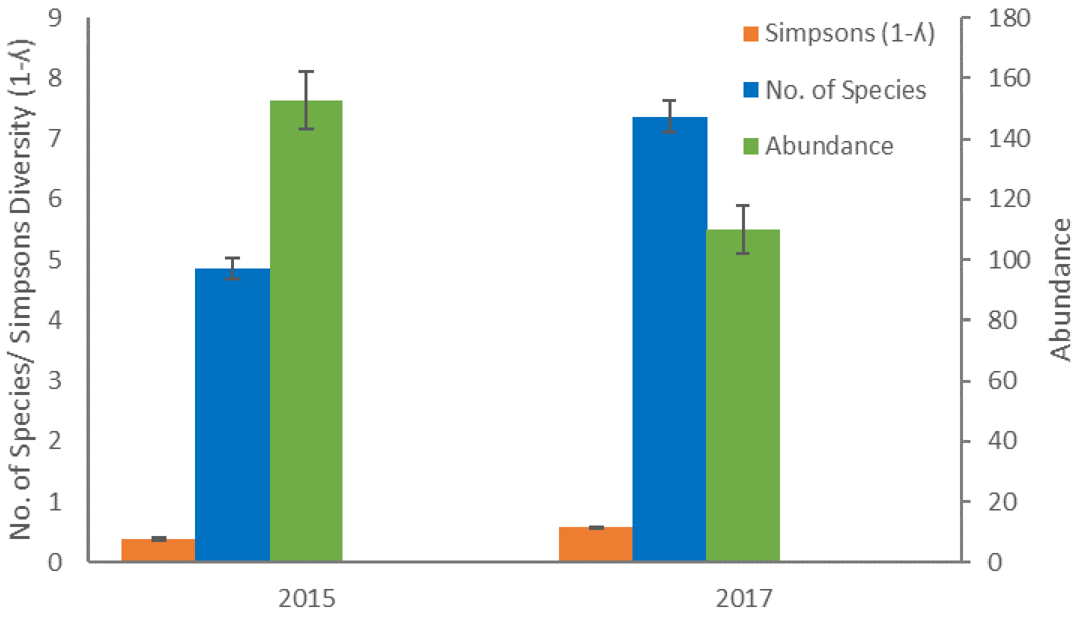


Figure 20. The abundance and species diversity of epifauna sampled at the Gann Flats in 2015 and 2017. Error bars show standard error

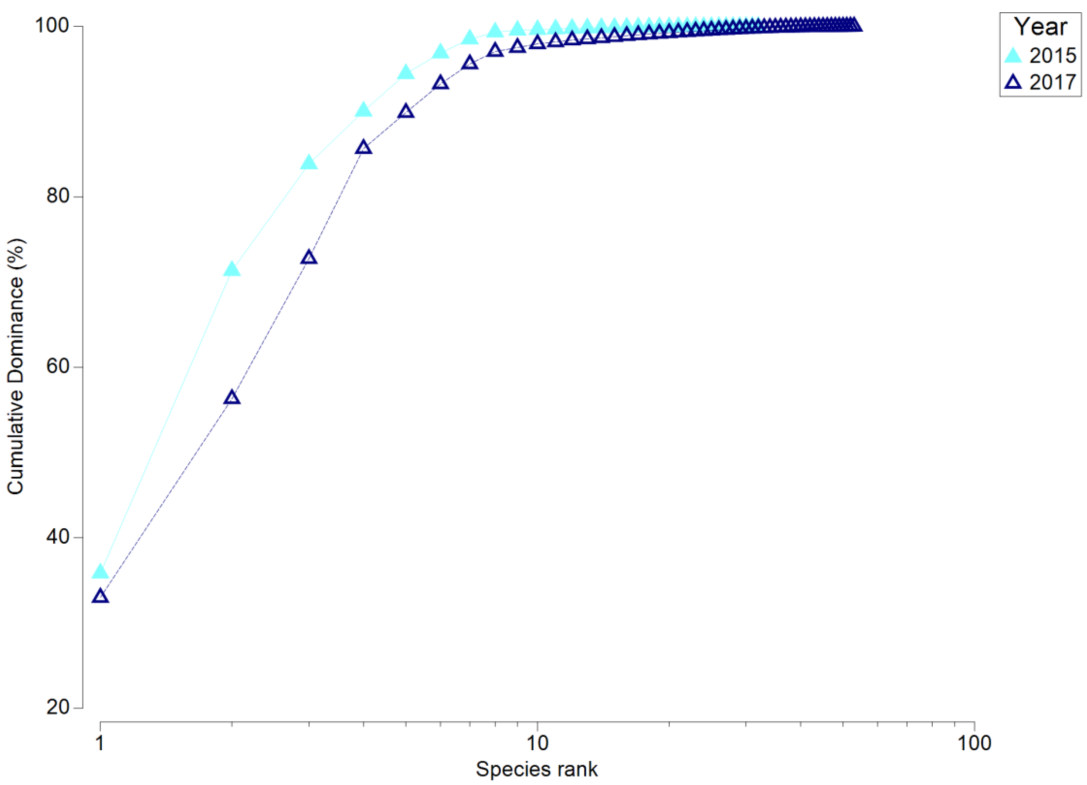


Figure 21. K-Dominance curve for average taxa abundance for epifauna at Gann Flats in 2015 and 2017.

To indicate the areas across the Gann Flats where abundance and diversity have increased or decrease between 2015 and 2017 a comparison has been undertaken, noting the areas where the number of individuals and Simpsons diversity (1-ʎ) have increased or decreased in 2017 compared to 2015 (Figure 22).

The figure shows that there has predominantly been an increase in epifaunal diversity across the Gann Flats between 2015 and 2017, in particular to the central-northern and eastern areas of the site. Similarly, abundance in the northern part of the Gann Flats has increased between 2015 and 2017, and in some of the low shore areas to the east. However, in comparison there appears to have been a reduction in abundance in the mid and low shore across much of the site, in particular to the central area of the Gann Flats.

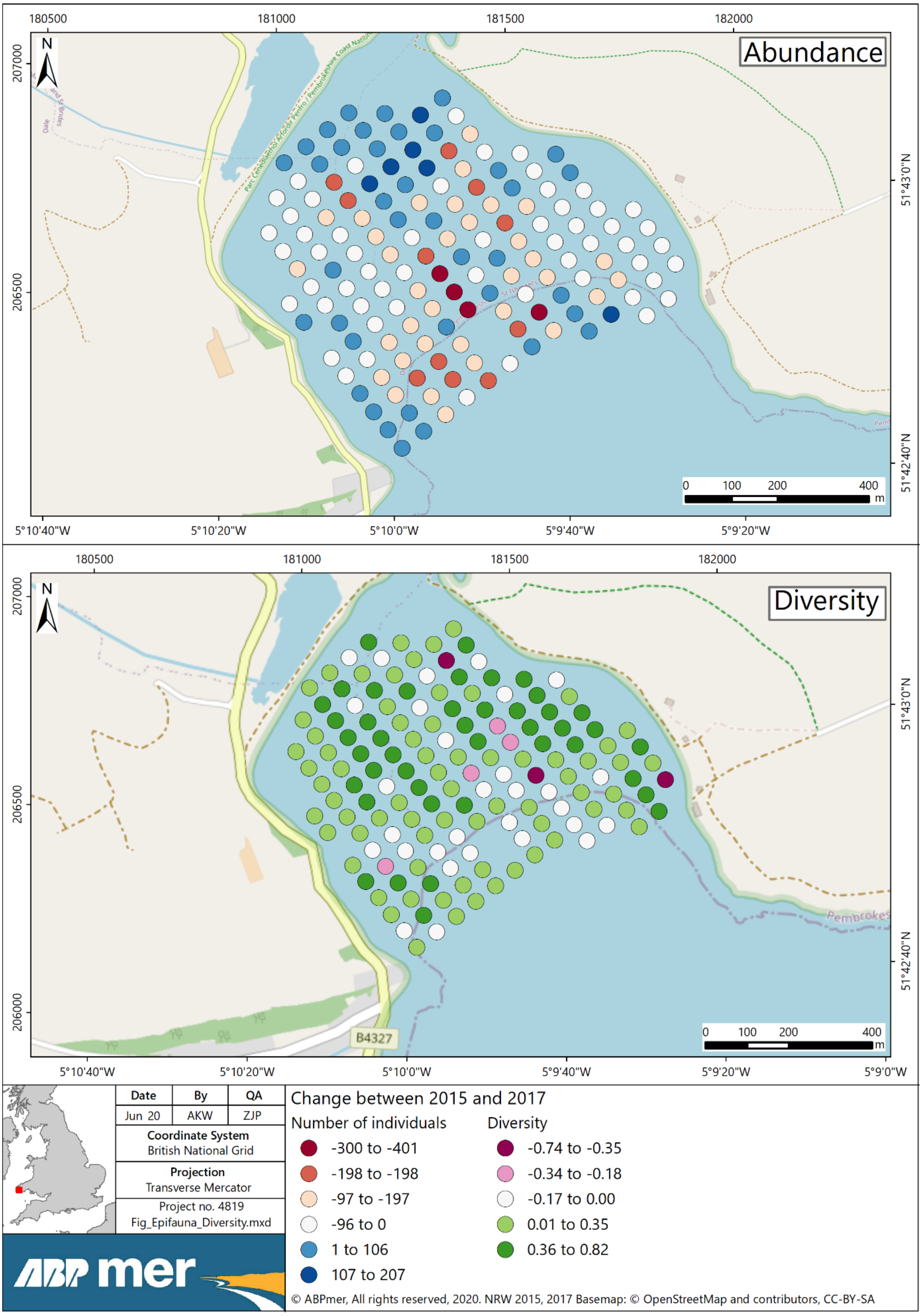


Figure 22. Change in abundance (number of individuals) and diversity (Simpsons Diversity index 1-ʎ) of epifaunal communities between 2015 and 2017.

The sediment composition across the Gann Flats is described in Section 3.2.1. Due to the Gravelly Sandy Mud nature of the substratum at the Gann Flats, there is relatively little development of dense algal cover as there are limited areas suitable for attachment. A range of algal species were recorded across the site but in relatively low abundances. Species recorded included *Ulva* sp., *Fucus* sp., Kelp, *Chorda* sp. and Rhodophyta.

Other species of note (Figure 20), which were recorded during the epifaunal monitoring were *Lanice* sp. and *Sabella* sp. Both species are burrowing worms which create tubes that project above the sediment surface and as such both species are susceptible to high levels of disturbance. *Lanice* sp. was recorded across the whole of the Gann Flats in abundances of up to 2072 per m². Similarly, *Sabella* sp. was also recorded widely across the mid and lower shore at the Gann Flats although in slightly lower abundances, up to 744 per m².

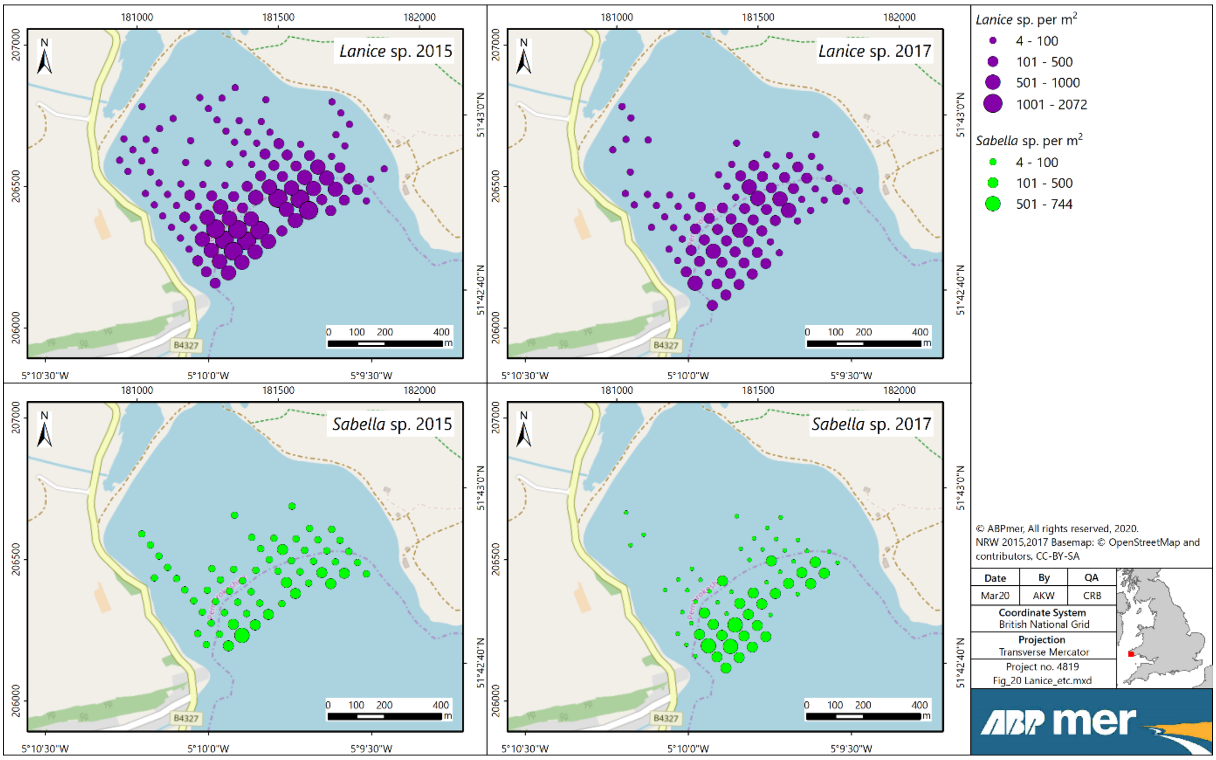


Figure 23: Distribution of Lancie sp. and Sabella sp. across the Gann Flats

It should be noted that there is a freshwater influence across the Gann Flats due to an area of running water from the Gann. Accurate mapping of the position of the freshwater stream is not available but records of the percentage coverage of running water were noted during the epifaunal survey (Figure 24). The potential influence of the freshwater on species distribution should be noted, especially at the upper shore stations. Figure 24 also shows the distribution of a suite of species normally associated with estuarine conditions, which show a higher abundance in the upper stations to the east of the site where the freshwater stream first enters the Gann Flats. These species include *T. benedii*, *Streblospia shrubsoli, Hediste diversicolor*, *M. palmata* and *Ulva* sp..

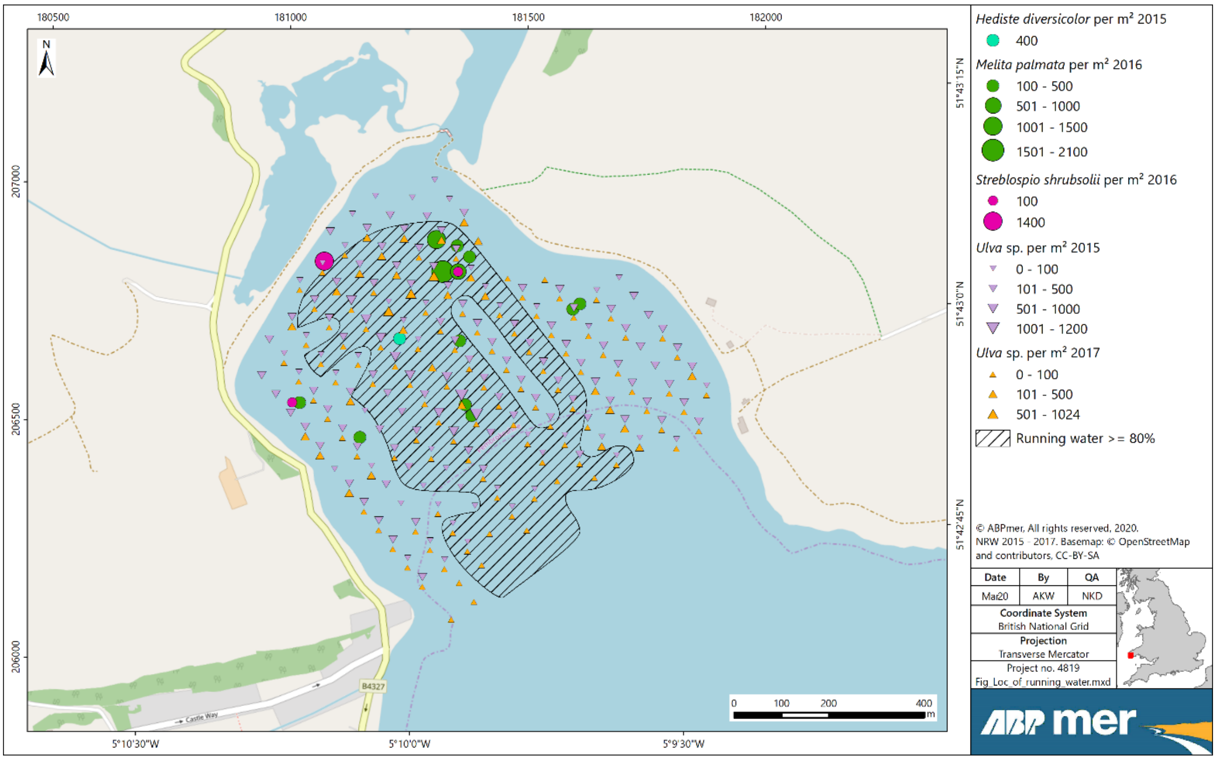


Figure 24: Location of running water across the Gann Flats and key species often associated with estuarine conditions.

Multivariate analysis of the epifaunal data collected during the 2015 and 2017 surveys was also undertaken to further investigate the current ecological status of the Gann Flats. To visualise the biological similarity between samples a SIMPROF cluster analysis was conducted. A total of eight distinct faunal groups were identified within the epifaunal abundance dataset. The distribution of the faunal groups are shown in Figure 25. Based on the distribution of groups it suggests that height up the shore is having the largest impact on determining the groupings.

The key species which were leading to dissimilarity between the groups were *Ulva sp., Rhodophyta, Lanice sp., Fucus sp.* and *Sabella sp.*. In particular in 2015 Group K and Group F were assigned to a large number of samples across Gann Flats. High abundances of *Ulva sp.* (tubular) caused the dissimilarity between Group K and other grouping across the Gann Flat. Group F also had relatively high abundances of *Ulva sp.*, and high abundances of *Lanice sp.* Group M was observed in both 2015 and 2017, recorded in the upper shore. *Fucus sp*. and *Ulva sp*. (tubular) were the key species defining this group, however both were seen in moderate abundances. Very low abundance of *Lanice sp*. and *Sabella sp*. were recorded which would be expected in the upper shore. Group D and Group G were predominantly recorded in the 2017 survey. Group G was recorded across all of the Gann Flats from the high to low shore, defined by relatively high levels of *Rhodophyta sp*., in comparison to other groupings. Group D was predominantly located on the low shore at the Gann Flats, especially in 2017. It was defined by high levels of *Lanice sp., Sabella sp.,* and *Rhodophyta sp*., species which would be expected on the low shore.

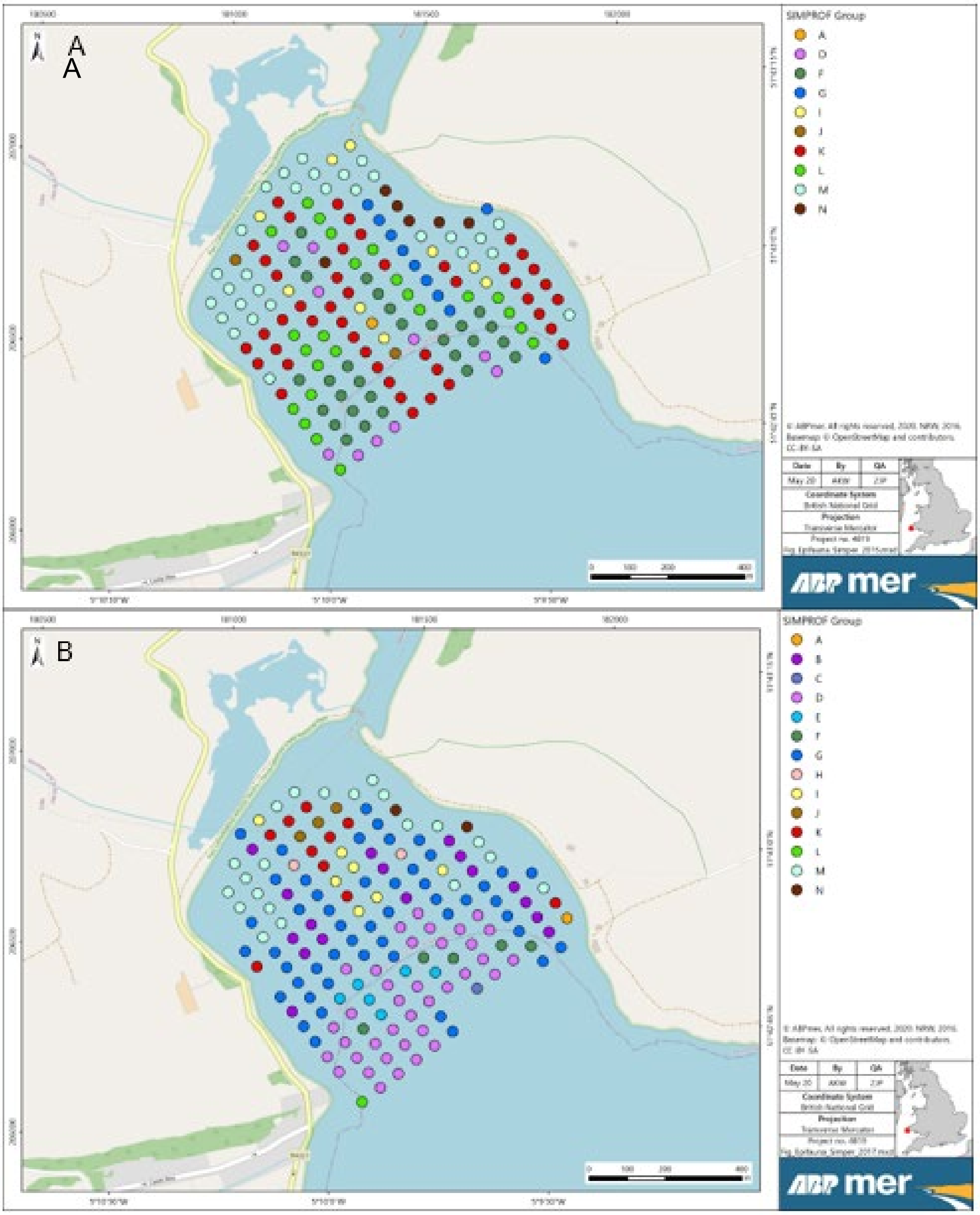


Figure 25: Distribution of faunal groups across the Gann Flats determined following SIMPROF analysis, (a) 2015, (b) 2017

There was also a split in groupings based on sampling year. This is further corroborated in the MDS plot shown in Figure 26. This indicates a higher degree of similarity between species communities within each year than at each sample location at the Gann Flats. The MDS plot also, shows a shift in the epifauna present at the Gann Flats between 2015 and 2017. An ANOSIM was conducted to further assess if there was a difference in epifaunal communities at the Gann Flats between 2015 and 2017. The results of the 1-way ANOSIM test showed a significant difference between 2015 and 2017, significance 0.1%. As would be expected from the patterns shown in the MDS plot (Figure 26) the global R statistic of 0.2 shows that there are large overall differences between the epifaunal communities in 2015 and 2017. SIMPER analysis (Appendix Table C5) found that these differences were predominantly caused by an increase in *Rhodophyta* and *Sabella sp*. in 2017 compared to 2015 but decreases in the abundance of *Ulva sp.* (tubular), *Lanice sp., and Fucus sp.*

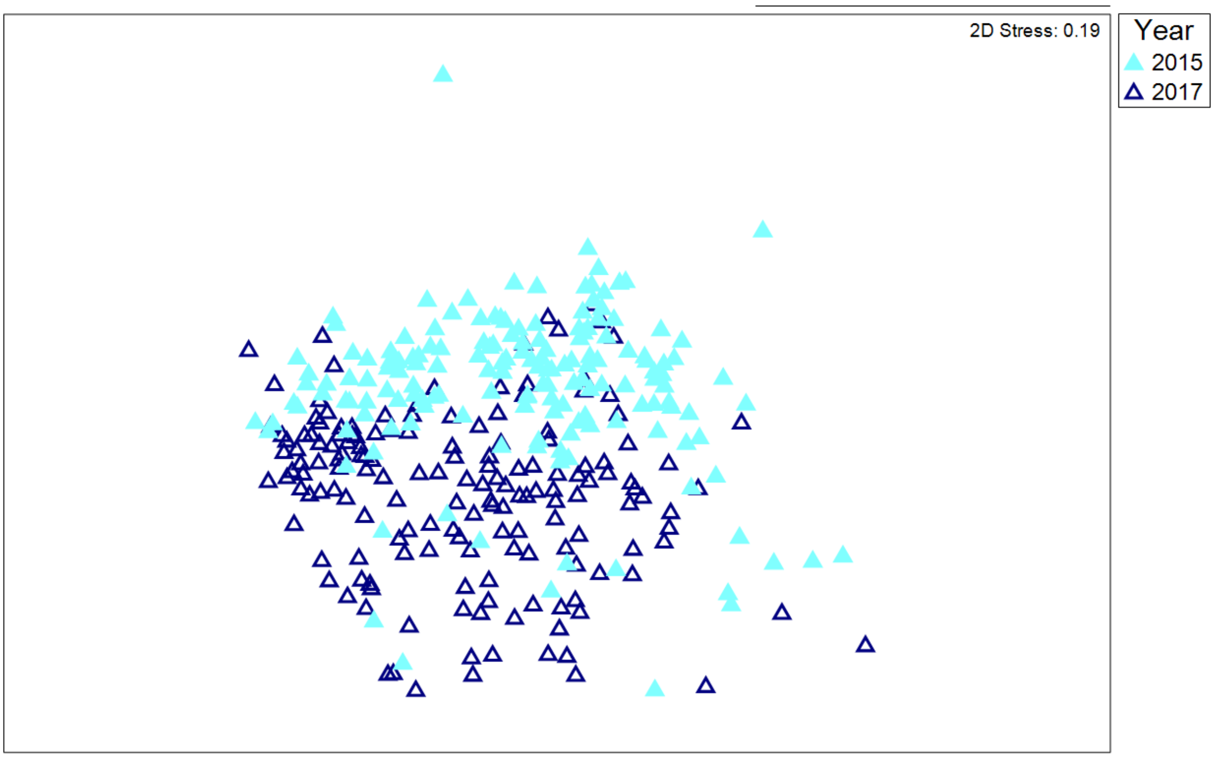


Figure 26: MDS plot of Bray-Curtis Similarity between square-root transformed mean epifaunal abundance data

4. Historic comparison

This section provides a historic comparison of faunal communities within the Gann Flats to provide context for the results of the current ecological status discussed above. A comparison of the data presented within reports from 1960 and 1992 is provided to identify major changes to the site over this timescale (Bassindale and Clark, 1960; Edwards *et al.,* 1992).

The study by Bassindale and Clark (1960) was undertaken prior to the commencement of any known bait digging and therefore provides a useful baseline description of the faunal composition of the Gann Flats. Edwards *et al.* (1992) noted the early potential impacts of bait digging in the area, but at low levels compared to the current day, and aimed to monitor changes which might be caused by the increased disturbance.

The historic reports therefore provide a useful picture of the nature of the biological communities of the Gann Flats prior to intensive bait digging. The results from both studies have been compared with infaunal and epifaunal data collected between 2015 and 2017, providing an assessment of the changes to biological communities within the Gann Flats across the 55-year period, and as a result of increased pressure from bait digging.

Methods

To undertake a qualitative comparison of the historic data from 1958, 1959, 1988 and the current data (2015, 2016 and 2017) GIS was used to visualise the distribution and density of key species during each survey. All mapping was undertaken using ArcGIS version 10.6.

Maps within the historic reports were digitised within ArcGIS to create shapefiles which could be used to create density maps, based on abundance of species recorded within the historic data. These were then compared with the equivalent current mapped abundance data to provide an indication of changes through time.

The study by Bassindale and Clark (1960) assessed epifaunal and infaunal composition across the Gann Flats between 1958 and 1959. The study estimated the distribution and abundance of species across 10 parallel transects taken across the Flats at intervals of around 60 m. Twenty stations were sampled along each transect using a metre squared quadrat, with counts of key discernible species recorded within each. For some species estimates of abundance were determined through digging and sieving. The specific details of this approach including how such sampling was undertaken and the sieve size (which would have influenced the species recorded) is not known. A total of 200 stations were monitored.

The later study by Edwards *et al.* (1992) reported the fauna of the Gann Flats from surveys undertaken in 1988. Following the growing popularity of the Gann Flats as a study site and due to the commencement of bait digging in the area, the study aimed to assess the changes in biological communities 30 years on. The study monitored 29 stations, covering approximately half of the area to the western side of the Gann Flats. Samples were collected by digging and sieving a 25 x 25 cm sample (to 15 cm depth) through a 1 mm mesh. In comparison the current monitoring method used a 0.01 m^2 core sieved over 0.5 mm mesh.

It should be noted that because the raw data from the two historic studies were not available the comparison has been a largely qualitative exercise. Additionally, due to the differences in sampling methodology between the two studies and the current monitoring (2015-2017) there are some limitations to the comparison that can be made. Despite using the best available evidence for the historic comparison, such limitations need to be considered when assessing potential changes in species abundance and distribution and to provide context to the results.

Differences in the sampling techniques including core size (e.g. depth and diameter) would also influence the results obtained. Similarly, sieve size would also impact the specific species recorded as well as the relative abundances given the size of organisms captured by the mesh. The method used by Edward *et al.* 1992, for example, extracted samples and washed them over a 1 mm sieve. The sieve size used in 2015 and 2016 was 0.5 mm. The specific mesh size applied by Bassindale and Clark (1960) is not known.

In addition, Bassindale and Clark (1960) limited their investigation to common species which were easily recognisable in the field and as such will have underestimated the full biological communities present across the area. Additionally, Edwards *et al.* (1992) did not assess the distribution of common algal species such as *Ulva* sp., *Fucus* sp. and *Chorda* sp., therefore changes in the abundance of algal species cannot be compared between all surveys.

There was also a difference in the spatial coverage of the respective studies. Edwards *et al.* (1992) had a limited period for sampling and therefore, only sampled a select area of the Gann Flats to the western side of the bay. This difference could have influenced the species present and relative diversity and density between the surveys.

It should also be noted that both natural and anthropogenic changes, in addition to bait digging, could have occurred over the time periods considered within this comparative study. These could have influenced the distribution and abundance of habitats and species across the Gann Flats over this time period.

Results

Sediment composition

Five PSA samples were collected from the Gann Flats by Bassindale and Clark during the 1959 sampling. All samples were described as fine to coarse sand (Table 4). Although not sampled, the report also maps the distribution of fluvioglacial gravel, fine sand and mud, which cover a large portion of the shore as mixed sediments. This compares to the predominantly Gravelly Muddy Sand observed in 2015 and 2016 (See Section 3.2.1).

Caution should be applied when inferring trends from mean particle size data in mixed sediment shores, given the inherent variability of such diverse sediment profiles. However, there is an apparent change in sediment composition from historic studies, which may have influenced changes in species abundance. The distribution of Folk sediment classifications across the Gann Flats are presented in Figure 27.

Table 4:Analysis of substrate samples undertaken by Bassindale and Clark (1960)

Station	Very fine sand <0.125 mm	Fine sand 0.125 - 0.25 mm	Medium and coarse sand >0.25 mm
A	8.43	66.46	25.11
B	14.52	82.63	2.82
C	9.96	30.93	59.10
D	48.57	16.71	38.73
E	13.00	86.62	0.37

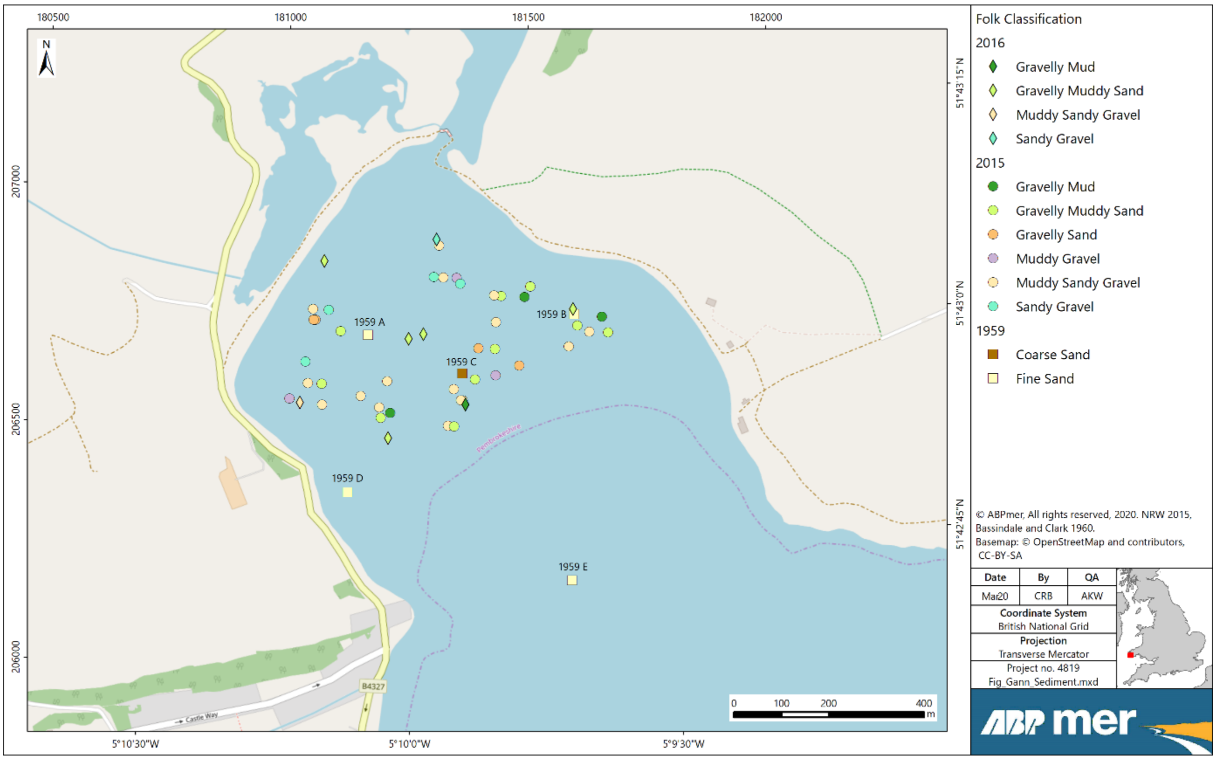


Figure 27: Sediment descriptors for the Gann Flats in 1959, 2015 and 2016.

Infaunal species composition

Overall, Bassindale and Clarke (1960) found that annelids were the dominant fauna at the Gann Flats, which corresponds to the findings of Edwards *et al.* (1992) and the recent 2015, 2016 data. Edwards *et al.* (1992) recorded a total of 111 species during the survey, of which 60 were polychaetes, 14 bivalve molluscs and 12 amphipods. Notable species at the Gann Flats across the sampling periods were *M. palmata, Lanice conchilega* and *Sabella* sp.. Among the more active burrowing species *Nephtys* sp. were also abundant.

L. conchilega is a terebellid, surface deposit feeding worm, which builds a tube that extends above the sediment surface. Across all surveys of the Gann Flats its distribution has been widespread across the whole site (Figure 29). However, during the recent survey higher abundances appear to be restricted to the low shore where the pressure of bait digging is reduced. This may also be a result of habitat preference as *L. conchilega* are often reported seaward of the low water neap tide mark. *Sabella* sp. show a similar distribution to that of *L. conchilega* being widely recorded across the Gann Flats in 1958 and 1959, although in lower abundances than *L. conchilega*. Higher *Sabella* abundances were generally recorded in the lower intertidal zone and shallow sublittoral. Despite the still widespread distribution, overall abundance appears to have declined across the site in the recent surveys (2015-2016). No *Sabella* sp. were noted in the 1988 survey (Figure 29; Edwards *et al*. 1992).

Edwards *et al.* (1992) noted a high presence of *M. palmata* on the mid-shore of the Gann Flats (Figure 29). *M. palmata* is a polychaete species, 15-20 mm in size, often found in muddy or fine sand sediments. Due to its short life history and larval dispersal it is able to easily colonise sediments and so is often associated with disturbed areas. Distribution appears to have increased across the Gann Flats since 1992, with a widespread distribution of *M. palmata* found across the mid-shore at the Gann Flats in 2015 and 2016. No records of *M. palmata* were made in the Bassindale and Clark's 1960 report, and due to the size of *M. palmata* it is unlikely to have been missed during the analysis if it was present.

Nephtys sp. are carnivorous polychaetes which burrow into the sand. Bassindale and Clark (1960) reported a wide distribution of *Nephtys* sp. across the Gann Flats, however in the 2015 and 2016 surveys the spatial distribution was more restricted and constrained to the centre of the Gann Flats (Figure 29). *Nephtys* sp. occupy fairly distinct habitats, usually in muddy sandy sediments, and are less likely to live in muddier, finer sediments. This could potentially explain the reduced density to the western side of the shore where sediments have been generally classified as Muddy Sandy Gravel in more recent years.

When describing the intertidal fauna of the Gann Flats in 1988, Edwards *et al*. (1992) noted a striking decline in *A. marina* (among other species) and dramatic increase in *A. virens* abundance compared to the earlier survey of Bassindale and Clark (1960) who did not record any presence of *A. virens* (it should be noted that the difference in sampling methods could attribute to this dramatic change). However, *A. virens* was only recorded at six stations during the 2016 infaunal monitoring and was not recorded at all in 2015 (Figure 28). *A. virens* can occur deep within sediments and therefore may not have been sampled as samples were only collected to a depth of 15 cm. *A. virens* are therefore likely to have been missed within a core-based survey.

Bassindale and Clark (1960) recorded a wide distribution of *A. marina* across the Gann Flats, with the species distributed across the whole beach and greatest abundance around Mean Low Water Neaps (MLWN), however no map was available to provide comparison within this report. No *A. marina* were recorded during 2015 and 2016 infaunal sampling, however, as with *A. virens*, *A. marina* often occur within deeper sediments and so abundance would be expected to be underrepresented by core sampling. The presence of *A. marina* casts were, however, recorded on the sediment surface during the epifaunal sampling in 2015 and 2017, with maximum abundance of 40 per m². Although recorded during the Edwards *et al*. (1992) survey abundance of *A. marina* was relatively low and distribution across the Gann Flats was not specifically discussed.

Bassindale and Clark (1960) also reported on the notable absence of oligochaetes across the Gann Flats which is in contrast to current findings, and those of Edwards *et al.* (1992), with relatively high abundances of *Tubificoides* sp. recorded in both studies (Figure 30). During the 2015 and 2016 surveys three species of *Tubificoides* were recorded*, T. benedii, T. insularis* and *T. pseudogaster.*

C. edule has been indicated as a species highly susceptible to the impacts of bait digging. In the current infaunal survey *C. edule* was patchily distributed across the whole of the Gann Flats with the highest abundance on the upper, western side of the shore. Edwards *et al.* (1992) recorded *C. edule* across most of the western side of the Gann Flats, which suggests its distribution has become patchier in recent years (Figure 31). *C. edule* were also recorded in a number of samples during the epifaunal survey, only a small number of individuals were recorded during the survey in densities of up to 4 per m², predominantly to the west of the bay with sporadic records to the very east of the site.

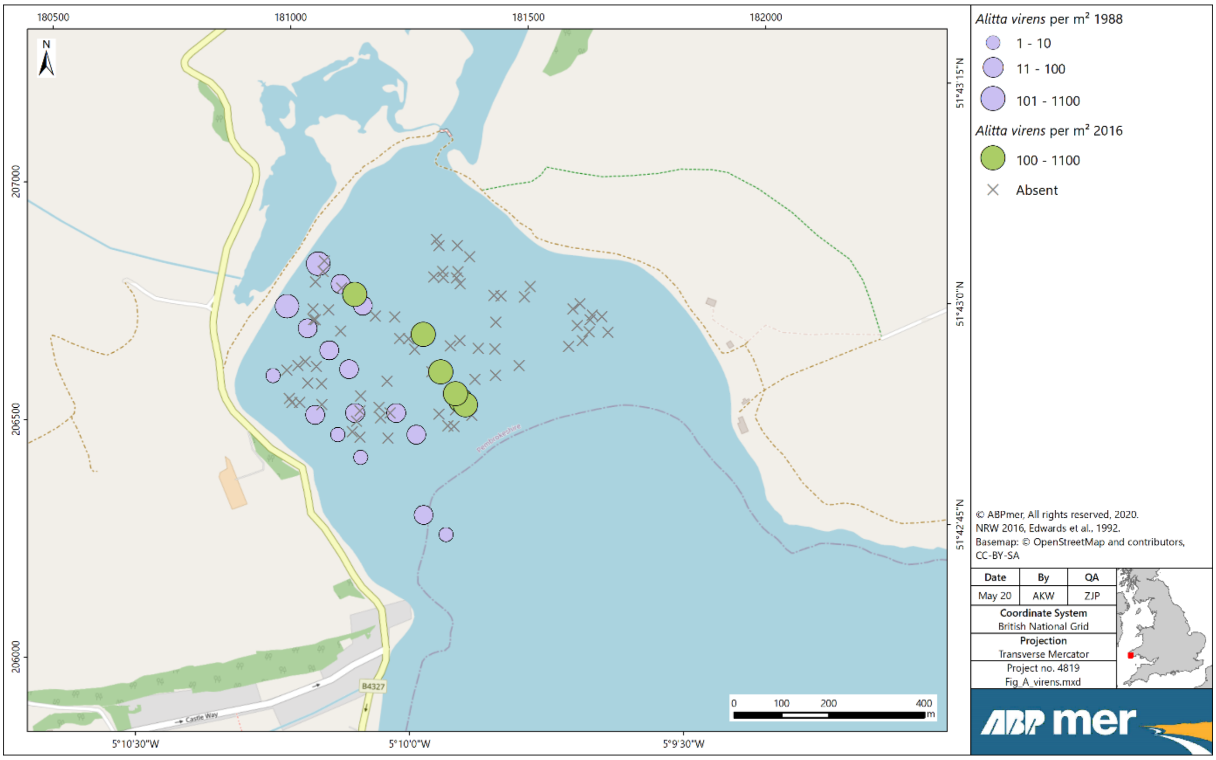


Figure 28:The distribution and abundance of *A. virens* at the Gann Flats in 1988 and 2016.

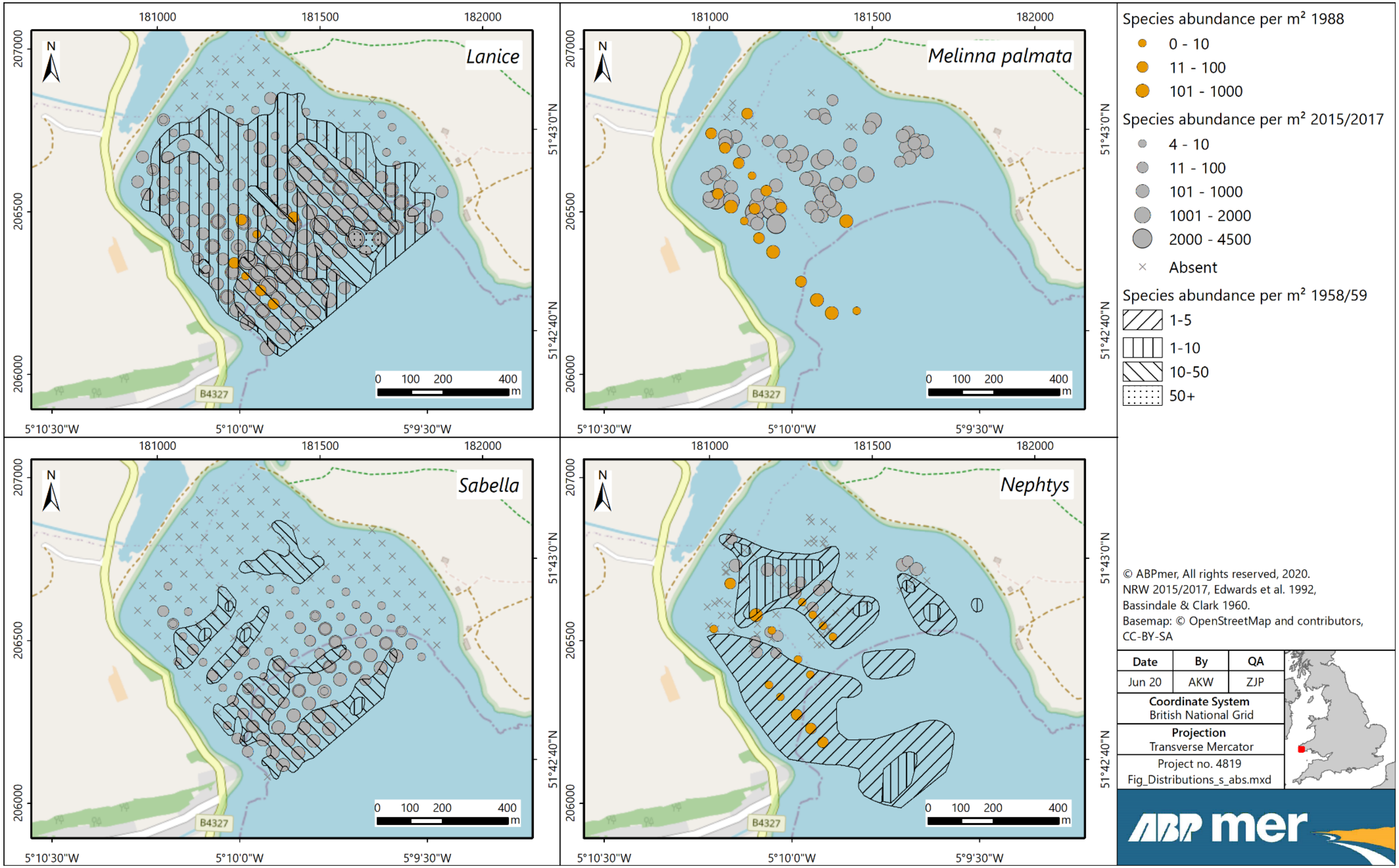


Figure 29: The distribution and abundance of infaunal species at the Gann Flats in 1958/59, 1988, 2015/2017.

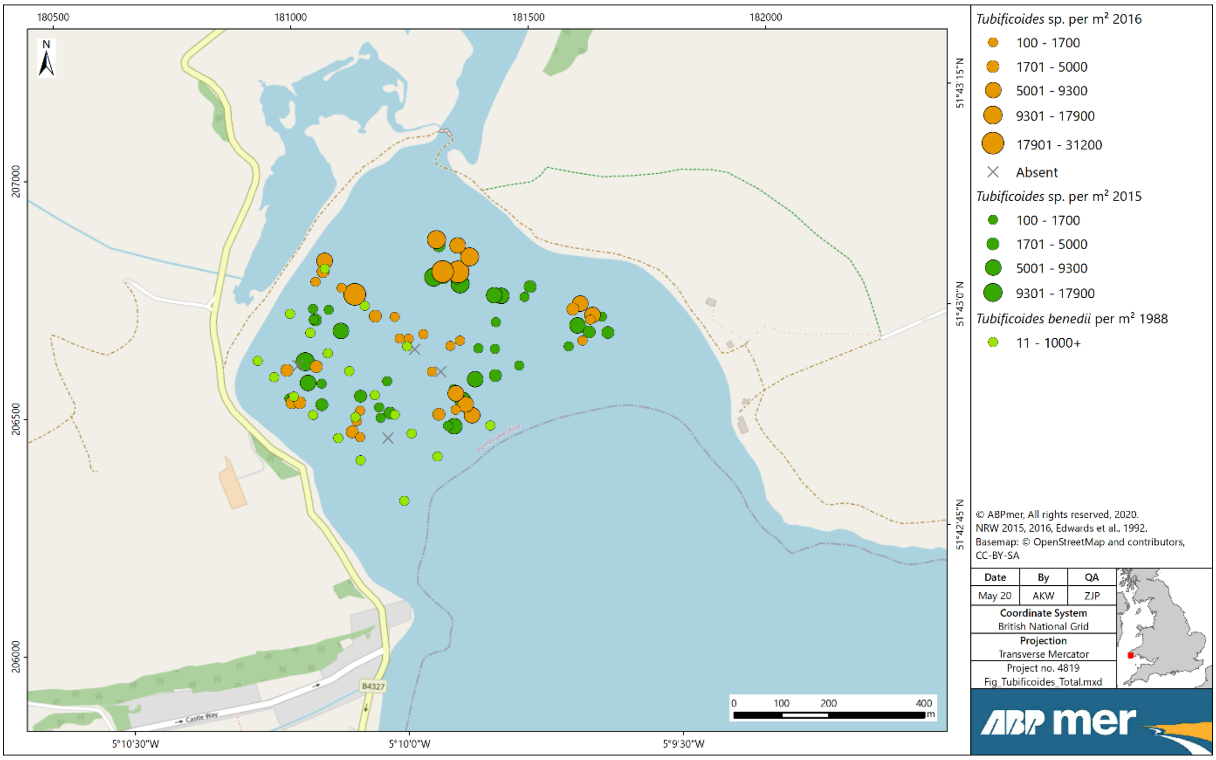


Figure 30: The distribution and abundance of *Tubificoides* sp. On the Gann Flats in 1988, 2015 and 2016.

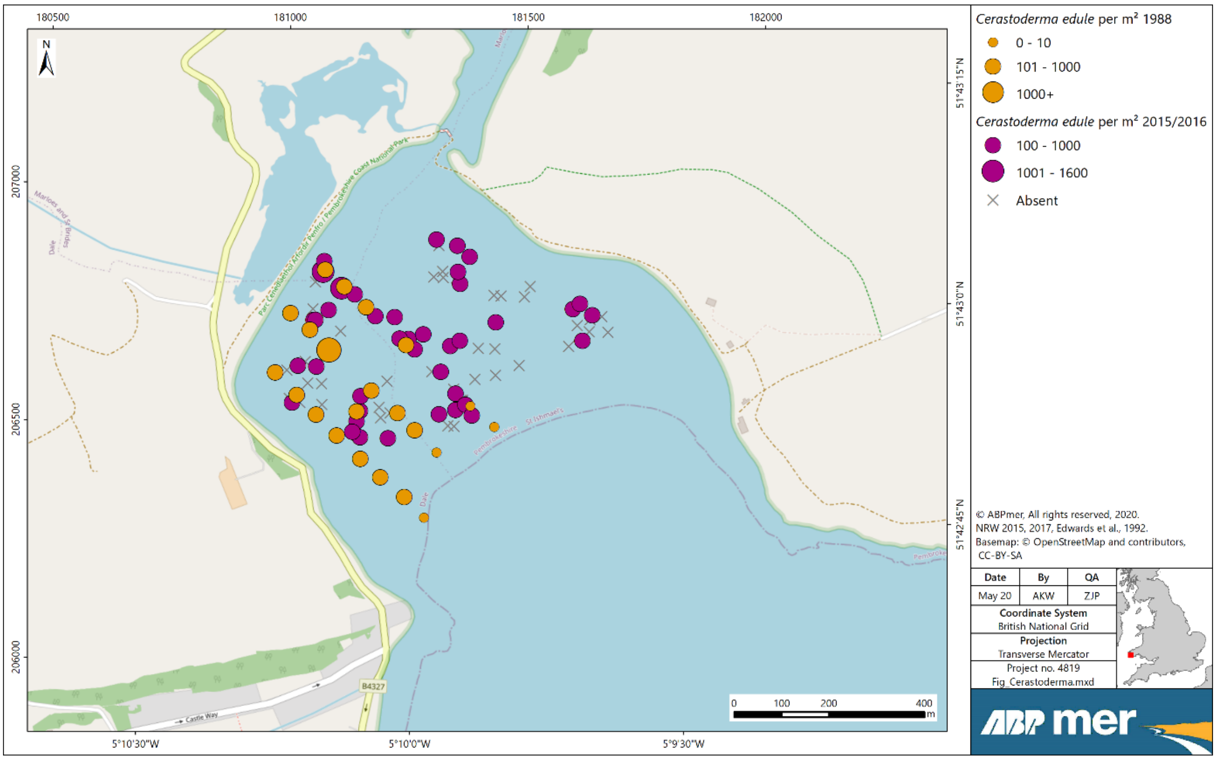


Figure 31: The distribution and abundance of *Cerastoderma edule* on the Gann Flats in 1988, 2015 and 2016.

Epifaunal species comparison

As discussed above, the Gann Flats currently comprise a varied and patchy substratum, predominantly formed of gravel overlain with mud and muddy sand. As such due to the nature of the substratum, there is relatively little development of dense algal cover. In 2015 and 2017 data were collected from across the Gann Flats to assess the epifaunal species composition, as shown in Figure 5.

Due to the differences in sampling methodology direct comparison between the abundances recorded in 2015/2017 and Bassindale and Clark (1960) are not possible. However, the relative differences in distribution can be described at a generic level. Comparison cannot be made with data from 1988 as the sampling method used by Edwards *et al*. (1992) did not record epifaunal data.

The most common algal species recorded in 2015 was *Ulva sp.,* which was also commonly recorded during 2017, although in slightly reduced abundances. Overall, the distribution of *Ulva* sp. has greatly increased across the entirety of the Gann Flats in recent years (2015 to 2017). *Ulva sp*. are opportunistic taxa that colonises bare hard substrate where scour or disturbance is present, such as conditions present in dug areas of the Gann Flats. It should also be noted that the presence of *Ulva sp*. could have been influenced by the presence of freshwater streams, the exact location of which is unknown. The potential increase is gravel sediment fractions, from sand to mixed sediment may also provide greater areas for attachment of *Ulva* sp. Bassindale and Clark (1960) recorded higher abundances of *Ulva* sp. at the east and west of the site with reduced abundance in the centre, in contrast to the current findings.

Furthermore, Bassindale and Clark (1960) mapped the distribution of *Ulva* sp. and *Enteromorpha sp*. separately. Due to a taxonomic name change both species are now classified as *Ulva* sp. When *Enteromorpha* sp. distribution is also considered, Bassindale and Clark (1960) noted a high abundance at the north of the Gann Flats, near to the area of freshwater input. A similar area can be seen in the 2015 and 2017 data (Figure 32).

Rhodophyta (red seaweeds) were the most abundant algal species during the 2017 survey (noting that such species are observed in relatively low abundances compared to Ulvae). *Fucus* sp. was also recorded in both 2015 and 2017. Similarly, Bassindale and Clark (1960) reported scattered algal cover in areas where small stones were available for attachment. Common algal species recorded included in both current and historic surveys included *Fucus spiralis*, *F. vesiculosis* and *F. serratus*, *Saccharina latissimi* (= *Laminaria saccharina*) and *Chorda filum*. Overall algal abundance has remained relatively patchy across the site.

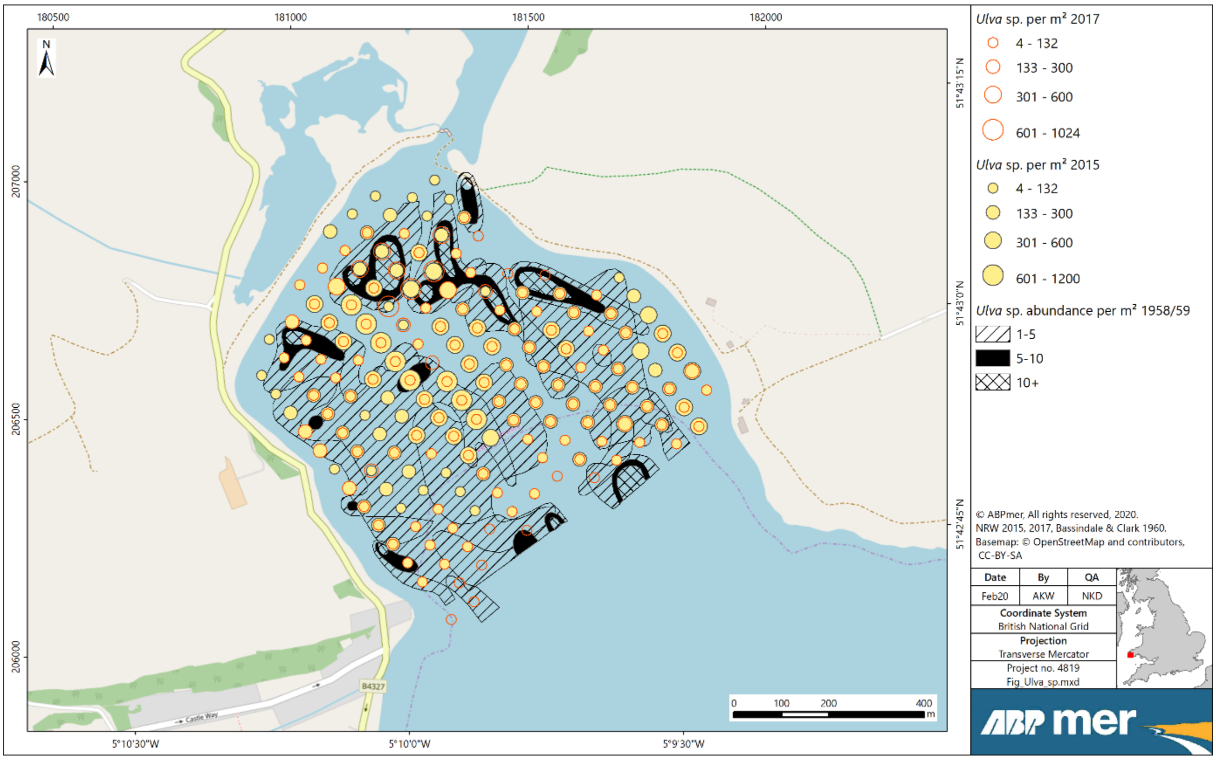


Figure 32:The distribution and abundance of *Ulva sp*. at the Gann Flats in 1958/59, 2015 and 2017.

Summary of temporal changes

Edwards *et al*. (1992) found substantial differences in the fauna since the surveys undertaken by Bassindale and Clark (1960), however, interpretation of these changes is not straightforward for the reasons discussed in Section 4 (essentially due to the differences in sampling approaches, recording and analysis methods). Cause and effect is also very difficult to determine in dynamic marine environments where numerous natural and anthropogenic processes occur.

During the Bassindale and Clark (1960) surveys *A. marina* was present over much of the Gann Flats*.* The western part of the Gann Flats was dominated by the sabellid polychaete *Acromegalomma vesiculosum* (= *Branchiomma vesiculosum)* with *M. palmata* in the mid-shore. *Sabella pavonia* was also reasonably abundant in sheltered muddy sediments down the western side of the Gann Flats, and *N. hombergii* was also widespread across the site.

By 1988 (Edwards *et al*., 1992) the fauna in the western part of the Gann Flats had changed considerably. The sabellids *A. vesiculosum* and *S. pavonia* had declined dramatically, with much of the area now dominated by *A. virens. M. palmata* was also seen to be more widespread than in the 1960s surveys. The spatial distribution of *A. marina* has shifted considerably with the species absent from much of the western side of the Gann Flats however, some records were still present along some of the more central areas. *L. conchilega* distribution was much more restricted and limited to the lower shore. No comparison can be made to the eastern side of the Gann Flats due to the more restricted survey area used by Edwards *et al*. (1992).

Since the 1988 survey there have been further changes to the distribution and abundance of species across the Gann Flats. The recent infaunal surveys (2015, 2016) found a reduced abundance of *C. edule* at stations across the Gann Flats.

The general distribution of *Nephtys* sp. remained similar between 1960 and 1990, however it was greatly restricted during the current surveys, with distribution mainly recorded on the upper shore. Similarly, the distributions of *L. conchilega* and *Sabella* sp. have become more restricted, mainly to the lower shore, than was recorded in the 1958 and 1959 surveys.

In contrast the distribution and abundance of *M. palmata* and *Tubificoides* sp. appear to have greatly increased across the Gann Flats compared to the distribution recorded during the 1988 survey. Overall, the distribution and abundance of fauna present at the Gann Flats appears to have changed through time. There has been a general reduction in longer-lived, larger species and an increase in more opportunistic, short lived species, such as *M. palmata* and *Tubificoides* sp. which are readily able to colonise areas of disturbed sediment. This is indicative of potentially increased levels of disturbance across the Gann Flats since the 1960s.

5. Assessing the Effectiveness of the Voluntary No-dig Zones

This section provides an assessment of the effectiveness of voluntary no-dig zones that have been trialled at the Gann Flats to reduce the impacts of bait digging activity. This section therefore reviews infaunal and epifaunal data collected at sites within and outside of the no-dig zones. A high-level comparison has also been made to data collected from the wider Milford Haven Waterway where bait digging is less extensive. The results of the analysis undertaken have been reviewed in the context of whether the current management regime implemented at the site is functioning effectively.

Methods

Voluntary management measures to reduce the impact of bait digging activities have been implemented at the Gann Flats since 2015. The initial management measure consisted of closing a large, highly impacted area to the west of the Gann Flats to allow recovery of the area, while the eastern side of the site remained open (Figure 33). The implementation of zoning was put in place prior to the start of the 2015 bait digging season.

The boundaries of the voluntary zone were then reconsidered the following year (2016). No-dig areas were changed and located on either side of the site, leaving an open zone down the centre of the Gann Flats (Figure 33). This current management regime is still in place in 2020, however, observations suggest that it is not effective with bait diggers not adhering to these zones.

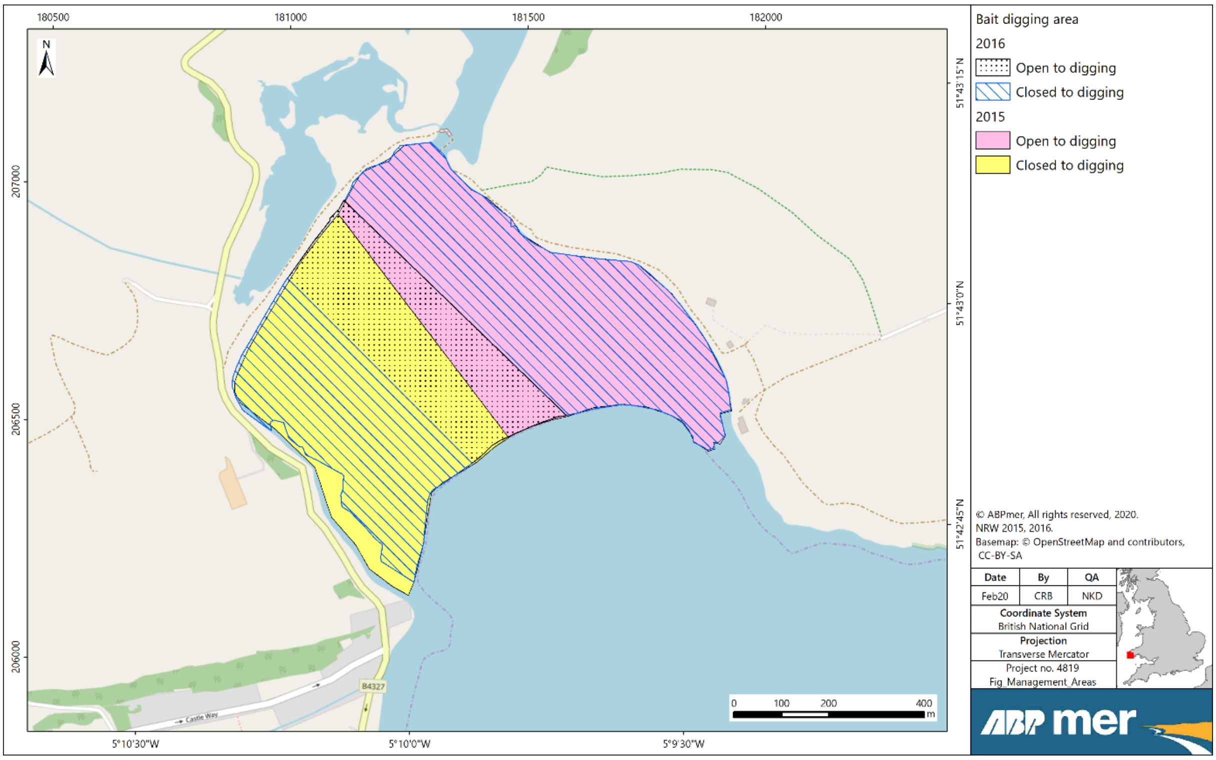


Figure 33: Bait digging management areas for the Gann Flats in 2015 and 2016.

Targeted monitoring surveys were undertaken between 2015 and 2017 to assess the effectiveness of the voluntary exclusion zones. The monitoring consisted of two components, epifauna and infauna monitoring. The sampling methods were the same as those described in Section 3.1. Epifaunal samples were also collected in 2015 and 2017 across the Gann Flats. Infaunal core samples were collected in 2015 and 2016. Core samples were collected from within closed and open zones for biological comparison. Due to the change in management zones in 2016, sample locations were moved to match the exclusion zones. Infaunal sample locations are shown in Figure 6.

To assess the effectiveness of the current voluntary no-dig zones, comparisons of infaunal data collected in 2016 (and within the management areas) have been undertaken to determine the changes in faunal composition. To achieve this each sample was assigned to one of four treatment groups prior to analysis:

- Open Since 2015 (O15O16);
- Closed Since 2015 (C15C16);
- Closed in 2015, Open in 2016 (C15O16); and
- Open in 2015, Closed in 2016 (O15C16).

Assessment of overall changes in communities between treatment groups was then undertaken using multivariate statistics in PRIMER v7 (as described in Section 3.1).

Results

Infauna

To assess the effectiveness of the voluntary no-dig zones at the Gann Flats infaunal sampling stations were assigned to a treatment group based on the management measures in place across the Gann Flats. Figure 34 shows the locations of treatment groups used for the analysis. It should be noted that this resulted in relatively low sample sizes per treatment, in particular group O15O16 which has only two samples.

The abundance, diversity and biomass of taxa recorded within each treatment group at the Gann Flats were assessed to compare faunal composition. Figure 35 shows the total number of taxa recorded from samples within each treatment group and shows the average abundance of fauna recorded in samples within each treatment.

The mean number of taxa at each treatment varied from 24 to 77 and the average abundance varied from 48 to 282. Highest abundance was recorded in treatment groups O15C16, whereas the highest biomass was recorded in treatment groups C15O16. The abundance and diversity of the treatment group O15O16 was much lower than all other groups (but with a small sample size) (Figure 35).

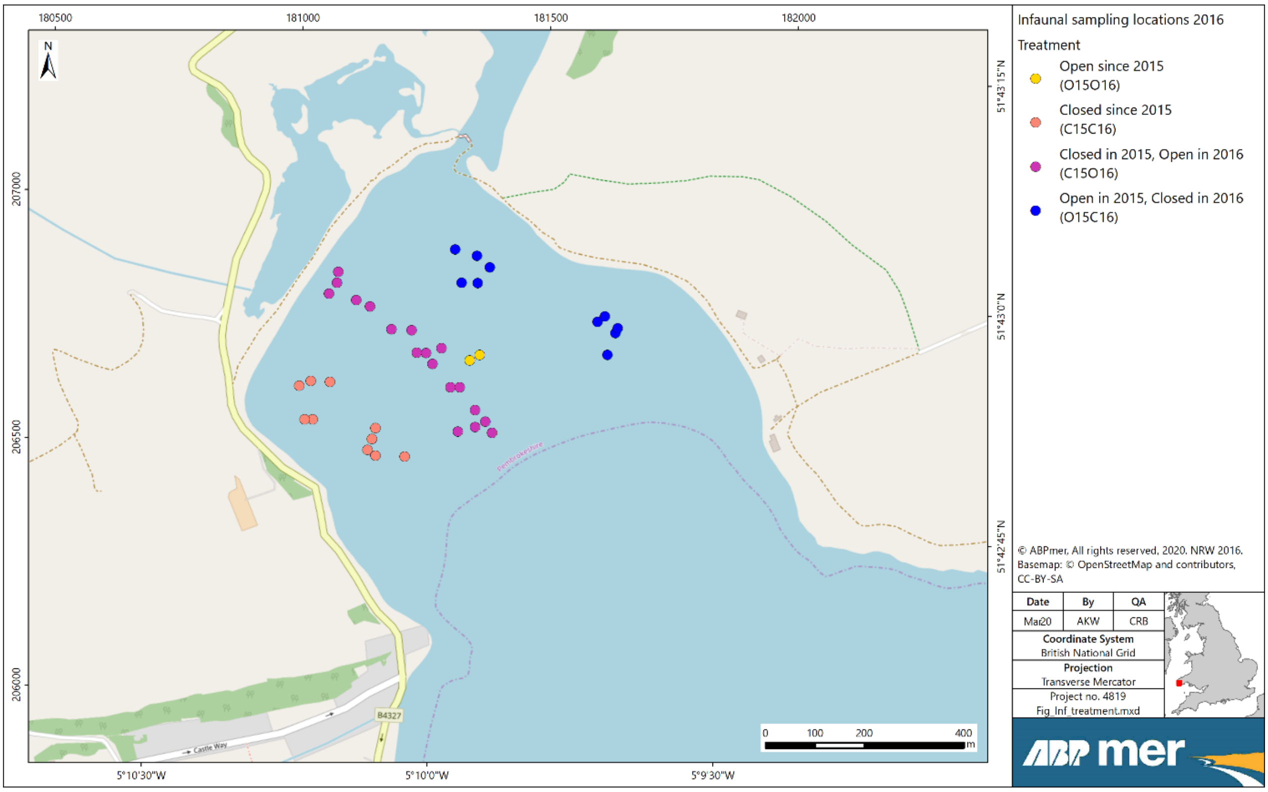


Figure 34: Treatment groups assigned to 2016 infaunal samples collected from the Gann Flats.

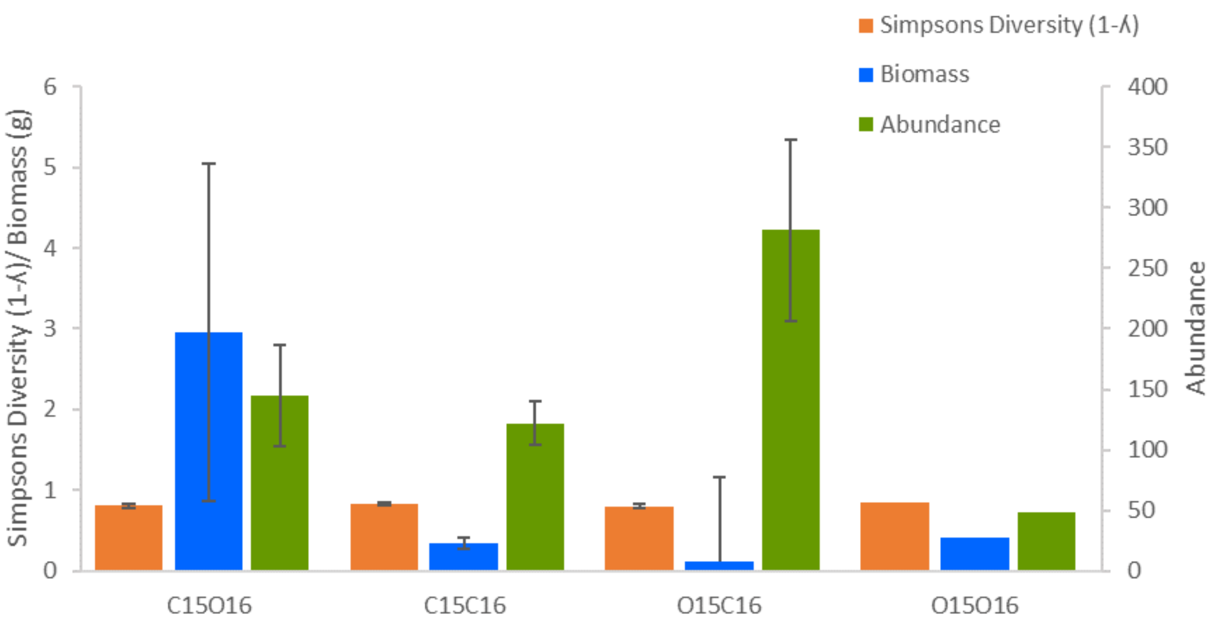


Figure 35: Average abundance, biomass and diversity of infaunal samples in treatment groups, bars show standard error.

Species which contributed most to biomass across all four treatment groups were *C.edule, Cirrifomia tentaculate, Glycera tridactyla, M. palmata and Notomastus.*

Within the group C15O16, which had the highest overall biomass, the species which contributed most was *C. tentaculate*, a polychaete which inhabit muddy inshore and estuarine areas. The group O15C16 had the lowest overall biomass, the key contributors being *C.edule, C. tentaculate* and *R. decussatus. C. edule* contributed most to the biomass within the group C15C16, to the west of the Gann Flats, in much higher abundances than recorded in the O15C16 group.

In contrast, the highest abundance of both *C. edule and M. edulis* were recorded in treatment group O15O16, in the centre of the Gann Flats. It should be noted, however, that presence of *C. edule and M. edulis* within the open zones would suggest that the area may not have been targeted for bait digging, as trampling and bait-digging can significantly reduce mussel cover, density and biomass. Additionally, *M. edulis* needs a point of attachment often requiring areas of increased gravel sediments which might indicate areas unsuitable for bait digging activities. The low sample replication in this group may also influence the results.

To provide an indication of the perceived sensitivity of macrobenthic communities to anthropogenic disturbance occurring within treatment groups at the Gann Flats, an AMBI assessment was undertaken. Samples at the Gann Flats were generally classified as moderate to good ecological status, with low Infaunal Quality Index (IQI) scores ranging from 0.35 to 0.99 with an average of 0.65 (good status).

Figure 36 shows the ecological status of samples (based on the IQI scores) across the Gann Flats. The samples collected from the Closed in 2015, Open in 2016 and Open in 2015 and Closed on 2015 treatment groups had a notably lower IQI score and higher proportion of opportunistic species.

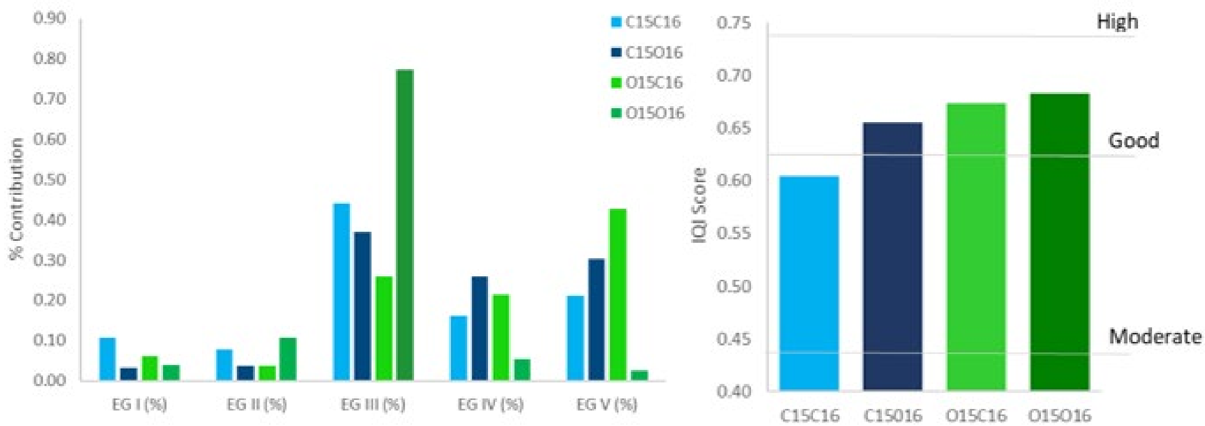


Figure 36: The average percentage contribution of the number of individuals classified into AMBI groups I – V within treatment groups at the Gann Flats and the average IQI score for each treatment group.

The treatment group Open in 2015 and 2016 had the highest IQI score and was assessed as having good ecological status, however this may be due to the lack of sample replication in this treatment group. The most abundant taxa within this group were *Melinna palmata, Cerastoderma edule* and *Nephtys sp*. Biomass within this group was similarly dominated by *M, palmata, Notomastus, Nephtys sp* and *C. edule.*

Samples with a lower IQI score and therefore assumed as having higher levels of disturbance were generally associated with high abundances of the oligochaete *T. benedii*, a species often associated with enriched muddy, estuarine sediments, as well as Nematoda and *Cirriformia tentaculata.* The treatment group closed in both 2015 and 2016 had the lowest IQI score and was the only group to be assessed as moderate ecological status.

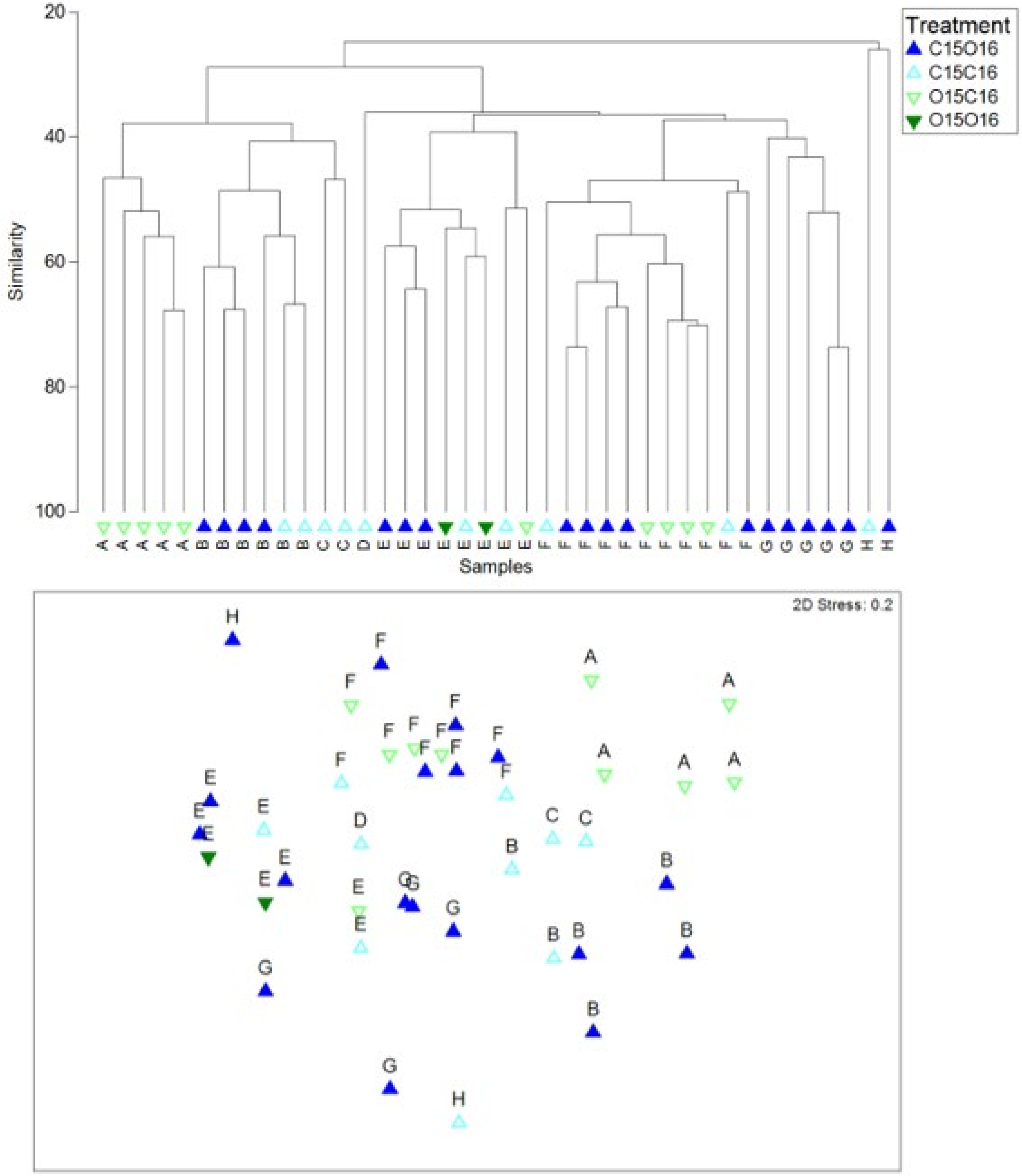
Multivariate analysis of the infaunal data collected during the 2016 surveys

was undertaken to further investigate the fauna present in each management zone. To visualise the biological similarity between samples collected from each management zone within the Gann Flats a SIMPROF cluster analysis was conducted. Eight distinct groups were identified within the infaunal abundance dataset, as presented in Figure 37. The corresponding MDS plot, presented in 2D format is also shown in Figure 37.

SIMPER analysis was run on the multivariate groups to identify the key taxa driving the dissimilarity between the groups.

The key species identified as contributing to the dissimilarity between the groups were the higher abundances of *T. benedii,* Nematoda sp.*, M. palmata* and

Capitella, within the three treatments C15C16, C15O16, O15C16 (Figure 38). There was a higher abundance of *Tellinoidea* sp., *C. edule* and *Mytilus edulis* in the treatment Open since 2015 which also contributed to the dissimilarity (Figure 39). As noted above the presence of *C. edule and M. edulis* within the open zones would suggest that the area may not have been targeted for bait digging, and potentially indicates areas unsuitable for bait digging due to increased gravel in sediments.



Colour codes denote the treatment groups.

SIMPROF cluster groups are labelled along the base of the dendrogram.

Figure 37: SIMPROF Cluster dendrogram (top) of Bray-Curtis similarity between square-root transformed average station abundance data for 2016 and corresponding 2D multidimensional scaling ordination (bottom).

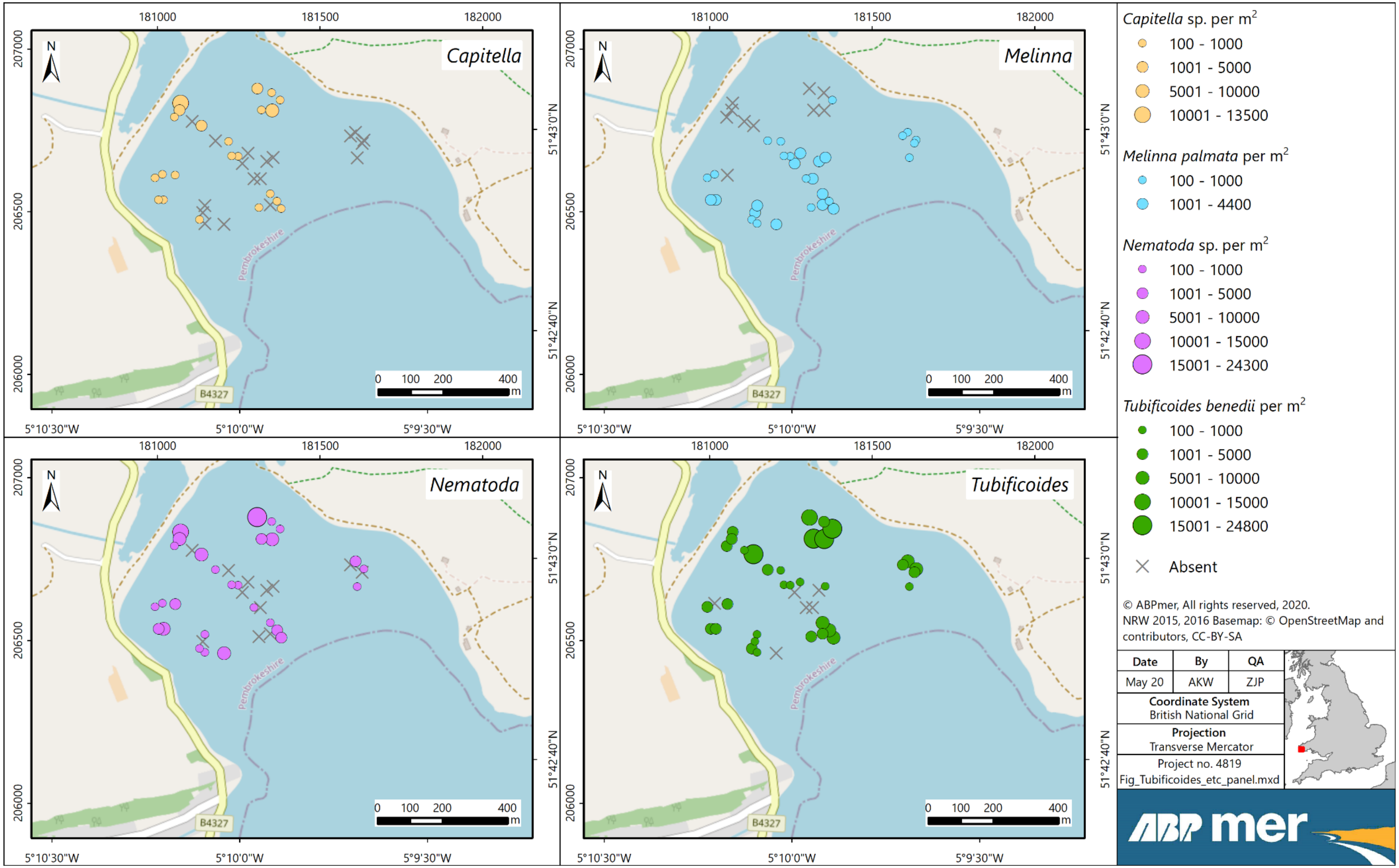


Figure 38: Distribution of *T. benedii,* Nematoda sp., *M. palmata* and *Capitella*

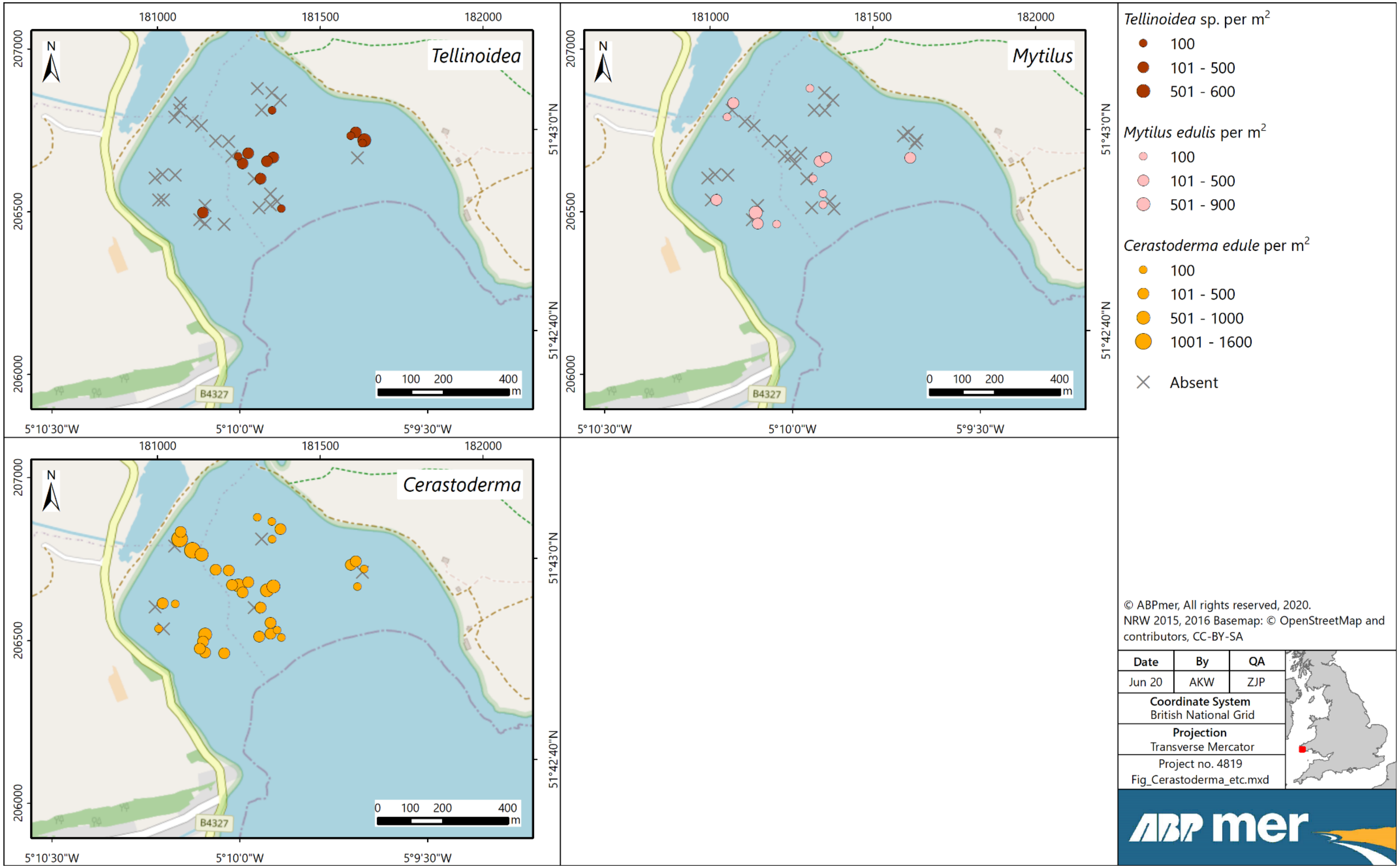


Figure 39: Distribution of *Tellinoidea* sp., *C. edule* and *Mytilus edulis.*

Figure 40 shows the distribution of faunal groups, derived from the SIMPROF analysis, across the Gann Flats. Based on the distribution of the groups it would suggest that the results of the analysis may be more related to the sampling location on the shore than due to the treatment group, and subsequent exposure to bait digging activities. This is again unsurprising given the lack of adherence to the voluntary management zones, demonstrated by the evidence collected on compliance following the implementation of the zone.

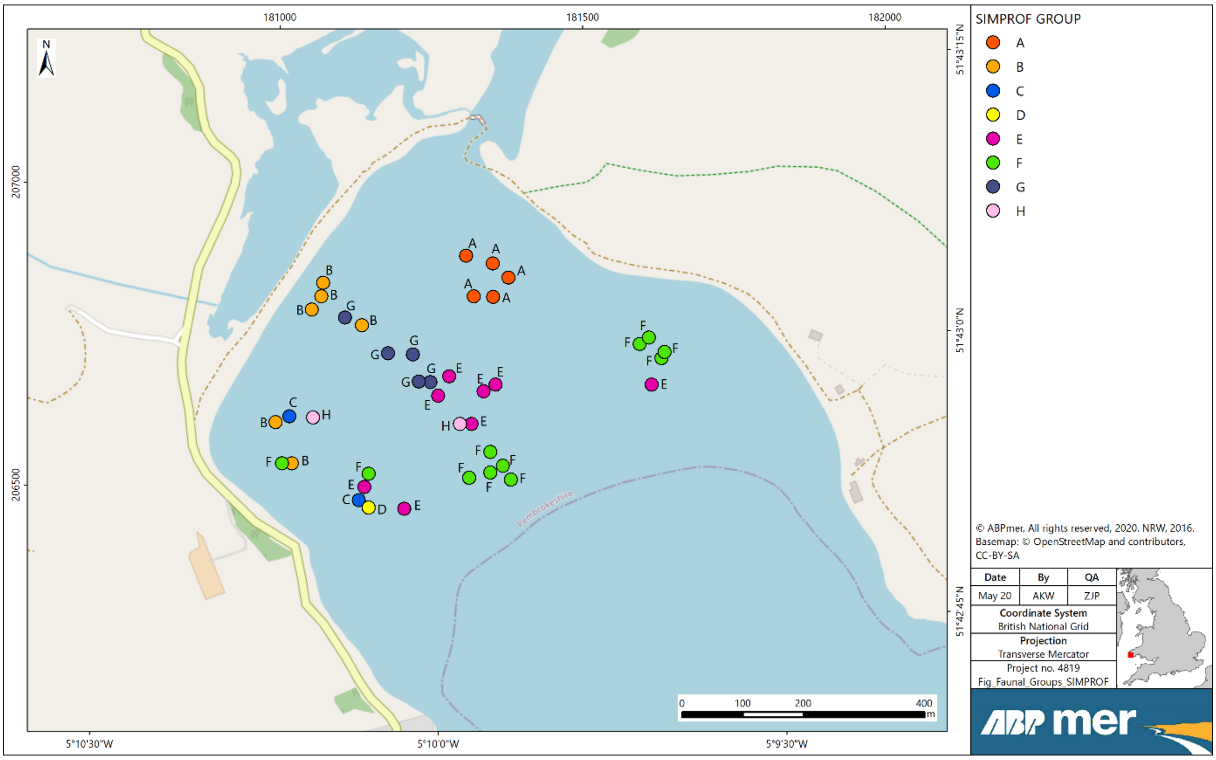


Figure 40: Distribution of faunal groups following SIMPROF analysis

ANOSIM was used to assess if there was an overall difference between the treatment groups. The results of the ANOSIM test between treatments showed a significant difference between treatment groups, however, the global R statistic of 0.14 shows there is only a very slight difference and therefore a high degree of overlap between the fauna in each of the treatment groups (significance <5%; Table 5). However, care should be taken when interpreting these results. Although ANOSIM has no restriction on the number of replicates, the power of the test may be compromised by the markedly unbalanced design due to the low replication of only 2 samples in the O15O16 treatment group.

Of particular note from the ANOSIM was the significant difference and low R value for the pairwise test between the C15C16 and O15C16 treatment groups. This suggests that the closure of the site in 2015 may be having a potential impact on the biological communities between the groups due to lower levels of disturbance. It is, however, noted that these two treatment groups are on opposite sides of the bay and therefore have the largest spatial difference which may also be influencing the biological composition between the treatment groups.

Table 5: Results of 1-way ANOSIM test between treatment groups on square-root transformed data (bold text indicates significant results)

Test	R statistic	Significance (%)	Possible permutations	Actual permutations	Number ≥ observed
Global test	0.145	1.1	13123110	999	10

Pairwise tests:

Test	R statistic	Significance	Possible permutations	Actual permutation	Number observed
C15O16, C15C16	0.081	13.6	13123110	999	135
C15O16, O15C16	0.149	**3.5**	13123110	999	34
C15O16, O15O16	0.076	34.7	190	190	66
C15C16, O15C16	0.214	**1.0**	92378	999	9
C15C16, O15O16	0.248	10.6	66	66	7
O15C16, O15O16	0.52	**1.5**	66	66	1
C15O16, C15C16	0.081	13.6	13123110	999	135

Overall minor differences are apparent between the assemblages in the treatment groups. However, as presumed from such a small sample size there are not significant relationships between the treatment groups. It is therefore not possible to distinguish distinct differences in community structure based on the “assumed” differences in bait digging activity (i.e. the open and closed zones). This is unsurprising given the observed lack of adherence to these zones (which is supported by the results of the epifaunal surveys (see Section below) and due to the lack of time since management measures were put in place. The data would also suggest that the samples classified as “Open” in both 2015 and 2016 may not have been targeted for bait digging (based on the presence of *C. edule* and *M. edulis*).

Epifauna

As part of the epifaunal monitoring methodology the presence of bait digging activity within each sample was noted. Samples where evidence of bait digging was recorded are shown in Figure 41, providing an indication of the spatial extent of this activity.

Due to the sheltered nature of the sediments at the Gann Flats recovery of sediments from bait digging is slow and therefore no accurate assessment of when bait digging holes were formed could be made. Therefore, despite there being evidence of bait digging in the closed area during 2017 it cannot be concluded that digging had occurred post-closure as holes may have been previously dug.

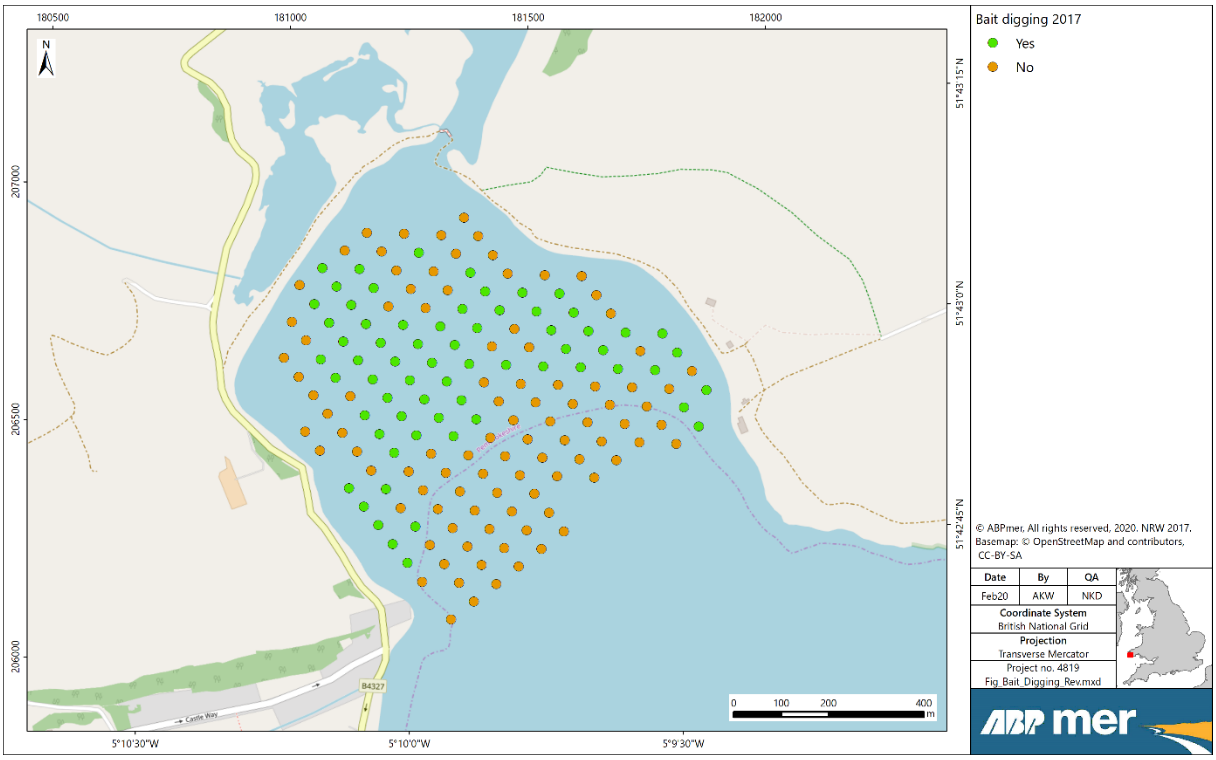


Figure 41: Evidence of previous bait digging activity across the Gann Flats, recorded during the 2017 epifaunal survey.

Despite this limitation the data is useful for inferring the impacts of bait digging disturbance to epifaunal communities. SIMPER analysis was run on the epifaunal data to identify the key taxa driving the dissimilarity between areas where evidence of bait digging was evident and where no evidence of bait digging was recorded. This did not necessarily relate to the no-dig zones assumed for the infaunal analysis (see page 63).

The results of the SIMPER analysis showed that in general, samples which were in areas with no recorded evidence of bait digging had a higher average abundance of epifauna. Key species which contributed to the dissimilarity between areas subject to bait digging, or not, were *Lanice* sp., red seaweeds, *Ulva* sp., *Sabella* sp. and *Fucus* sp.. In areas where there was no record of bait digging activity, increased abundance of *Lanice* sp. and red seaweeds contributed to 41.01% of the dissimilarity. In general, all of the species indicated as having the greatest influence on the dissimilarity between areas had reduced abundances in areas of digging activity (Table 6). It should be noted that this is not necessarily an indication of causality, as bait diggers may target particular sediment types that do not support conspicuous epifauna.

It should be further noted that due to tidal access restrictions there is reduced bait digging activity in the lower shore. Stations located within the lower shore are naturally likely to be more diverse than upper shore stations and therefore some differences may be attributed to this as opposed to reduced bait digging pressure.

Table 6: 1-way SIMPER analysis of bait digging activity across the Gann Flats in 2017

Average dissimilarity 62.14	Mean abundance No Digging	Mean abundance Digging	Mean dissimil-arity	Diss/SD	Contri-bution %	Cumul ative %
Lanice species	4.60	0.77	12.81	1.06	20.62	20.62
Red Seaweeds	5.96	3.50	12.67	1.37	20.39	41.01
Ulva species	3.41	2.91	9.74	1.02	15.67	56.68
Sabella species	3.00	0.18	7.31	0.90	11.77	68.45
Fucus species	1.49	0.76	6.36	0.75	10.23	78.68

As with the infaunal data, to assess the effectiveness of the voluntary no-dig zones at the Gann Flats epifaunal sampling stations were assigned to a treatment group based on the management measures in place across the Gann Flats (Figure 34).

Multivariate analysis of the epifaunal data collected during the 2017 surveys was undertaken to assess the biological similarity of samples collected from each management zone across the Gann Flats. ANOSIM was used to assess if there was an overall difference between the treatment groups. The results of the ANOSIM test showed a significant difference between treatment groups, however, the global R statistic of 0.105 shows there is only a very slight difference and therefore a high degree of overlap between the fauna in each of the treatment groups (significance <5%; Table 5). Additionally, across the pairwise tests there is no clear result with regards to significant differences between closed and open treatment groups. The MDS plot (Figure 42) corroborates the results of the ANOSIM showing a high degree of overlap between the fauna in each of the treatment groups.

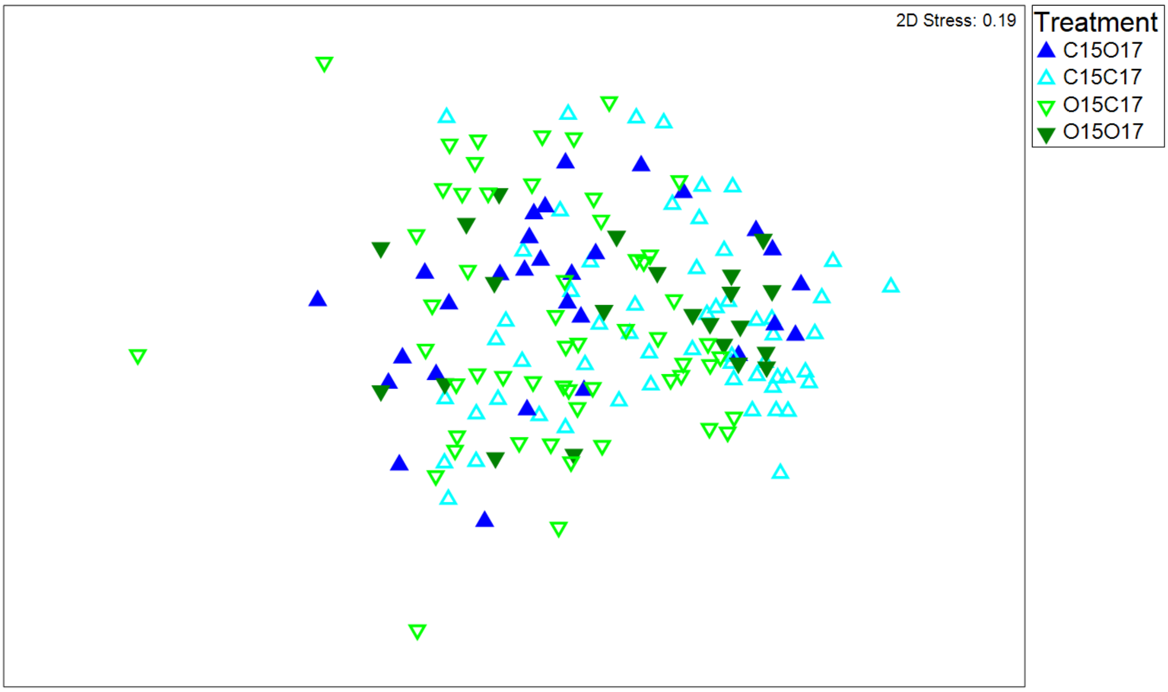


Figure 42. MDS plot of Bray-Curtis Similarity between square-root transformed mean epifaunal abundance data for each treatment group.

Table 7: Results of 1-way ANOSIM test between treatment groups on square-root transformed epifaunal data (bold text indicates significant results)

Test	R statistic	Significance (%)	Possible permutations	Actual permutations	Number ≥ observed
Global test	0.105	0.1	Very large	999	0

Pairwise tests:

Test	R statistic	Significance (%)	Possible permutations	Actual permutations	Number ≥ observed
C15C17, C15O17	0.187	**0.1**	Very large	999	0
C15C17, C15O17	0.187	**0.1**	Very large	999	0
C15C17, O15O17	0.047	18.4	Very large	999	183
C15C17, O15C17	0.136	**0.1**	Very large	999	0
C15O17, O15O17	0.041	9.7	Very large	999	96
C15O17, O15C17	0.039	12.9	Very large	999	128
O15O17, O15C17	0.084	**5**	Very large	999	49
C15C17, C15O17	0.187	**0.1**	Very large	999	0

As with the infaunal data, minor differences are apparent between the assemblages in the treatment groups. However, due to the short time frame between monitoring and changes in management measures it is not possible to distinguish distinct differences in community structure based on the “assumed” differences in bait digging activity (i.e. the open and closed zones). This is also likely to be in part due to the apparent lack of compliance to management zones, which has been documented by NRW following implementation of the voluntary zoning.

Summary of results

Overall, there is a small difference in the infauna recorded within different treatment groups that have been assigned according to whether they are located within or outside the voluntary no-dig zones. However, the results from the analysis are inconclusive and suggest that only minor differences are apparent between groups, confounded by the short time of protection from area closure and low levels of compliance.

The key species identified as contributing to the dissimilarity between the groups were higher abundances of opportunistic species, *T. benedii,* Nematoda sp. and *M. palmata* within the three treatments within areas that have experienced some degree of closure since 2015. The higher abundances of *C. edule* and *M. edulis* in the treatment O15O16 (open in both 2015 and 2016) is in contrast to what would be expected given that such species are typically longer lived and sensitive to disturbance. However, due to the low number of samples it is difficult to assess if results are representative. McLusky *et al*. 1983 and Farrell, 1996 suggest that numbers of *C. edule* and *M. edulis* are generally reduced in abundance in areas of high bait digging. This suggests that these sample locations may not have been targeted for bait digging.

It should also be noted that only two samples were located within the treatment group O15O16. The small number of samples, and therefore low replication, in the O15O16 treatment group again limit the comparisons that can be made and ultimately the conclusions that can be derived. Similarly, the lack of differences in community structure is unsurprising given the observed lack of adherence to these zones which is supported by the results of the epifaunal surveys.

The results of the epifaunal analysis indicate differences in epifaunal composition between areas that have and have not experienced recent digging. While this may indicate an impact of digging, it could also reflect the areas of sediment targeted by bait diggers and is therefore not conclusive. It does, however, provide an indication that digging has been occurring in closed areas and supports the evidence that that compliance to management measures has been low.

6. Conclusions

Current ecological status

The Gann Flats are currently predominantly characterised by Gravelly Sandy Mud and Muddy Sandy Gravels. These habitats support relatively diverse communities. The most dominant infaunal species recorded at the Gann Flats in the 2015/2016 surveys were the oligochaete *T. benedii* and the polychaetes*, P. elegans* and *M. palmata,* all of which are short lived species with high dispersal potential and are often associated with more disturbed habitats. *C. edule, C. tentaculata* and *M. palmata* contributed most to biomass.

The most distinctive groupings of infaunal species were based on sampling year as opposed to specific locations. This indicates a higher degree of similarity between species communities within each year than at each sample location across the years.

To provide a comparison to faunal communities in the wider Milford Haven Waterway a comparison between the fauna at the Gann Flats was made with samples collected at nearby sites, Angle Bay and Pwllcrochan. The results of the analysis suggest that there is a distinct difference in community structure between the samples at the Gann Flats and Angle Bay and Pwllcrochan. Key species leading to dissimilarity were higher abundances of *T. benedii*, Nematoda species, *Capitella* sp., and *P. elegans* at samples across the Gann Flats compared to Angle Bay and Pwllcrochan. These species are again considered to be characteristic of more disturbed locations.

Due to the Gravelly Sandy Mud nature of the substratum in the Gann Flats, there is relatively little development of dense algal cover as there are limited areas suitable for attachment. A range of algal species were recorded across the site in 2015 and 2017 but in relatively low abundances. Species recorded included *Ulva* sp.*, Fucus* sp., Kelp, *Chorda* sp. and Rhodophyta. Other species of note, which were recorded during the epifaunal monitoring were the polychaetes *Lanice* sp. and *Sabella* sp. Both species are burrowing worms which create tubes that project above the sediment surface and as such both species are susceptible to high levels of disturbance.

It should be noted that there is a freshwater influence across the Gann Flats due to an area of running water from the Gann. Accurate mapping of the position of the freshwater stream is not available but this could be an important factor influencing both the infaunal and epifaunal assemblage across the site.

Historic comparison

A historic comparison of faunal communities associated with the Gann Flats was undertaken to provide context to the results of the current ecological status. This was largely based on a comparison of data presented within reports from 1960 and 1992 (Bassindale and Clark, 1960; Edwards *et al.,* 1992). The study by Bassindale and Clark (1960) was undertaken prior to the commencement of any known bait digging and therefore provides a useful baseline description of the faunal composition of the Gann Flats. Edwards *et al.* (1992) noted the early potential impacts of bait digging in the area, but at low levels compared to the present day.

Edwards *et al*. (1992) found substantial differences in the fauna present at the Gann Flats since the surveys undertaken by Bassindale and Clark (1960), in particular noting a dramatic increase in the abundance of *A. virens.* Similarly, it is evident from the results of the 2015-2017 epifauna surveys that there have been further changes to the distribution and abundance of species across the Gann Flats. There has been a general reduction in longer-lived, larger species to more opportunistic, short lived species which are readily able to colonise areas of disturbed sediment. This is indicative of potentially increased levels of disturbance across the Gann Flats since the 1960's.

There also appears to have been a change in sediment type from what were reported as fine sands in the late 1950's through to the present day more mixed sediments. The reasons for such changes are unclear but could be related to disturbance from bait digging. Changes in sediment composition would cause changes to infaunal composition but not necessarily of the type recorded by the 2015-2017 surveys which noted increases in opportunistic species.

It should be noted that interpretation of these changes is not straightforward for a number of reasons (essentially due to the differences in spatial coverage, sampling approaches, recording and analysis methods). Cause and effect is also difficult to determine in dynamic marine environments where a range of natural processes and anthropogenic pressures occur.

Effectiveness of voluntary no-dig zones

Voluntary management measures to reduce the impact of bait digging activities have been implemented at the Gann Flats since 2015. This current management regime is still in place in 2020, however, observations suggest that it is not effective, with evidence showing that bait diggers are not adhering to these zones.

Overall, there is no statistically distinguishable difference in the infauna recorded either within or outside of the voluntary no-dig zones. However, the lack of differences in community structure is unsurprising given the observed lack of adherence to these zones, which is supported by the results of the epifaunal surveys (which included observations of bait digging from across the Gann Flats). The Gann Flats is a low energy environment and as such recovery is likely to take a long time, which may be a confounding factor affecting any evidence of recovery at closed sites.

In addition, due to changes in the management zones between 2015 and 2016, the original robust sample design was not as relevant which meant that sample sizes used within the analysis were small, which again limits the comparisons that can be made and ultimately the conclusions that can be derived.

The results of the epifaunal analysis indicate differences in epifaunal composition between areas that have and have not experienced recent digging. While this may indicate an impact of digging, it could also reflect the areas of sediment targeted by bait diggers and is therefore not conclusive.

7. Recommendations

The sampling strategy originally designed for Gann Flats to monitor the effectiveness of the initial voluntary management zone was modified due to a change in management regime. When combined with partial changes in sampling that accompanied this, it is clear that the resulting dataset would be of limited use to fully address many of the key questions posed in this report, especially regarding effectiveness of management.

It is recommended that to more fully understand the impacts of bait digging at Gann Flats and the effectiveness of management measures to control this activity, a robust sampling strategy is required. Monitoring will be required over the longer term, using a consistent methodology, an adequate number of samples and carefully considered sampling locations. This will be especially important if new management measures are implemented in the future at this site, as monitoring will be key to understanding and evaluating the effectiveness of these measures and help to distinguish the cause and effect of any changes that are observed in what is already a dynamic system.

As mentioned above, due to the change in management zones between 2015 and 2016, the current sample design is not statistically robust due to the small sample sizes, especially in the Open since 2015 group. It is suggested that the sample stations are more evenly distributed between treatment groups, with at least five samples per group, to get more representative data, and are only sampled from areas which would be suitable for bait digging. Additionally, increasing the duration of monitoring across all sites to get better temporal resolution, will allow a more accurate assessment of recovery within closed areas. Comparable monitoring should also be implemented at Angle Bay and Pwllcrochan, which act as control sites to monitor changes in fauna in the wider Milford Haven Waterway. The duration of any monitoring to assess the effectiveness of management measures to assess recovery would need to be long term, as recovery in unique mixed muddy gravels is likely to take a considerable time.

Furthermore, any future management actions considered at the Gann Flats will need to be designed and implemented to allow a sufficient recovery period for the desired improvements to occur. General measures that limit the duration, extent, frequency and intensity of bait digging activity are required to help to reduce detrimental impacts caused by the disturbance. To be effective these need to be underpinned by effective regulation and enforcement.

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Abbreviations

2D	Two-dimension(al)
AB	Angle Bay
AZTI	AZTI-Tecnalia
AMBI	AZTI Marine Biotic Index
ANOSIM	Analysis of Similarity
C15C16	Closed since 2015
C15O16	Closed in 2015, Closed in 2016
CCW	Countryside Council for Wales
DIVERSE	Diversity Indices Calculation Component of PRIMER
GF	Gann Flats
GIS	Geographic Information System
GPS	Global Positioning System
GRADISTAT	A grain size distribution and statistics package (Kenneth Pye Associates Ltd)
H_0	Null Hypothesis
IQI	Infaunal Quality Index
MDS	Multidimensional Scaling
MLWN	Mean Low Water Neaps
MSBAIS	Marine Species Name Check Tool
NRW	Natural Resources Wales
O15C16	Open in 2015, Closed in 2016
O15O16	Open since 2015
PCA	Principle Component Analysis
PRIMER	Plymouth Routines In Multivariate Ecological Research
PSA	Particle Size Analysis
PW	Pwllcrochan

R	R Statistics
SD	Standard Deviation
SAC	Special Area of Conservation
SIMPER	SIM- ilarity PERcentages
SIMPROF	Similarity Profile Permutation Test
SSSI	Site of Special Scientific Interest
UK	United Kingdom
WoRMS	World Register of Marine Species

Appendices

Data Truncation

Table A1: Data truncation results

Original Taxa Name	Qualifier	Name/ Qualifier Change	Final Truncation Name	Truncation Notes
Abra tenuis	N/A	N/A	*Abra tenuis*	N/A
Acrocnida brachiata	N/A	N/A	*Acrocnida brachiata*	N/A
Acromegalomma messapicum	N/A	N/A	*Acromegalomma messapicum*	N/A
Actiniaria	N/A	N/A	*Actiniaria*	N/A
Alitta virens	N/A	N/A	*Alitta virens*	N/A
Amathia	N/A	N/A	*Amathia*	N/A
Ampelisca	Fragment	Changed	*Ampelisca*	N/A
Ampelisca brevicornis	N/A	Changed	*Ampelisca*	N/A
Ampharete	N/A	N/A	*Ampharete*	N/A
Ampharete acutifrons	Sp?mid	N/A	*Ampharete acutifrons_Sp?mid*	N/A
Ampharete lindstroemi	Aggregate	N/A	*Ampharete lindstroemi_Aggregate*	N/A
Ampharete lindstroemi	N/A	Changed	*Ampharete lindstroemi_Aggregate*	N/A
Amphipholis squamata	N/A	N/A	*Amphipholis squamata*	N/A
Annelida	Fragment	N/A	*Annelida_Fragment*	Removed

Original Taxa Name	Qualifier	Name/ Qualifier Change	Final Truncation Name	Truncation Notes
Anoplodactylus	Juvenile	N/A	*Pycnogonida_Juvenile*	Incompletely developed raised to Pycnogonida (Juv)
Anoplodactylus petiolatus	N/A	N/A	*Anoplodactylus petiolatus*	N/A
Aonides oxycephala	N/A	N/A	*Aonides oxycephala*	N/A
Aonides paucibranchiata	N/A	N/A	*Aonides paucibranchiata*	N/A
Aoridae	Female	N/A	*Aoridae_Female*	Kept separate to species as females will be consistently separated and are morphologically different to males
Aphelochaeta marioni	N/A	N/A	*Aphelochaeta marioni*	N/A
Arachnida	N/A	N/A	*Arachnida*	Removed
Aricidea (Aricidea) minuta	N/A	N/A	*Aricidea (Aricidea) minuta*	N/A
Austrominius modestus	N/A	N/A	*Austrominius modestus*	N/A
Balanoidea	N/A	N/A	*Balanoidea*	N/A
Balanus crenatus	N/A	N/A	*Balanus crenatus*	N/A
Baltidrilus costatus	N/A	N/A	*Baltidrilus costatus*	N/A
Barentsia	N/A	N/A	*Barentsia*	Removed
Bivalvia	Fragment	Changed	*Bivalvia*	N/A
Bivalvia	N/A	N/A	*Bivalvia*	N/A
Campanulariidae	N/A	N/A	*Campanulariidae*	N/A
Capitella capitata	Aggregate	Changed	*Capitella_Aggregate*	Changed to genus

Original Taxa Name	Qualifier	Name/ Qualifier Change	Final Truncation Name	Truncation Notes
Carcinus maenas	N/A	Changed	*Carcinus maenas_Juvenile*	N/A
Carcinus maenas	Juvenile	N/A	*Carcinus maenas_Juvenile*	N/A
Ceramium	N/A	N/A	*Ceramium*	Removed - One lab did not record algae
Cerastoderma edule	N/A	Changed	*Cerastoderma edule_Inc Juveniles*	N/A
Cerastoderma edule	Juvenile	Changed	*Cerastoderma edule_Inc Juveniles*	N/A
Cerebratulus	N/A	N/A	*Cerebratulus*	N/A
Chaetomorpha	N/A	N/A	*Chaetomorpha*	Removed
Chaetozone gibber	N/A	N/A	*Chaetozone gibber*	N/A
Chlorophyta	N/A	N/A	*Chlorophyta*	Removed
Chlorophyta	Sp?end	N/A	*Chlorophyta*	Removed
Cirratulus	N/A	N/A	*Cirratulus*	N/A
Cirriformia tentaculata	N/A	N/A	*Cirriformia tentaculata*	N/A
Cladophora	N/A	N/A	*Cladophora*	Removed - One lab did not record algae
Copepoda	N/A	N/A	*Copepoda*	Removed
Corophiidae	Juvenile	N/A	*Corophiidae_Inc Juvenile*	N/A
Corophium	N/A	Changed	*Corophiidae_Inc Juvenile*	Raised to Corophiidae
Corophium arenarium	N/A	N/A	*Corophium arenarium*	N/A
Coryne	N/A	N/A	*Coryne*	N/A
Crangon crangon	N/A	N/A	*Crangon crangon*	N/A

Original Taxa Name	Qualifier	Name/ Qualifier Change	Final Truncation Name	Truncation Notes
Crangonidae	N/A	N/A	*Crangonidae*	N/A
Crustacea	Fragment	N/A	*Crustacea_Fragment*	Removed
Cyathura carinata	N/A	N/A	*Cyathura carinata*	N/A
Decapoda	Megalopa	N/A	*Decapoda_Megalopa*	N/A
Dexamine	Juvenile	N/A	*Dexamine_Juvenile*	N/A
Dipolydora	N/A	N/A	*Dipolydora*	N/A
Dipolydora quadrilobata	N/A	N/A	*Dipolydora*	N/A
Edwardsiidae	N/A	N/A	*Edwardsiidae*	N/A
Electra pilosa	N/A	N/A	*Electra pilosa*	N/A
Enchytraeidae	N/A	N/A	*Enchytraeidae*	N/A
Endeis spinosa	N/A	N/A	*Endeis spinosa*	N/A
Enteropneusta	N/A	N/A	*Enteropneusta*	Removed
Eteone longa	Aggregate	N/A	*Eteone longa_Aggregate*	N/A
Eteone longa	N/A	Changed	*Eteone longa_Aggregate*	N/A
Euclymene oerstedii	N/A	N/A	*Euclymene oerstedii*	N/A
Eumida	N/A	N/A	*Eumida*	N/A
Eumida sanguinea	Aggregate	Changed	*Eumida*	Raised
Eusarsiella zostericola	N/A	N/A	*Eusarsiella zostericola*	Removed
Exogone naidina	N/A	N/A	*Exogone naidina*	N/A
Fucus vesiculosus	N/A	N/A	*Fucus vesiculosus*	Removed - One lab did not record algae

Original Taxa Name	Qualifier	Name/ Qualifier Change	Final Truncation Name	Truncation Notes
Galathowenia oculata	N/A	N/A	*Galathowenia oculata*	N/A
Gammarus	Juvenile	N/A	*Gammarus_Juvenile*	N/A
Gammarus locusta	N/A	N/A	*Gammarus locusta*	N/A
Gastropoda	Fragment	Changed	*Gastropoda*	N/A
Gastropoda	N/A	N/A	*Gastropoda*	N/A
Gibbula	no shell	N/A	*Gibbula_no shell*	N/A
Glycera	N/A	N/A	*Glycera*	N/A
Glycera tridactyla	N/A	N/A	*Glycera tridactyla*	N/A
Glycinde nordmanni	N/A	N/A	*Glycinde nordmanni*	N/A
Golfingia (Golfingia) elongata	N/A	N/A	*Golfingia (Golfingia) elongata*	N/A
Harmothoe	Juvenile	Changed	*Polynoidae_Inc Juveniles*	Raised to family
Harmothoe	N/A	N/A	*Polynoidae_Inc Juveniles*	Raised to family
Hediste diversicolor	N/A	N/A	*Hediste diversicolor*	N/A
Heteromastus filiformis	N/A	N/A	*Heteromastus filiformis*	N/A
Hildenbrandiaceae	N/A	N/A	*Hildenbrandiaceae*	Removed - One lab did not record algae
Jaera	N/A	N/A	*Jaera*	N/A
Jaera (Jaera) albifrons	N/A	N/A	*Jaera (Jaera) albifrons_Aggregate*	N/A
Jaera (Jaera) forsmani	N/A	N/A	*Jaera (Jaera) forsmani*	N/A
Kurtiella bidentata	N/A	N/A	*Kurtiella bidentata*	N/A

Original Taxa Name	Qualifier	Name/ Qualifier Change	Final Truncation Name	Truncation Notes
Lagotia viridis	N/A	N/A	*Lagotia viridis*	Removed - One lab did not record algae
Lanice conchilega	N/A	N/A	*Lanice conchilega*	N/A
Lekanesphaera levii	N/A	N/A	*Lekanesphaera levii*	N/A
Lekanesphaera monodi	N/A	N/A	*Lekanesphaera monodi*	N/A
Lekanesphaera rugicauda	N/A	N/A	*Lekanesphaera rugicauda*	N/A
Lepidochitona cinerea	N/A	N/A	*Lepidochitona cinerea*	N/A
Leucothoe incisa	N/A	N/A	*Leucothoe incisa*	N/A
Leucothoe lilljeborgi	N/A	N/A	*Leucothoe lilljeborgi*	N/A
Limecola balthica	N/A	N/A	*Limecola balthica*	N/A
Littorina	Juvenile	N/A	*Littorina_Juvenile*	N/A
Littorina littorea	N/A	N/A	*Littorina littorea*	N/A
Littorina saxatilis	N/A	N/A	*Littorina saxatilis*	N/A
Lucinoma borealis	Juvenile	N/A	*Lucinoma borealis_Inc Juvenile*	N/A
Lucinoma borealis	N/A	Changed	*Lucinoma borealis_Inc Juvenile*	N/A
Lumbrineris aniara/cingulata	N/A	N/A	*Lumbrineris aniara/cingulata*	N/A
Lysidice unicornis	N/A	N/A	*Lysidice unicornis*	N/A
Magelona filiformis	N/A	N/A	*Magelona filiformis*	N/A
Malacoceros tetracerus	N/A	N/A	*Malacoceros tetracerus*	N/A
Maldanidae	N/A	N/A	*Maldanidae*	N/A
Manayunkia aestuarina	N/A	N/A	*Manayunkia aestuarina*	N/A

Original Taxa Name	Qualifier	Name/ Qualifier Change	Final Truncation Name	Truncation Notes
Mediomastus fragilis	N/A	N/A	*Mediomastus fragilis*	N/A
Melinna palmata	N/A	N/A	*Melinna palmata*	N/A
Melita palmata	N/A	N/A	*Melita palmata*	N/A
Melitidae	Juvenile	N/A	*Melitidae_Juvenile*	N/A
Microphthalmus sczelkowii	N/A	N/A	*Microphthalmus sczelkowii*	N/A
Mollusca	Fragment	N/A	*Mollusca_Fragment*	Removed
Mytilus edulis	Juvenile	N/A	*Mytilus edulis_Inc Juvenile*	N/A
Mytilus edulis	N/A	Changed	*Mytilus edulis_Inc Juvenile*	N/A
Naididae	N/A	N/A	*Naididae*	N/A
Nematoda	N/A	N/A	*Nematoda*	N/A
Nemertea	N/A	N/A	*Nemertea*	N/A
Neoamphitrite figulus	N/A	N/A	*Neoamphitrite figulus*	N/A
Nephtys	Juvenile	N/A	*Nephtys_Inc Juveniles*	N/A
Nephtys hombergii	N/A	Changed	*Nephtys_Inc Juveniles*	N/A
Nereididae	Juvenile	N/A	*Nereididae_Inc Juveniles*	N/A
Nereididae	N/A	Changed	*Nereididae_Inc Juveniles*	N/A
Nicolea venustula	N/A	N/A	*Nicolea venustula*	N/A
Notomastus	N/A	N/A	*Notomastus*	N/A
Nototropis falcatus	N/A	N/A	*Nototropis falcatus*	N/A
Odontosyllis ctenostoma	N/A	N/A	*Odontosyllis ctenostoma*	N/A

Original Taxa Name	Qualifier	Name/ Qualifier Change	Final Truncation Name	Truncation Notes
Odontosyllis gibba	N/A	N/A	*Odontosyllis gibba*	N/A
Ophiuroidea	N/A	N/A	*Ophiuroidea_Fragment*	Removed
Ostracoda	N/A	N/A	*Ostracoda*	Removed
Parapionosyllis macaronesiensis	Sp?mid	N/A	*Parapionosyllis macaronesiensis_Sp?mid*	N/A
Parexogone hebes	N/A	N/A	*Parexogone hebes*	N/A
Parvicardium exiguum	N/A	N/A	*Parvicardium exiguum*	N/A
Paucibranchia bellii	Aggregate	N/A	*Paucibranchia bellii_Aggregate*	N/A
Perinereis cultrifera	N/A	N/A	*Perinereis cultrifera*	N/A
Peringia ulvae	N/A	N/A	*Peringia ulvae*	N/A
Perioculodes longimanus	N/A	N/A	*Perioculodes longimanus*	N/A
Pholoe baltica	N/A	N/A	*Pholoe baltica*	N/A
Pholoe inornata	N/A	N/A	*Pholoe inornata*	N/A
Phoronida	N/A	N/A	*Phoronida*	N/A
Phyllodoce mucosa	N/A	N/A	*Phyllodoce mucosa*	N/A
Phyllophora	N/A	N/A	*Phyllophora*	Removed - One lab did not record algae
Platynereis dumerilii	N/A	N/A	*Platynereis dumerilii*	N/A
Polycirrus	N/A	N/A	*Polycirrus*	N/A
Polydora ciliata	Aggregate	N/A	*Polydora ciliata_Aggregate*	N/A
Polydora cornuta	N/A	N/A	*Polydora cornuta*	N/A

Original Taxa Name	Qualifier	Name/ Qualifier Change	Final Truncation Name	Truncation Notes
Polynoidae	Juvenile	N/A	*Polynoidae_Inc Juveniles*	N/A
Polysiphonia	N/A	N/A	*Polysiphonia*	Removed - One lab did not record algae
Pomatoschistus microps	N/A	N/A	*Pomatoschistus microps*	N/A
Portunidae	N/A	Changed	*Decapoda*	Larvea
Potamopyrgus antipodarum	N/A	N/A	*Potamopyrgus antipodarum*	N/A
Psamathe fusca	N/A	N/A	*Psamathe fusca*	N/A
Pseudopolydora pulchra	N/A	N/A	*Pseudopolydora pulchra*	N/A
Pygospio elegans	N/A	N/A	*Pygospio elegans*	N/A
Retusa obtusa	N/A	N/A	*Retusa obtusa*	N/A
Rhodophyta	N/A	N/A	*Rhodophyta*	Removed - One lab did not record algae
Ruditapes decussatus	N/A	N/A	*Ruditapes decussatus*	N/A
Scalibregma inflatum	N/A	N/A	*Scalibregma inflatum*	N/A
Scoloplos armiger	N/A	N/A	*Scoloplos armiger*	N/A
Spio decorata	N/A	N/A	*Spio decorata*	N/A
Spio martinensis	N/A	N/A	*Spio martinensis*	N/A
Spirobranchus lamarcki	N/A	N/A	*Spirobranchus lamarcki*	N/A
Steromphala umbilicalis		N/A	*Steromphala umbilicalis*	N/A
Sthenelais	Juvenile	N/A	*Sthenelais_Inc Juveniles*	N/A
Sthenelais boa	N/A	N/A	*Sthenelais_Inc Juveniles*	Raised to genus for consistency

Original Taxa Name	Qualifier	Name/ Qualifier Change	Final Truncation Name	Truncation Notes
Streblospio shrubsolii	N/A	N/A	*Streblospio shrubsolii*	N/A
Tanaopsis graciloides	N/A	N/A	*Tanaopsis graciloides*	N/A
Tellinoidea	Juvenile	N/A	*Tellinoidea_Inc Juvenile*	N/A
Tellinoidea	Fragment	Changed	*Tellinoidea_Inc Juvenile*	N/A
Tharyx	Species A	N/A	*Tharyx_Species A*	N/A
Tubificoides benedii	N/A	N/A	*Tubificoides benedii*	N/A
Tubificoides insularis	N/A	N/A	*Tubificoides insularis*	N/A
Tubificoides pseudogaster	Aggregate	N/A	*Tubificoides pseudogaster_Aggregate*	N/A
Tubificoides pseudogaster	N/A	Changed	*Tubificoides pseudogaster_Aggregate*	N/A
Ulva intestinalis	Aggregate	N/A	*Ulva intestinalis_Aggregate*	Removed - One lab did not record algae
Veneridae	Juvenile	N/A	*Veneridae_Inc Juvenile*	N/A
Venerupis	Juvenile	Changed	*Veneridae_Inc Juvenile*	Raised

AMBI Marine Biotic Index Species Scores

Table B1: AMBI Marine Biotic Index Species Scores

Species	AMBI Name	EG Score
Abra tenuis	*Abra tenuis* III	III
Acrocnida brachiata	*Acrocnida brachiata*	I
Acromegalomma messapicum	**Not listed**	N/A
Actiniaria	*ACTINIARIA*	I
Alitta virens	*Alitta virens*	III
Amathia	*Amathia*	I
Ampelisca	*Ampelisca*	I
Ampharete	*Ampharete*	I
Ampharete acutifrons	*Ampharete*	I
Ampharete lindstroemi	*Ampharete lindstroemi*	I
Amphipholis squamata	*Amphipholis squamata*	I
Annelida	*ANNELIDA*	N/A
Anoplodactylus petiolatus	*Anoplodactylus petiolatus*	II
Aonides oxycephala	*Aonides oxycephala*	III
Aonides paucibranchiata	*Aonides paucibranchiata*	III
Aoridae	*Aoridae*	I
Aphelochaeta marioni	*Aphelochaeta marioni*	IV
Arachnida	*ARACHNIDA*	N/A
Aricidea (Aricidea) minuta	*Aricidea minuta*	I
Austrominius modestus	*Elminius modestus*	II
Balanoidea	**Not listed**	N/A
Balanus crenatus	*Balanus crenatus*	N/A
Baltidrilus costatus	*Heterochaeta costata*	V
Barentsia	*Barentsia*	N/A
Bivalvia	**Not listed**	N/A

Species	AMBI Name	EG Score
Campanulariidae	*Campanulariidae*	I
Capitella	*Capitella*	V
Carcinus maenas	*Carcinus maenas*	III
Ceramium	*Ceramium*	N/A
Cerastoderma edule	*Cerastoderma edule*	III
Cerebratulus	*Cerebratulus*	III
Chaetomorpha	*Chaetomorpha*	N/A
Chaetozone gibber	*Chaetozone gibber*	IV
Chlorophyta	*CHLOROPHYTA*	N/A
Cirratulus	*Cirratulus*	IV
Cirriformia tentaculata	*Cirriformia tentaculata*	IV
Cladophora	*Cladophora*	N/A
Copepoda	*COPEPODA*	N/A
Corophiidae	*Corophiidae*	N/A
Corophium arenarium	*Corophium arenarium*	III
Coryne	*Coryne*	I
Crangon crangon	*Crangon crangon*	I
Crangonidae	*Crangonidae*	I
Crustacea	*CRUSTACEA*	N/A
Cyathura carinata	*Cyathura carinata*	III
Decapoda	*DECAPODA*	N/A
Dexamine	*Dexamine*	III
Dipolydora	**Not listed**	N/A
Edwardsiidae	*Edwardsiidae*	II
Electra pilosa	*Electra pilosa*	II
Enchytraeidae	*Enchytraeidae*	V
Endeis spinosa	*Endeis spinosa*	II
Enteropneusta	*ENTEROPNEUSTA*	N/A

Species	AMBI Name	EG Score
Eteone longa	*Eteone longa*	III
Euclymene oerstedii	*Euclymene oerstedii*	N/A
Eumida	*Eumida*	II
Eusarsiella zostericola	*Eusarsiella zostericola*	I
Exogone naidina	*Exogone naidina*	II
Fucus vesiculosus	*Fucus vesiculosus*	N/A
Galathowenia oculata	*Galathowenia oculata*	III
Gammarus locusta	*Gammarus locusta*	I
Gammarus	*Gammarus*	I
Gastropoda	*GASTROPODA*	N/A
Gibbula_no shell	*Gibbula*	I
Glycera	*Glycera*	II
Glycera tridactyla	*Glycera tridactyla*	II
Glycinde nordmanni	*Glycinde nordmanni*	II
Golfingia (Golfingia) elongata	*Golfingia elongata*	I
Hediste diversicolor	*Hediste diversicolor*	III
Heteromastus filiformis	*Heteromastus filiformis*	IV
Hildenbrandiaceae	*Hildenbrandia*	N/A
Jaera	*Jaera*	I
Jaera (Jaera) albifrons	*Jaera albifrons*	I
Jaera (Jaera) forsmani	*Jaera forsmani*	I
Kurtiella bidentata	*Kurtiella bidentata*	III
Lagotia viridis	*Lagotia viridis*	N/A
Lanice conchilega	*Lanice conchilega*	II
Lekanesphaera levii	*Lekanesphaera levii*	III
Lekanesphaera monodi	*Lekanesphaera*	III
Lekanesphaera rugicauda	*Lekanesphaera rugicauda*	III
Lepidochitona cinerea	*Lepidochitona cinerea*	II

Species	AMBI Name	EG Score
Leucothoe incisa	*Leucothoe incisa*	I
Leucothoe lilljeborgi	*Leucothoe lilljeborgi*	I
Limecola balthica	*Macoma balthica*	III
Littorina littorea	*Littorina littorea*	II
Littorina saxatilis	*Littorina saxatilis*	II
Littorina	*Littorina*	II
Lucinoma borealis	*Lucinoma borealis*	I
Lumbrineris aniara/cingulata	*Lumbrineris aniara*	II
Lysidice unicornis	*Nematonereis unicornis*	II
Magelona filiformis	*Magelona filiformis*	I
Malacoceros tetracerus	*Malacoceros tetracerus*	III
Maldanidae	*Maldanidae*	N/A
Manayunkia aestuarina	*Manayunkia aestuarina*	III
Mediomastus fragilis	*Mediomastus fragilis*	III
Melinna palmata	*Melinna palmata*	III
Melita palmata	*Melita palmata*	I
Melitidae	*Melitidae*	N/A
Microphthalmus sczelkowii	*Microphthalmus sczelkowii*	II
Mollusca	*MOLLUSCA*	N/A
Mytilus edulis	*Mytilus edulis*	III
Naididae	*Naididae*	V
Nematoda	*NEMATODA*	III
Nemertea	*NEMERTEA*	III
Neoamphitrite figulus	*Neoamphitrite figulus*	I
Nephtys	*Nephtys*	II
Nereididae	*Nereididae*	N/A
Nicolea venustula	*Nicolea venustula*	II
Notomastus	*Notomastus*	III

Species	AMBI Name	EG Score
Nototropis falcatus	*Atylus falcatus*	I
Odontosyllis ctenostoma	*Odontosyllis ctenostoma*	II
Odontosyllis gibba	*Odontosyllis gibba*	II
Ophiuroidea	*OPHIUROIDEA*	II
Ostracoda	*OSTRACODA*	N/A
Parapionosyllis macaronesiensis	*Parapionosyllis*	II
Parexogone hebes	*Exogone hebes*	II
Parvicardium exiguum	*Parvicardium exiguum*	I
Paucibranchia bellii	**Not listed**	N/A
Perinereis cultrifera	*Perinereis cultrifera*	III
Peringia ulvae	*Hydrobia ulvae*	III
Perioculodes longimanus	*Perioculodes longimanus*	II
Pholoe baltica	*Pholoe baltica (sensu petersen)*	IV
Pholoe inornata	*Pholoe inornata (sensu petersen)*	II
Phoronida	*PHORONIDA*	II
Phyllodoce mucosa	*Phyllodoce*	II
Phyllophora	*Phyllophora*	N/A
Platynereis dumerilii	*Platynereis dumerilii*	III
Polycirrus	*Polycirrus*	IV
Polydora ciliata	*Polydora ciliata*	IV
Polydora cornuta	*Polydora cornuta*	IV
Polynoidae	*Polynoidae*	N/A
Polysiphonia	*Polysiphonia*	N/A
Pomatoschistus microps	*Pomatoschistus microps*	N/A
Potamopyrgus antipodarum	*Potamopyrgus antipodarum*	II
Psamathe fusca	*Psamathe fusca*	III
Pseudopolydora pulchra	*Pseudopolydora pulchra*	IV
Pycnogonida	*Pycnogonida*	II

Species	AMBI Name	EG Score
Pygospio elegans	*Pygospio elegans*	III
Retusa obtusa	*Retusa obtusa*	II
Rhodophyta	*RHODOPHYTA*	N/A
Ruditapes decussatus	*Tapes decussatus*	I
Scalibregma inflatum	*Scalibregma inflatum*	III
Scoloplos armiger	*Scoloplos armiger*	III
Spio decorata	*Spio decorata*	III
Spio martinensis	*Spio martinensis*	III
Spirobranchus lamarcki	*Pomatoceros lamarcki*	II
Steromphala umbilicalis	*Gibbula umbilicalis*	I
Sthenelais	*Sthenelais*	II
Streblospio shrubsolii	*Streblospio shrubsolii*	III
Tanaopsis graciloides	*Tanaopsis graciloides*	III
Tellinoidea	**Not listed**	N/A
Tharyx_Species A	*Tharyx*	IV
Tubificoides benedii	*Tubificoides benedii*	V
Tubificoides insularis	*Tubificoides insularis*	V
Tubificoides pseudogaster	*Tubificoides pseudogaster*	V
Ulva intestinalis	*Ulva*	N/A
Veneridae	*Veneridae*	I

Results of Multivariate Analysis

ANOSIM analysis

Table C1: Results of 1-way ANOSIM test between sites and years on square-root transformed data.

Test	R Statistic	Significance (%)	Possible permutations	Actual permutations	Number ≥ observed
Global test	**0.69**	**0.1**	**Very large**	**999**	**0**

Pairwise tests:	R Statistic	Significance (%)	Possible permutations	Actual permutations	Number ≥ observed
Gann Flats 2016, Gann Flats 2015	0.591	0.1	Very large	999	0
Gann Flats 2016, Angle Bay 2016	0.635	0.1	1086008	999	0
Gann Flats 2016, Pwllcrochan 2016	0.656	0.1	1086008	999	0
Gann Flats 2016, Pwllcrochan 2015	0.811	0.2	1086008	999	1
Gann Flats 2016, Angle Bay 2015	0.781	0.1	1086008	999	0
Gann Flats 2015, Angle Bay 2016	0.929	0.1	1221759	999	0

Gann Flats 2015, Pwllcrochan 2016	0.959	0.1	1221759	999	0
Gann Flats 2015, Pwllcrochan 2015	0.889	0.1	1221759	999	0
Gann Flats 2015, Angle Bay 2015	0.952	0.1	1221759	999	0
Angle Bay 2016, Pwllcrochan 2016	0.240	0.8	126	126	1
Angle Bay 2016, Pwllcrochan 2015	0.678	0.8	126	126	1
Angle Bay 2016, Angle Bay 2015	0.800	0.8	126	126	1
Pwllcrochan 2016, Pwllcrochan 2015	0.104	20.6	126	126	24
Pwllcrochan 2016, Angle Bay 2015	0.280	0.8	126	126	1
Pwllcrochan 2015, Angle Bay 2015	0.184	6.3	126	126	8

SIMPER analysis

Table C2: Results of 1-way SIMPER analysis between years and sites using square-root transformed abundance data (per 0.01 m²) for Gann Flats

Groups Gann Flats 2016 and Gann Flats 2015 Average dissimilarity 73.53	**Mean abundance Gann Flats 2015**	**Mean abundance Gann Flats 2015**	**Mean dissimilarity**	**Diss/SD**	**Contribution %**	**Cumulative %**
Tubificoides benedii	5.27	4.83	5.32	1.37	7.24	7.24
Ampharete lindstroemi_Aggregate	0.09	3.37	4.49	1.79	6.11	13.35
Pygospio elegans	1.71	3.59	4.23	1.22	5.76	19.1
Nematoda	3.08	0.42	3.31	1.09	4.51	23.61
*Nereididae*_Inc Juvenile	0	2.13	2.94	1.35	4	27.61
*Tharyx*_Species A	1.47	1.35	2.9	0.79	3.94	31.56
Cirriformia tentaculata	1.23	1.62	2.6	1.02	3.53	35.09
Melinna palmata	2.18	2.29	2.37	1.24	3.23	38.31
*Cerastoderma edule*_Inc Juvenile	1.56	0.19	2.14	1.23	2.91	41.22
Chaetozone gibber	1.44	0.82	1.83	1.09	2.49	43.71
Polydora cornuta	1.47	0.04	1.82	0.96	2.48	46.19
Mediomastus fragilis	1.22	1.02	1.79	1.1	2.44	48.63
Capitella_Aggregate	1.58	0.27	1.72	0.85	2.33	50.96
*Gammarus*_Juvenile	1.41	0.17	1.7	0.91	2.32	53.28
Phyllodoce mucosa	1.53	0.57	1.69	1.32	2.3	55.58
Tubificoides pseudogaster_Aggregate	1.64	0.05	1.66	0.71	2.26	57.84
Copepoda	1.14	0	1.47	1.02	2	59.84
Ampharete acutifrons_sp?mid	0.99	0	1.28	1.1	1.75	61.59
Notomastus	0.64	0.99	1.12	1.09	1.53	63.11
Heteromastus filiformis	0.87	0.05	1.1	0.65	1.5	64.62
Aphelochaeta marioni	0.85	0.27	1.06	0.58	1.45	66.06

Groups Gann Flats 2016 and Gann Flats 2015 Average dissimilarity 73.53	Mean abundance Gann Flats 2015	Mean abundance Gann Flats 2015	Mean dissimilarity	Diss/SD	Contribution %	Cumulative %
Scoloplos armiger	0.8	0.51	1.05	1.08	1.43	67.49
Glycera tridactyla	0.67	0.8	1.05	1.07	1.43	68.93
Eteone longa_Aggregate	0.39	0.61	0.96	0.91	1.31	70.23

Table C3: Results of 1-way SIMPER analysis between years and sites -using square-root transformed abundance data (per 0.01 m²) for Gann Flats

Groups Gann Flats and Angle Bay Average dissimilarity 79.94	Mean abundance Gann Flats	Mean abundance Angle Bay	Mean Dissimilarity	Diss/SD	Contribution %	Cumulative %
Tubificoides benedii	5.05	0	8.99	1.53	11.25	11.25
Pygospio elegans	2.66	1.26	5.01	1.1	6.27	17.52
Ampharete lindstroemi_Aggregate	1.75	0	4.13	0.88	5.17	22.69
Cirriformia tentaculata	1.43	0	3.09	0.75	3.86	26.55
*Nereididae_*Inc Juvenile	1.08	0.1	2.79	0.79	3.48	30.03
*Nephtys_*Inc Juvenile	0.26	1.34	2.75	1.41	3.44	33.48
Tharyx_Species A	1.41	0	2.55	0.56	3.2	36.67
Peringia ulvae	0.18	1.78	2.44	0.41	3.05	39.73
Melinna palmata	2.24	2.62	2.44	1.13	3.05	42.78
Foraminifera	0	1.68	2.3	0.77	2.88	45.66
Nematoda	1.73	0	2.16	0.77	2.7	48.36
Chaetozone gibber	1.12	1.44	2.02	1.23	2.52	50.88
Mediomastus fragilis	1.12	0	2.01	0.83	2.51	53.39
Euclymene oerstedii	0.04	0.92	1.86	0.84	2.33	55.72
Notomastus	0.82	1.12	1.79	1.16	2.24	57.96
Phyllodoce mucosa	1.04	0.34	1.64	1.07	2.05	60.01

Groups Gann Flats and Angle Bay Average dissimilarity 79.94	Mean abundance Gann Flats	Mean abundance Angle Bay	Mean Dissimilarity	Diss/SD	Contribution %	Cumulative %
Leucothoe incisa	0.12	0.82	1.42	1.07	1.78	61.78
Glycera tridactyla	0.74	0	1.42	0.93	1.77	63.56
Scoloplos armiger	0.65	0.57	1.3	1.05	1.63	65.18
*Cerastoderma edule*_Inc Juvenile	0.87	1.13	1.22	0.84	1.53	66.71
Capitella_Aggregate	0.92	0	1.14	0.64	1.43	68.14
Eteone longa_Aggregate	0.5	0	1.1	0.71	1.38	69.52
*Gammarus*_Juvenile	0.78	0	1.02	0.62	1.28	70.8

Groups Gann Flats and Pwllcrochan Average dissimilarity 65.71	Mean abundance Gann Flats	Mean abundance Pwllcrochan	Mean dissimilarity	Diss/SD	Contribution %	Cumulative %
Tubificoides benedii	5.05	0.1	8.07	1.55	10.17	10.17
Pygospio elegans	2.66	0.1	4.41	1	5.55	15.72
Austrominius modestus	0.04	2.08	3.19	0.54	4.02	19.75
Cirriformia tentaculata	1.43	0.2	2.8	0.8	3.53	23.28
Melinna palmata	2.24	2.5	2.65	1.22	3.34	26.62
Ampharete lindstroemi_Aggregate	1.75	0.83	2.39	0.73	3.02	29.64
*Tharyx*_Species A	1.41	0	2.38	0.57	3	32.64
*Nephtys*_Inc Juvenile	0.26	1.24	2.26	1.12	2.85	35.49
*Nereididae*_Inc Juvenile	1.08	0	2.19	0.72	2.76	38.25
Nematoda	1.73	0.32	2.11	0.76	2.66	40.91
Kirkegaardia dorsobranchialis	0	1.58	2.05	0.58	2.59	43.49
Chaetozone gibber	1.12	1.53	1.99	1.32	2.5	46
Mediomastus fragilis	1.12	0.35	1.88	0.91	2.37	48.37
Lanice conchilega	0.03	1.05	1.76	0.99	2.22	50.59

Groups Gann Flats and Pwllcrochan Average dissimilarity 65.71	Mean abundance Gann Flats	Mean abundance Pwllcrochan	Mean dissimilarity	Diss/SD	Contribution %	Cumulative %
Euclymene oerstedii	0.04	0.92	1.63	0.65	2.06	52.65
Phyllodoce mucosa	1.04	0.1	1.61	1.02	2.03	54.68
Notomastus	0.82	0.72	1.44	1.08	1.81	56.49
Scoloplos armiger	0.65	0.47	1.33	0.94	1.67	58.17
Peringia ulvae	0.18	0.78	1.31	0.53	1.65	59.82
Glycera tridactyla	0.74	0.1	1.28	0.98	1.62	61.43
*Cerastoderma edule*_Inc Juvenile	0.87	0.57	1.18	0.82	1.49	62.93
*Tubificoides pseudogaster*_*Aggregate*	0.83	0.32	1.17	0.6	1.48	64.4
*Capitella*_*Aggregate*	0.92	0	1.14	0.62	1.44	65.84
*Gammarus*_Juvenile	0.78	0	1.05	0.61	1.33	67.17
*Eteone longa*_*Aggregate*	0.5	0.3	1.03	0.8	1.3	68.47
Polydora cornuta	0.74	0	1	0.57	1.26	69.73
Lumbrineris aniara/cingulata	0.09	0.56	0.99	0.76	1.24	70.97

Groups Angle Bay and Pwllcrochan Average dissimilarity 79.31	**Mean abundance Angle Bay**	**Mean abundance Pwllcrochan**	**Mean dissimilarity**	**Diss/SD**	**Contribution %**	**Cumulative %**
Austrominius modestus	0.42	2.08	4.46	0.62	6.78	6.78
Peringia ulvae	1.78	0.78	3.98	0.53	6.05	12.84
Euclymene oerstedii	0.92	0.92	3.19	0.87	4.85	17.68
Chaetozone gibber	1.44	1.53	3.14	1.55	4.78	22.46
Ampharete lindstroemi_Aggregate	0	0.83	2.8	0.6	4.26	26.72
Foraminifera	1.68	0.1	2.79	0.77	4.25	30.97
Kirkegaardia dorsobranchialis	0	1.58	2.72	0.6	4.15	35.11
Lanice conchilega	0.3	1.05	2.57	1.22	3.92	39.03
Pygospio elegans	1.26	0.1	2.54	1.22	3.86	42.89
Melinna palmata	2.62	2.5	2.3	1.11	3.49	46.38
Notomastus	1.12	0.72	2.14	1.16	3.25	49.64
*Nephtys*_Inc Juvenile	1.34	1.24	1.88	1.25	2.87	52.51
Leucothoe incisa	0.82	0	1.84	1.04	2.81	55.31
*Cerastoderma edule*_Inc Juvenile	1.13	0.57	1.83	0.93	2.78	58.1
Scoloplos armiger	0.57	0.47	1.74	0.81	2.65	60.75
Lumbrineris aniara/cingulata	0	0.56	1.37	0.69	2.09	62.84
Kurtiella bidentata	0.1	0.61	1.37	0.65	2.09	64.92

Groups Angle Bay and Pwllcrochan Average dissimilarity 79.31	**Mean Abundance Angle Bay**	**Mean Abundance Pwllcrochan**	**Mean dissimilarity**	**Diss/SD**	**Contribution%**	**Cumulative**
Galathowenia oculata	0.44	0.2	1.07	0.7	1.62	66.55
Bivalvia	0.1	0.2	0.87	0.51	1.33	67.87
Ampharete acutifrons	0.34	0.5	0.85	0.64	1.29	69.17
Phyllodoce mucosa	0.34	0.1	0.85	0.56	1.29	70.46

Table C4: Results of 1-way SIMPER analysis over time between Gann Flats in 2015 (A), Gann Flats in 2016 (B), Angle Bay and Pwllcrochan in 2015 (C) and Angle Bay and Pwllcrochan in 2016 (D), and a comparison between the four groups (E), -using square-root transformed abundance data (per 0.01 m²).

A. Gann Flats 2015 Average Similarity 46.91	Mean abundance	Mean similarity	Sim/SD	Contribution (%)	Cumulative (%)
Tubificoides benedii	4.83	9.93	1.57	21.18	21.18
Ampharete lindstroemi_Aggregate	3.37	7.61	2.04	16.21	37.39
Pygospio elegans	3.59	6.41	1.35	13.67	51.07
Melinna palmata	2.29	5.15	1.35	10.99	62.06
Nereididae_Inc Juvenile	2.13	4.28	1.37	9.12	71.18

B. Gann Flats 2016 Average Similarity 34.54	Mean abundance	Mean similarity	Sim/SD	Contribution (%)	Cumulative (%)
Tubificoides benedii	5.27	6.05	1.18	17.53	17.53
Melinna palmata	2.18	3.29	0.92	9.52	27.05
Phyllodoce mucosa	1.53	2.48	1.32	7.19	34.23
Cerastoderma edule_Inc Juvenile	1.56	2.48	1.06	7.18	41.42
Nematoda	3.08	2.23	0.76	6.45	47.86
Chaetozone gibber	1.44	1.97	0.80	5.70	53.56
Polydora cornuta	1.47	1.17	0.62	3.38	56.94
Copepoda	1.14	1.06	0.67	3.07	60.00
Ampharete acutifrons_sp?mid	0.99	1.06	0.76	3.06	63.07
Gammarus_Juvenile	1.41	1.05	0.63	3.05	66.12
Pygospio elegans	1.71	1.04	0.72	3.00	69.12
Cirriformia tentaculata	1.23	0.90	0.42	2.62	71.74

C. Angle Bay & Pwllcrochan 2015 Average Similarity 38.47	Mean abundance	Mean similarity	Sim/SD	Contribution (%)	Cumulative (%)
Melinna palmata	2.39	14.33	1.64	37.24	37.24
Nephtys_Inc Juvenile	1.59	10.00	1.64	26.00	63.24
Chaetozone gibber	1.06	3.28	0.89	8.51	71.75

D. Angle Bay & Pwllcrochan 2016 Average Similarity 35.41	Mean abundance	Mean similarity	Sim/SD	Contribution (%)	Cumulative (%)
Melinna palmata	2.73	9.27	2.46	26.19	26.19
Chaetozone gibber	1.92	5.17	1.51	14.59	40.78
Cerastoderma edule_Inc Juvenile	1.46	3.47	1.09	9.80	50.58
Notomastus	1.23	3.08	1.14	8.70	59.28
Foraminifera	1.78	2.08	0.59	5.87	65.15
Pygospio elegans	1.16	1.99	0.67	5.62	70.78

E. Gann Flats 2015 and Gann Flats 2016 Average dissimilarity 73.53	Mean abundance Gann Flats 2016	Mean abundance Gann Flats 2015	Mean Dissimilarity	Diss/SD	Contribution %	Cumulative %
Tubificoides benedii	5.27	4.83	5.32	1.37	7.24	7.24
Ampharete lindstroemi_Aggregate	0.09	3.37	4.49	1.79	6.11	13.35
Pygospio elegans	1.71	3.59	4.23	1.22	5.76	19.10
Nematoda	3.08	0.42	3.31	1.09	4.51	23.61
Nereididae_Inc Juvenile	0.00	2.13	2.94	1.35	4.00	27.61
Tharyx_Species A	1.47	1.35	2.90	0.79	3.94	31.56
Cirriformia tentaculata	1.23	1.62	2.60	1.02	3.53	35.09
Melinna palmata	2.18	2.29	2.37	1.24	3.23	38.31
Cerastoderma edule_Inc Juvenile	1.56	0.19	2.14	1.23	2.91	41.22
Chaetozone gibber	1.44	0.82	1.83	1.09	2.49	43.71

E. Gann Flats 2015 and Gann Flats 2016 Average dissimilarity 73.53	Mean abundance Gann Flats 2016	Mean abundance Gann Flats 2015	Mean Dissimilarity	Diss/SD	Contribution %	Cumulative %
Polydora cornuta	1.47	0.04	1.82	0.96	2.48	46.19
Mediomastus fragilis	1.22	1.02	1.79	1.10	2.44	48.63
Capitella_Aggregate	1.58	0.27	1.72	0.85	2.33	50.96
Gammarus_Juvenile	1.41	0.17	1.70	0.91	2.32	53.28
Phyllodoce mucosa	1.53	0.57	1.69	1.32	2.30	55.58
Tubificoides pseudogaster_Aggregate	1.64	0.05	1.66	0.71	2.26	57.84
Copepoda	1.14	0.00	1.47	1.02	2.00	59.84
Ampharete acutifrons_sp?mid	0.99	0.00	1.28	1.10	1.75	61.59
Notomastus	0.64	0.99	1.12	1.09	1.53	63.11
Heteromastus filiformis	0.87	0.05	1.10	0.65	1.50	64.62
Aphelochaeta marioni	0.85	0.27	1.06	0.58	1.45	66.06
Scoloplos armiger	0.80	0.51	1.05	1.08	1.43	67.49
Glycera tridactyla	0.67	0.80	1.05	1.07	1.43	68.93
Eteone longa_Aggregate	0.39	0.61	0.96	0.91	1.31	70.23

Gann Flats 2016 and Angle Bay & Pwllcrochan 2016 Average dissimilarity 78.70	Mean abundance Gann Flats 2016	Mean abundance AB & PW 2016	Mean dissimilarity	Diss/SD	Contribution %	Cumulative %
Tubificoides benedii	5.27	0.00	6.72	1.51	8.53	8.53
Peringia ulvae	0.36	2.46	3.56	0.59	4.52	13.05
Nematoda	3.08	0.32	3.45	1.08	4.39	17.44
Austrominius modestus	0.09	1.84	2.72	0.51	3.46	20.90
Foraminifera	0.00	1.78	2.52	0.87	3.20	24.09
Pygospio elegans	1.71	1.16	2.22	1.03	2.82	26.92
Melinna palmata	2.18	2.73	2.17	1.30	2.76	29.68

Gann Flats 2016 and Angle Bay & Pwllcrochan 2016 Average dissimilarity 78.70	Mean abundance Gann Flats 2016	Mean abundance AB & PW 2016	Mean dissimilarity	Diss/SD	Contribution %	Cumulative %
Tharyx_Species A	1.47	0.00	2.05	0.62	2.60	32.28
Phyllodoce mucosa	1.53	0.30	1.93	1.39	2.45	34.74
Polydora cornuta	1.47	0.00	1.89	0.95	2.41	37.14
Chaetozone gibber	1.44	1.92	1.88	1.33	2.39	39.54
Cirriformia tentaculata	1.23	0.20	1.84	0.77	2.34	41.88
Gammarus_Juvenile	1.41	0.00	1.78	0.89	2.26	44.14
Tubificoides pseudogaster_Aggregate	1.64	0.22	1.78	0.74	2.26	46.40
Capitella_Aggregate	1.58	0.00	1.75	0.80	2.22	48.63
Cerastoderma edule_Inc Juvenile	1.56	1.46	1.62	1.12	2.06	50.68
Mediomastus fragilis	1.22	0.17	1.55	0.91	1.97	52.65
Copepoda	1.14	0.10	1.52	1.02	1.93	54.58
Notomastus	0.64	1.23	1.36	1.15	1.73	56.31
Ampharete acutifrons_sp?mid	0.99	0.84	1.33	1.09	1.70	58.01
Nephtys_Inc Juvenile	0.45	0.98	1.29	1.13	1.64	59.64
Lanice conchilega	0.05	0.77	1.20	0.79	1.53	61.17
Scoloplos armiger	0.80	0.37	1.12	1.02	1.42	62.59
Heteromastus filiformis	0.87	0.00	1.11	0.63	1.41	64.01
Exogone naidina	0.13	0.69	1.10	0.93	1.40	65.40
Galathowenia oculata	0.39	0.54	1.07	0.83	1.35	66.76
Kirkegaardia dorsobranchialis	0.00	0.98	0.98	0.33	1.25	68.00
Aphelochaeta marioni	0.85	0.00	0.87	0.50	1.11	69.11
Glycera tridactyla	0.67	0.10	0.86	0.94	1.10	70.21

Gann Flats 2015 and Angle Bay & Pwllcrochan 2016 Average dissimilarity 81.08	Mean abundance Gann Flats 2015	Mean abundance AB & PW 2016	Mean dissimilarity	Diss/SD	Contribution %	Cumulative %
Tubificoides benedii	4.83	0.00	8.24	1.70	10.16	10.16
Ampharete lindstroemi_Aggregate	3.37	0.00	5.78	2.05	7.13	17.28
Pygospio elegans	3.59	1.16	4.74	1.27	5.84	23.13
Peringia ulvae	0.00	2.46	4.28	0.59	5.27	28.40
Nereididae_Inc Juvenile	2.13	0.10	3.54	1.38	4.36	32.76
Austrominius modestus	0.00	1.84	3.20	0.51	3.95	36.72
Cirriformia tentaculata	1.62	0.20	3.05	0.89	3.77	40.48
Foraminifera	0.00	1.78	3.01	0.91	3.72	44.20
Cerastoderma edule_Inc Juvenile	0.19	1.46	2.52	1.39	3.11	47.31
Chaetozone gibber	0.82	1.92	2.48	1.36	3.06	50.37
Tharyx_Species A	1.35	0.00	2.27	0.55	2.80	53.17
Melinna palmata	2.29	2.73	2.14	1.03	2.64	55.81
Mediomastus fragilis	1.02	0.17	1.80	0.89	2.22	58.03
Nephtys_Inc Juvenile	0.09	0.98	1.70	1.24	2.10	60.13
Lanice conchilega	0.00	0.77	1.47	0.81	1.81	61.94
Ampharete acutifrons_sp?mid	0.00	0.84	1.41	0.98	1.74	63.68
Notomastus	0.99	1.23	1.41	1.20	1.73	65.41
Glycera tridactyla	0.80	0.10	1.38	1.09	1.70	67.11
Exogone naidina	0.03	0.69	1.31	0.95	1.61	68.73
Eteone longa_Aggregate	0.61	0.10	1.13	0.89	1.39	70.12

Gann Flats 2016 and Angle Bay & Pwllcrochan 2015 Average dissimilarity 84.34	Mean abundance Gann Flats 2016	Mean abundance AB & PW 2015	Mean dissimilarity	Diss/SD	Contribution %	Cumulative %
Tubificoides benedii	5.27	0.10	8.03	1.53	9.52	9.52
Nematoda	3.08	0.00	4.19	1.09	4.97	14.50
Melinna palmata	2.18	2.39	2.81	1.35	3.33	17.82
Cerastoderma edule_Inc Juvenile	1.56	0.24	2.75	1.14	3.26	21.08
Phyllodoce mucosa	1.53	0.14	2.57	1.49	3.05	24.13
Tharyx_Species A	1.47	0.00	2.52	0.62	2.99	27.13
Nephtys_Inc Juvenile	0.45	1.59	2.34	1.46	2.78	29.91
Polydora cornuta	1.47	0.00	2.31	0.96	2.74	32.64
Chaetozone gibber	1.44	1.06	2.28	1.10	2.71	35.35
Cirriformia tentaculata	1.23	0.00	2.23	0.74	2.64	37.99
Gammarus_Juvenile	1.41	0.00	2.16	0.90	2.56	40.55
Pygospio elegans	1.71	0.20	2.16	0.85	2.56	43.11
Euclymene oerstedii	0.06	1.20	2.15	0.91	2.55	45.66
Capitella_Aggregate	1.58	0.00	2.08	0.82	2.46	48.12
Tubificoides pseudogaster_Aggregate	1.64	0.10	2.02	0.74	2.40	50.52
Mediomastus fragilis	1.22	0.17	1.89	0.93	2.24	52.76
Copepoda	1.14	0.00	1.87	1.02	2.22	54.98
Ampharete acutifrons_sp?mid	0.99	0.00	1.63	1.09	1.94	56.92
Ampharete lindstroemi_Aggregate	0.09	0.83	1.45	0.63	1.72	58.64
Scoloplos armiger	0.80	0.67	1.41	1.06	1.67	60.31
Heteromastus filiformis	0.87	0.00	1.35	0.63	1.60	61.90
Notomastus	0.64	0.61	1.31	0.99	1.55	63.45
Austrominius modestus	0.09	0.66	1.08	0.37	1.29	64.74
Lanice conchilega	0.05	0.59	1.04	0.75	1.24	65.98
Glycera tridactyla	0.67	0.00	1.04	0.92	1.23	67.21
Aphelochaeta marioni	0.85	0.00	1.01	0.51	1.20	68.41
Mytilus edulis_Inc Juvenile	0.46	0.10	0.89	0.66	1.06	69.47

Gann Flats 2016 and Angle Bay & Pwllcrochan 2015 Average dissimilarity 84.34	Mean abundance Gann Flats 2016	Mean abundance AB & PW 2015	Mean dissimilarity	Diss/SD	Contribution %	Cumulative %
Tellinoidea_no shell	0.43	0.00	0.89	0.59	1.05	70.52

Gann Flats 2015 and Angle Bay & Pwllcrochan 2015 Average dissimilarity 80.53	Mean abundance Gann Flats 2015	Mean abundance AB & PW 2015	Mean dissimilarity	Diss/SD	Contribution %	Cumulative %
Tubificoides benedii	4.83	0.10	10.30	1.73	12.79	12.79
Pygospio elegans	3.59	0.20	7.13	1.47	8.86	21.64
Ampharete lindstroemi_Aggregate	3.37	0.83	6.31	1.64	7.83	29.48
Nereididae_Inc Juvenile	2.13	0.00	4.74	1.42	5.89	35.37
Cirriformia tentaculata	1.62	0.00	4.01	0.87	4.98	40.35
Nephtys_Inc Juvenile	0.09	1.59	3.69	1.90	4.59	44.94
Melinna palmata	2.29	2.39	2.90	1.17	3.61	48.55
Tharyx_Species A	1.35	0.00	2.87	0.55	3.57	52.11
Euclymene oerstedii	0.03	1.20	2.64	0.96	3.28	55.39
Mediomastus fragilis	1.02	0.17	2.33	0.89	2.89	58.29
Chaetozone gibber	0.82	1.06	2.12	1.24	2.63	60.91
Notomastus	0.99	0.61	1.86	1.14	2.31	63.22
Glycera tridactyla	0.80	0.00	1.82	1.11	2.26	65.49
Scoloplos armiger	0.51	0.67	1.50	1.00	1.86	67.35
Eteone longa_Aggregate	0.61	0.20	1.47	0.90	1.82	69.18
Phyllodoce mucosa	0.57	0.14	1.33	0.80	1.65	70.82

Angle Bay & Pwllcrochan 2016 and Angle Bay & Pwllcrochan 2015 Average dissimilarity 71.16	Mean abundance Gann Flats 2015	Mean abundance AB & PW 2015	Mean dissimilarity	Diss/SD	Contribution %	Cumulative %
Peringia ulvae	2.46	0.10	5.76	0.60	8.09	8.09
Austrominius modestus	1.84	0.66	5.09	0.61	7.16	15.25
Foraminifera	1.78	0.00	4.07	0.94	5.72	20.97
Cerastoderma edule_Inc Juvenile	1.46	0.24	3.43	1.35	4.82	25.79
Chaetozone gibber	1.92	1.06	3.13	1.27	4.40	30.20
Euclymene oerstedii	0.64	1.20	3.04	1.03	4.27	34.47
Pygospio elegans	1.16	0.20	2.82	1.07	3.96	38.42
Nephtys_Inc Juvenile	0.98	1.59	2.35	1.17	3.31	41.73
Kirkegaardia dorsobranchialis	0.98	0.60	2.34	0.54	3.29	45.02
Notomastus	1.23	0.61	2.33	1.23	3.27	48.30
Lanice conchilega	0.77	0.59	2.24	0.99	3.15	51.45
Melinna palmata	2.73	2.39	2.13	1.18	2.99	54.44
Ampharete acutifrons_sp?mid	0.84	0.00	1.91	0.95	2.68	57.13
Exogone naidina	0.69	0.00	1.86	0.96	2.62	59.75
Ampharete lindstroemi_Aggregate	0.00	0.83	1.82	0.60	2.56	62.30
Scoloplos armiger	0.37	0.67	1.74	1.00	2.44	64.75
Leucothoe incisa	0.58	0.24	1.49	0.87	2.09	66.84
Galathowenia oculata	0.54	0.10	1.40	0.78	1.97	68.81
Kurtiella bidentata	0.28	0.42	1.20	0.69	1.69	70.51

Table C5: Results of 1-way SIMPER analysis over time between epifaunal data at Gann Flats in 2015 (A) and 2017 (B), and a comparison between the two years (C), using square-root transformed abundance data.

A. Gann Flats 2015 Average Similarity 43.15	**Mean abundance**	**Mean similarity**	**Sim/SD**	**Contribution (%)**	**Cumulative (%)**
Ulva_tubular	6.40	25.16	1.38	58.29	58.29
Lanice	4.62	6.30	0.62	14.59	72.89

B. Gann Flats 2017 Average Similarity 38.59	**Mean abundance**	**Mean similarity**	**Sim/SD**	**Contribution (%)**	**Cumulative (%)**
Rhodophyta	4.96	14.74	1.50	38.19	38.19
Ulva_tubular	3.20	9.66	1.06	25.03	63.23
Lanice	3.05	3.69	0.49	9.56	72.78

C. Gann Flats 2015 and Gann Flats 2017 Average dissimilarity 65.89	**Mean abundance Gann Flats 2015**	**Mean abundance Gann Flats 2017**	**Mean Dissimilarity**	**Diss/SD**	**Contribution %**	**Cumulative %**
Ulva_tubular	6.40	3.20	13.32	1.18	20.21	20.21
Lanice	4.62	3.05	12.12	1.06	18.40	38.61
Rhodophyta	2.68	4.96	11.13	1.27	16.89	55.50
Fucus	1.66	1.19	6.20	0.76	9.42	64.91
Sabella	1.21	1.86	4.94	0.82	7.50	72.41

Table C6: Results of 1-way SIMPER analysis between SIMPROF Groupings following analysis of management zones at the Gann Flats, using square-root transformed infaunal abundance data (per 0.01 m²) for Gann Flats 2016.

Groups SIMPROF A and B Gann 2016 management zone Average dissimilarity 84.75	**Mean abundance SIMPROF A**	**Mean abundance SIMPROF B**	**Mean dissimilarity**	**Diss/SD**	**Contribution %**	**Cumulative %**
Tubificoides benedii	5.66	0.50	7.14	2.74	12.11	12.11
Nematoda	3.39	0.00	4.83	8.36	8.19	20.29
Melinna palmata	2.10	4.00	2.69	2.19	4.56	24.85
Capitella_Aggregate	1.56	0.00	2.30	2.61	3.89	28.75
*Tharyx*_Species A	1.31	0.00	2.03	1.30	3.45	32.20
*Tellinoidea*_Inc Juvenile	0.40	1.71	1.95	2.90	3.32	35.51
Mediomastus fragilis	1.36	0.00	1.83	1.47	3.10	38.61
Cirriformia tentaculata	1.32	0.00	1.79	1.55	3.03	41.64
Pygospio elegans	1.69	0.50	1.71	2.60	2.91	44.55
*Gammarus*_Juvenile	1.58	0.50	1.61	1.26	2.73	47.28
*Cerastoderma edule*_Inc Juveniles	1.41	2.55	1.59	4.05	2.71	49.98
Tubificoides pseudogaster_Aggregate	1.68	0.50	1.58	1.18	2.69	52.67
*Nephtys*_Inc Juveniles	0.37	1.37	1.46	5.85	2.47	55.14
Heteromastus filiformis	0.93	0.00	1.45	1.35	2.46	57.60
*Mytilus edulis*_Inc Juvenile	0.43	1.41	1.43	3.47	2.43	60.03
Aphelochaeta marioni	1.07	0.00	1.38	1.02	2.34	62.37
Polydora cornuta	1.37	0.50	1.34	1.57	2.28	64.65
Chaetozone gibber	1.46	0.87	0.83	3.35	1.40	66.05
Melita palmata	0.67	0.50	0.78	1.53	1.32	67.37

Particle Size Analysis

Table D1: PSA results for data collected during 2015 and 2016 at Gann Flats, Angle Bay and Pwllcrochan

Station	Year	>8 mm	4-8 mm	2-4 mm	1-2 mm	500-999 um	250-499 um	125-249 um	63-125 um	< 63 um	Sediment Folk Classification
Gann 1.1	2015	10.51	7.82	8.99	6.1	0.9	7.91	13.73	10.16	33.9	Gravelly Muddy Sand
Gann 1.2	2015	20.17	5.9	6.72	3.66	0.93	6.98	21.4	14.32	19.96	Muddy Sandy Gravel
Gann 1.3	2015	3.58	5.91	11.03	9.41	3.17	11.51	33.9	17.49	3.97	Gravelly Sand
Gann 1.4	2015	8.37	5.24	6.71	4.09	1.78	11.87	38.9	18.79	4.28	Gravelly Sand
Gann 1.5	2015	17.07	7.85	7.49	5.26	2.82	9.69	27.7	15.61	6.45	Sandy Gravel
Gann 2.1	2015	39.77	8.67	9.01	4.54	0.87	3.37	5.6	5.87	22.32	Muddy Gravel
Gann 2.2	2015	10.66	5.87	4.21	1.95	2.37	9.97	29.5	20.55	14.91	Gravelly Muddy Sand
Gann 2.3	2015	25.2	8.65	8.66	4.61	4.24	14.16	19.49	7.42	7.55	Muddy Sandy Gravel
Gann 2.4	2015	34.26	10.26	8.32	3.55	1.24	8.71	22.7	9.24	1.82	Sandy Gravel
Gann 2.5	2015	23.9	8.1	8.86	5.37	4.2	13.85	14.65	5.97	15.13	Muddy Sandy Gravel
Gann 3.1	2015	17.88	6.95	6.45	4.82	3.15	8.03	17.45	14.94	20.33	Muddy Sandy Gravel
Gann 3.2	2015	24.52	9.51	7.27	4.35	3.21	8.94	13.09	10.3	18.83	Muddy Sandy Gravel
Gann 3.3	2015	16.33	5.13	5.44	3.52	2.2	7.81	17.09	15.74	26.75	Gravelly Muddy Sand
Gann 3.4	2015	17.68	12.24	8.77	4.91	0.85	6.57	10.58	8.49	29.92	Muddy Sandy Gravel
Gann 3.5	2015	11.71	3.91	5.71	3.64	0.62	6.76	11.57	11.19	44.9	Gravelly Mud

Station	Year	>8 mm	4-8 mm	2-4 mm	1-2 mm	500-999 um	250-499 um	125-249 um	63-125 um	< 63 um	Sediment Folk Classification
Gann 4.1	2015	8.63	15.3	12.1	5.43	0.48	4.61	12.08	11.56	29.8	Muddy Sandy Gravel
Gann 4.2	2015	13.99	11.17	10.28	4.37	0.87	7.23	18.49	13.76	19.83	Muddy Sandy Gravel
Gann 4.3	2015	22.58	10.71	10.74	5.47	1.07	4.5	14.4	11.29	19.26	Muddy Sandy Gravel
Gann 4.4	2015	17.34	3.96	9.42	5.71	3.24	8.53	17.4	13.43	21.01	Muddy Sandy Gravel
Gann 4.5	2015	6.52	8.5	13.62	7.07	1.24	8.21	13.04	10.74	31.04	Gravelly Muddy Sand
Gann 5.1	2015	18.34	13.41	13.49	8.85	0.45	2.09	2.46	3.68	37.22	Muddy Gravel
Gann 5.2	2015	55.06	14.3	10.39	6.69	3.95	4.15	2.04	0.74	2.69	Muddy Sandy Gravel
Gann 5.3	2015	26.01	15.02	14.24	10.1	7	13.89	9.67	2.13	1.94	Sandy Gravel
Gann 5.4	2015	22.35	11.39	12.95	7.7	5.67	17.21	16	3.29	3.4	Sandy Gravel
Gann 5.5	2015	51.12	12.61	10.1	6.83	2.38	5.16	4.93	2.18	4.72	Muddy Sandy Gravel
Gann 6.1	2015	12.34	5.7	7.93	5	0.1	4.78	10.39	10.76	42.99	Gravelly Mud
Gann 6.2	2015	40.79	7.02	6.64	3.61	0.12	3.46	12.12	9.66	16.62	Muddy Sandy Gravel
Gann 6.3	2015	9.88	4.77	6.17	4.61	1.48	5.34	19.02	19.25	29.45	Gravelly Muddy Sand
Gann 6.4	2015	10.05	6.68	8.05	6.93	1.9	7.81	12.25	12.06	34.24	Gravelly Muddy Sand
Gann 6.5	2015	25.99	7.17	7.91	5.92	1.49	6.38	9.88	7.55	27.7	Muddy Sandy Gravel
Gann 7.1	2015	13.74	6.68	8.21	4.95	2.37	7.77	19.61	13.03	23.66	Gravelly Muddy Sand
Gann 7.2	2015	10.21	6.64	6.39	4	1.2	10.22	44	16.17	1.14	Gravelly Sand

Station	Year	>8 mm	4-8 mm	2-4 mm	1-2 mm	500-999 um	250-499 um	125-249 um	63-125 um	< 63 um	Sediment Folk Classification
Gann 7.3	2015	10.92	8.72	10.34	6.59	5.64	12.46	30.3	13.58	1.51	Gravelly Sand
Gann 7.4	2015	20.85	8.97	10.62	5.71	0.08	1.2	4.14	8.16	40.22	Muddy Gravel
Gann 7.5	2015	9.35	6.21	6.62	4.03	1.25	9.46	35.7	19.12	8.21	Gravelly Muddy Sand
Gann 8.1	2015	20.95	8.61	6.37	4.84	0.51	5.41	14.78	15.61	22.92	Muddy Sandy Gravel
Gann 8.2	2015	10	8.73	9.03	6.18	1.72	5.33	9.45	11.85	37.7	Gravelly Mud
Gann 8.3	2015	16.79	8.7	7.07	4.24	0.99	5.65	14.83	12.21	29.54	Muddy Sandy Gravel
Gann 8.4	2015	13.29	5.35	6.64	5.44	4.16	8.39	15.73	12.61	28.37	Gravelly Muddy Sand
Gann 8.5	2015	12.17	7.15	8.07	4.11	2.22	5.79	11	14.75	34.73	Gravelly Muddy Sand
Gann 1	2016	4.58	4.96	4.44	4.90	5.74	12.36	36.43	10.41	16.18	Gravelly Muddy Sand
Gann 2	2016	10.17	14.89	16.85	10.71	9.58	12.27	14.37	4.67	6.49	Muddy Sandy Gravel
Gann 3	2016	2.37	6.25	5.60	4.04	5.04	11.52	27.26	12.63	25.29	Gravelly Muddy Sand
Gann 4	2016	0	6.24	4.45	3.37	2.94	4.09	16.37	11.04	51.50	Gravelly Mud
Gann 5	2016	15.93	8.80	11.26	13.11	13.02	14.85	15.02	2.38	5.65	Sandy Gravel
Gann 6	2016	4.30	9.88	7.39	4.05	3.06	3.77	17.20	21.84	28.51	Gravelly Muddy Sand
Gann 7	2016	12.65	3.79	4.58	3.83	3.22	5.75	17.24	19.08	29.85	Gravelly Muddy Sand
Gann 8	2016	4.13	7.73	4.83	3.39	2.71	4.53	41.42	11.15	20.11	Gravelly Muddy Sand
Angel Bay	2016	0	0	0.02	0.04	0.10	9.84	57.63	10.19	22.18	Slightly Gravelly Muddy Sand

Station	Year	>8 mm	4-8 mm	2-4 mm	1-2 mm	500-999 um	250-499 um	125-249 um	63-125 um	< 63 um	Sediment Folk Classification
Pwllcrochan	2016	1.84	0.77	1.78	1.83	1.39	7.20	13.20	26.03	45.96	Slightly Gravelly Muddy Sand

Data Archive Appendix

No data outputs were produced as part of this project.

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