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# JNCC/Cefas Partnership Report Series

*Report No. 11*

## Dogger Bank SCI 2014 Monitoring R&D Survey Report

Eggleton, J., Murray, J., McIlwaine, P., Mason, C., Noble-James, T., Hinchen, H., Nelson, M., McBreen, F., Ware, S. & Whomersley, P.

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ISSN 2051-6711

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ISSN 2051-6711

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**This report should be cited as:**

Eggleton, J., Murray, J., McIlwaine, P., Mason, C., Noble-James, T., Hinchen, H., Nelson, M., McBreen, F., Ware, S. & Whomersley, P. 2016. Dogger Bank SCI 2014 Monitoring R&D Survey Report. *JNCC/Cefas Partnership Report*, **No. 11**.

This report is compliant with the JNCC Evidence Quality Assurance Policy http://jncc.defra.gov.uk/default.aspx?page=6675 and has been both internally and externally reviewed.

**Acknowledgements**

The authors would like to thank Dr Ingrid Kröncke, from the Senckenberg Research Institute, who provided data to enable a study of long-term trends at historical sampling stations at Dogger Bank.

The authors would also like to thank Forewind for providing data in advance of the survey, which were incorporated into the power analyses.

# Summary

This study was carried out jointly by Cefas and JNCC under an overarching marine monitoring strategy in which monitoring options, within the context of fisheries management measures at the Dogger Bank Site of Community Importance (SCI), were investigated. The Dogger Bank SCI comprises the largest expanse of shallow sandbanks in UK waters; ranging depth from 20–60m below chart datum, and represents more than 70% of the UK Annex I sandbank resource. It is located in the Southern North Sea, approximately 150km north-east of the Humber estuary and is comprised of sands and discrete areas of coarser sediments. The Dogger Bank is a geological feature and therefore differs from other UK sandbank features that are formed by hydrological processes and, as such, represents a variation of typical offshore Annex I sandbanks. The Dogger Bank feature was formed by glacial processes prior to submersion through sea level rise and extends across international maritime boundaries. Separate SCIs have been designated in the Netherlands and Germany to incorporate the entire feature. Proposed fisheries management zones, currently for consideration under the common fisheries policy (CFP), were jointly submitted by the UK, the Netherlands and Germany and aim to regulate fisheries for the protection of the Habitats Directive Annex I habitat type 'sandbanks which are slightly covered by sea water all the time'.

A survey was conducted within the Dogger Back SCI, on the *Research Vessel Cefas Endeavour* in the spring of 2014, employing fauna and sediment sampling and seabed imagery methods with stations located for use in one or all of the survey objectives.

The aims of this study included three types of monitoring objectives:

1. **Sentinel Monitoring (Type 1)** involved assessing the current spatial and temporal variability in benthic communities and sediment characteristics of the Dogger Bank SCI to enable any directional trends to be better understood within the context of natural variability. An additional aim, given the multinational interests of the SCI, was to understand how the choice of sediment sampling gear affects the various metrics applied to infer conservation status or ecological condition of the feature. A subset of stations, surveyed in the 1980s and/or 1990s with a Van Veen grab, were revisited with two sediment sampling gears (Mini Hamon and Van Veen grabs) to enable 1) a temporal comparison of faunal communities and 2) an investigation into how gear selection affects the derived metrics.

**Null hypothesis 1:**

*Benthic communities and sediment characteristics of the Dogger Bank SCI do not change over time.*

2. **Operational Monitoring (Type 2)** involved measuring the current state of benthic communities and sediment characteristics and relating observations to an abrasion pressure gradient. Abrasion pressure was calculated using data on fishing activity obtained from Vessel Monitoring Systems (VMS). VMS data were aggregated and gridded at 0.05 decimal degrees (dd). Ten areas representing five pressure levels, comprising two spatial replicates of each, were sampled to determine sediment characteristics and benthic community composition.

**Null Hypothesis 2:**

*Benthic communities and sediment characteristics of the Dogger Bank SCI, subject to varying levels of abrasion pressure, do not differ.*

3. **Investigative Monitoring (Type 3)** involved assessing the benthic communities and sediment characteristics within and outside four proposed management areas as part of a longer term manipulative study into the response of benthic habitats to the cessation of bottom trawling. This survey is limited to the provision of data collected at the 'Before' (management) stage of the 'Before-After-Control-Impact' (BACI) experimental design employed.

**Null Hypothesis 3:**

*At T0, benthic communities and sediment characteristics do not differ between control and impact stations located within/out with the proposed fishery management areas.*

All three monitoring strategies complement each other and provide datasets against which future monitoring data may be compared to explore spatial and temporal change, and potentially infer causality of changes where they are observed (e.g. in relation to changes in spatial and temporal distribution of given pressures).

Findings of the current study support historical observations that sediments and biological communities are both spatially and temporally variable across the Dogger Bank SCI. Therefore, in order to understand the effects of physical disturbance on benthic habitats, attributable to demersal trawling, it is vital to consider the wider ecosystem of the Dogger Bank SCI in the context of the prevailing, natural environmental regime. Additionally, the provenance of any historic data must be clearly understood to ensure that it is used and interpreted appropriately in combination with newly acquired data and evidence.

Changes in community composition along the perceived gradient of increasing abrasion pressure were not detected from the univariate metrics or multivariate analyses. This may be due to a number of factors, including:

1) the method used to calculate the pressure gradient may not be sufficiently spatially and/or temporally resolute to capture the direct effects of the trawling activity;
2) additional pressure on the benthic habitats of Dogger Bank attributable to trawling may be within the envelope of natural, prevailing physical disturbance;
3) status of benthic habitats across the study area may be equally impoverished as a result of sustained historical fishing activity; or
4) there is no relationship in a mobile sedimentary habitat between the abrasion pressure and the benthic metrics used in this study.

The current study also included an experimental BACI element to allow the efficacy of future management measures to be assessed in terms of maintaining and/or recovering the habitat features to favourable condition. Results of the 'Before' element of the data analysis indicated high levels of variability occur across the Control and Impact treatments of the four management areas proposed for the UK sector of the SCI, reflecting the dynamic nature of the study site. Therefore, it is suggested that these relatively high levels of variability observed across the SCI, in combination with patterns in the distribution of fishing activities and other offshore developments (offshore windfarms, oil and gas and telecommunication installatons), should be considered in informing the prioritisation and design of future monitoring campaigns (e.g. direct assessment of condition vs pressure based monitoring).

The outputs of this study have resulted in a number of recommendations relating to the application of the monitoring approaches explored, both in the context of the Dogger Bank Annex I sandbank feature, and also in the context of wider sentinel monitoring as part of an integrated, ecosystem based approach. These recommendations are summarised below.

Further development is required in relation to:

1) the methods applied for assessing and illustrating spatial and temporal distribution of pressures and gradients in their intensity; and

2) the selection of both responsive and ecologically meaningful measures/indicators which effectively describe the conservation status or condition of a given feature.

In turn, operational testing of the indicators selected will allow thresholds of acceptable change to be identified in the context of natural variability, across the full range of prevailing conditions relevant to the feature of interest. In adopting such an approach, the result will be an improved understanding of conservation status and efficacy of management at comparable sites and features that maximises scientific advances whilst at the same time achieves optimal efficiencies.

In conclusion, it is recommended that, where possible, monitoring strategies employed across the MPA network should ensure that results from feature/site specific operational and/or investigative monitoring can be put in context of sentinel monitoring of the wider marine environment. This will require a concerted effort to be made in the short-medium term to coordinate and integrate current and future monitoring activities to provide a more ecosystem based approach to monitoring going forward. This, in turn, will ensure that available survey and reporting budgets are spent in the most effective and efficient manner to allow common goals, across the full suite of relevant policy objectives, to be adequately met.

# Contents

# 1 Introduction

## 1.1 Project Background

UK Governments have a requirement to monitor biodiversity across UK waters in order to fulfil their national and international obligations for marine biodiversity assessment and management. To address this, the UK Marine Biodiversity Monitoring R&D Programme (UK MBMP), a partnership between the Statutory Nature Conservation Bodies (SNCBs) including the Joint Nature Conservation Committee (JNCC) and the UK Marine Monitoring and Assessment Strategy (UKMMAS) community, was formed to develop options for an integrated monitoring scheme for all marine biodiversity across all UK waters. The overall aim of this scheme is to collect the evidence necessary to fulfil marine biodiversity obligations and provide timely and effective advice for marine management (for more information on UK's marine biodiversity obligations see Hinchen 2014). The sheer scale and potential cost of monitoring all biodiversity across UK waters necessitated the development of an overarching strategy to ensure that monitoring is prioritised effectively and robust monitoring data are collected using standardised approaches (Kröger & Johnston 2016).

The overarching strategy recognised that monitoring can be carried out to fulfil two broad objectives: firstly, to identify the need for management measures; and secondly to identify whether management measures have been effective (Kröger & Johnston 2016). Once the broad objectives have been clarified then monitoring approaches can be developed to address the specific requirements of the area in question. The strategy categorised monitoring approaches into three 'types of monitoring' which are described below (Kröger & Johnston 2016). It should be noted that at this stage in the development of the UK MBMP, these approaches are used to detect change, but do not aim to assess current condition against established thresholds or targets. As such, the current focus of monitoring activities is to begin to develop robust indicators, investigate relationships, and establish datasets against which future data may be compared to identify whether a change has occurred.

**Sentinel Monitoring (Type 1):** provides the context to distinguish directional, long-term trends from local and/or short-term variability. To achieve this objective efficiently, a long-term commitment to regular and consistent data collection is necessary; this means time-series must be established as their power in identifying trends is far superior to any combination of independent studies. To accurately interpret Type 1 data, precise information on the distribution and intensity of anthropogenic pressures is also required in the context of natural prevailing conditions.

**Operational Monitoring (Type 2):** is intended to measure the state of a given feature and relate observed changes to possible causes. This objective compliments longer term trend monitoring and is best suited to exploring the likely impacts of pressures on habitats and species and the identification of emerging problems. It leads to the setting of hypotheses which relate processes to the underlying, observed patterns. It also relies on determining relationships between changes in biodiversity and variability in pressures in the context of the prevailing environmental regime. It provides inference but is not proof of cause and effect.

**Investigative Monitoring (Type 3):** is intended to investigate the cause of observed change. It complements Type 1 and Type 2 monitoring by testing specific hypotheses through targeted manipulative studies.

Sampling strategies and methods for seabed habitat surveys, both within and outside Marine Protected Areas (MPAs), are under development as part of the UK MBMP. In 2014, two case study monitoring surveys were undertaken to test the developing monitoring concepts, sampling designs, monitoring methods and metrics/indicators for detecting meaningful change. These monitoring R&D surveys visited the Fladen Grounds Nature Conservation MPA (NCMPA) and the Dogger Bank Site of Community Importance (SCI). Whilst there will clearly be site and feature specific requirements for monitoring (to detect change in the range, extent and condition of different habitat types and conservation features subject to impact by different human pressures) the overarching concepts that underpin the purpose and approach to undertaking effective monitoring will be similar across all habitat types. This R&D report, therefore, forms part of the evidence base for the development of monitoring options for benthic habitats as part of the UK MBMP.

This report describes the findings of a dedicated survey which was carried out between 17$^{th}$ May and 6$^{th}$ June 2014 on the *RV Cefas Endeavour* (cruise CEND 10/14) to collect evidence to support the development of monitoring options specifically for the Dogger Bank SCI and, more generally, for other comparable offshore shallow sand and coarse sediment habitats.

## 1.2 Overview of Dogger Bank SCI

The Dogger Bank SCI comprises the largest single continuous expanse of shallow sandbank in UK waters. It is located in the southern North Sea, approximately 150km north east of the Humber Estuary, and was formed by glacial processes before being submerged through sea level rise. Water depth across the feature ranges from 20m at its shallowest extent, sloping down to a maximum depth of 60m. The bank extends across international maritime boundaries, and therefore separate SCIs have been designated to incorporate the entire feature which extends into Dutch and German waters (Figure 1).

Annex I sandbank habitats occur widely in both inshore and offshore UK waters. At the UK scale, sediments associated with sandbank features are classified within the EUNIS level 3 categories: ‘sublittoral coarse sediment’ (A5.1); ‘sublittoral sand’ (A5.2); ‘sublittoral mixed sediments’ (A5.4); and ‘sublittoral macrophyte dominated sediment’ (A5.5), which include various constituent biotope complexes (Robson, 2014). The exposed location of the Dogger Bank prevents colonisation of the sediments by vegetation and therefore, the constituent biotopes of A5.5, namely ‘maerl beds’ (A5.51) and ‘sublittoral seagrass beds’ (A5.53), are not present.

The Dogger Bank differs to other UK sandbank features in that it derives from geological glacial processes as opposed to being formed by hydrological processes (Diesing *et al* 2009). In this respect, Dogger Bank is representative of a different sub-type of the typical offshore Annex I sandbank feature (e.g. North Norfolk Sandbanks and Saturn Reef, Inner Dowsing, Race Bank and North Ridge SCI and Haisborough, Hammond and Winterton SCI) and, given that it comprises more than 70% of the UK Annex I sandbank resource, is particularly important in terms of its contribution as part of an ecologically coherent network of MPAs (JNCC 2013).

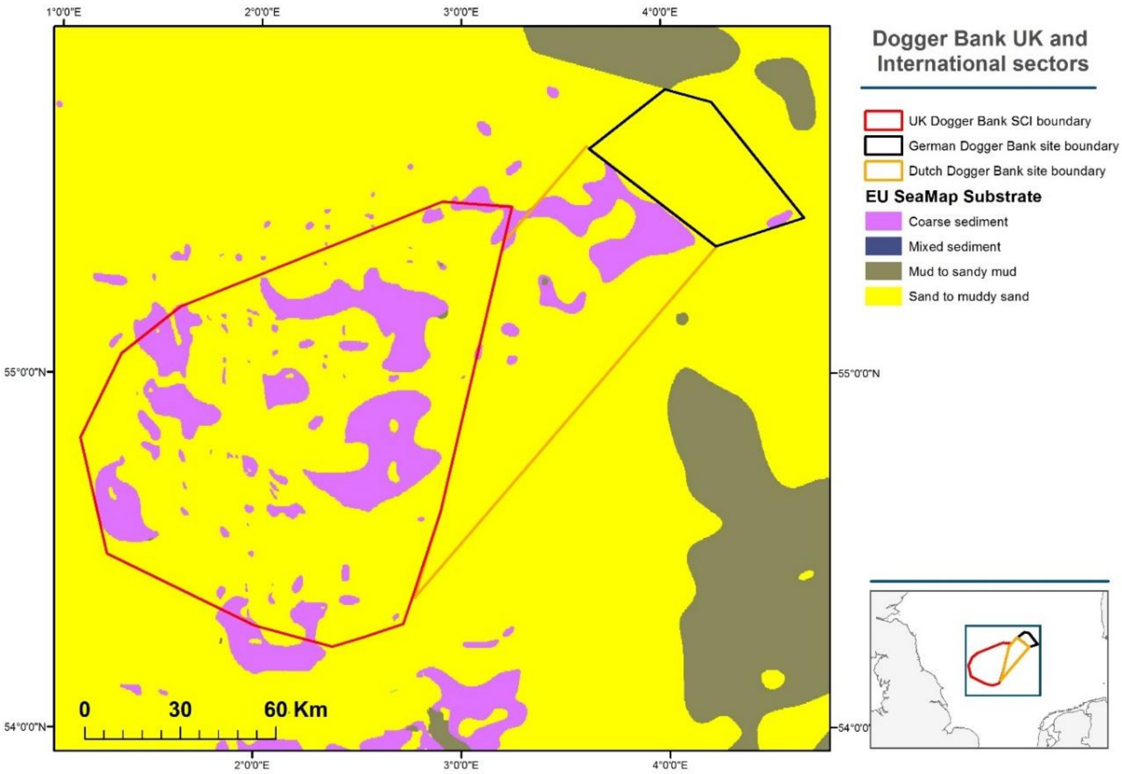



**Figure 1.** Location of the UK and international sectors of the Dogger Bank SCI.

Sediments across the Dogger Bank and within the SCI range from shallow fine sands containing many shell fragments, to muddy sands at greater water depths, (Kröncke & Knust 1995). The sedimentary habitats present across the bank are characterised by faunal communities which are considered to be typical of temperate sandbank features. These include both errant and sessile polychaetes, amphipods and bivalves, with typical motile benthic fauna comprising a variety of hermit crabs, flatfish, starfish and brittlestars (Wieking & Kröncke 2001). Sand eels are an important prey resource found at varying densities on the bank (Diesing *et al* 2009), and their population has been shown to support a range of fish, seabirds and cetaceans; in particular, the harbour porpoise *Phocoena phocoena* (Cefas 2007). Occasional, discrete areas of coarser sediments (comprising cobbles and pebbles) have been recorded within the SCI. These localised patches of coarse sediment have been shown to be dominated by the soft coral *Alcyonium digitatum*, the bryozoan *Alcyonidium diaphanum* and serpulid worms (Diesing *et al* 2009).

A number of factors have been identified which influence the spatial and temporal variability in benthic communities on the Dogger Bank. These include natural variables such as water depth, sediment type, climate variability, hydrographic regime, temperature and supply of organic matter (Kröncke 1990; Kröncke & Rachor 1992; Wieking & Kröncke 2001; Reiss & Kröncke 2005). In addition, there are also a number of historical anthropogenic influences, including commercial fishing activities, which have also been shown to affect both the structural and functional characteristics of the benthic communities found in association with the Dogger Bank feature (Kröncke 1990; Kröncke & Rachor 1992; Wieking & Kröncke 2001).

### 1.2.1 Rationale for site designation

In 2011, the Dogger Bank site was submitted to the European Commission (EC), due to the presence of the Annex I habitat H1110 ‘Sandbanks which are slightly covered by sea water all the time’. The site was approved as a SCI in 2012 with the UK Dogger Bank SCI constituting the majority of the delineated international sandbank area, containing 66% of the feature and the remaining 9% and 25% located in German and Dutch waters respectively.

The Dogger Bank SCI was delineated based on an analysis of physical and biological attributes (Figure 1), with reference to the Habitats Directive Annex I H1110 habitat definition (EC 2013). A slope analysis was conducted for the wider Dogger Bank area using the methodology described by Klein (2006), where a sandbank is defined by the change in slope from the bank to the surrounding plains. From this analysis, a clear delineation of the morphological bank feature was evident on the south and western edges, although the northern edge of the bank was indistinct (Cefas 2008). Sub-bottom profiles collected across the bank were used to confirm the delineation of the formation and to improve accuracy (Diesing *et al* 2009).

While ‘Sandbanks slightly covered by seawater all the time’ are typically associated with water depths of <20m below chart datum, characteristic sandbank assemblages have also been observed to extend below this depth (EC 2013). Infaunal and epifaunal data, acquired by JNCC and Cefas in 2008 (Diesing *et al* 2009), were analysed to verify the extent of the sandbank feature from an ecological perspective, with reference to the infaunal communities previously described by Wieking and Kröncke (2003). The composition of macrofaunal communities have been observed to gradually change across the bank with the main bank feature characterised by fauna typically associated with sandy and coarse sediments. The deeper slope area in the northern portion of the site was found to be characterised by assemblages more typical of muddy sediments (Diesing *et al* 2009). The spatial distribution of sand eel populations within the site was also taken into consideration in locating the site boundary. As such, the site boundary was defined to include the shallow biological communities associated with the delineated bank feature whilst excluding adjacent linear banks present to the north-west and south-west, which were not considered to be representative of the Annex I sandbank feature.

### 1.2.2 Known human activities at Dogger Bank[3]

Existing evidence suggests that the Dogger Bank Annex I sandbank feature and the associated biological communities are vulnerable to the following pressures (i.e. the designated features are both coincident with, and perceived to be sensitive to, a number of pressure categories) (JNCC 2012):

- physical damage through physical disturbance or abrasion (mobile demersal fishing) at a moderate level;
- biological disturbance through selective extraction of species (mobile demersal fishing) at a moderate level;
- physical loss through obstruction (oil and gas industry infrastructure, wrecks and cables) at moderate levels and through removal (infrastructure development) and smothering (oil and gas drill cuttings) at low levels;
- non-toxic contamination through changes in turbidity (cable laying) at low levels.

However, the main pressure at the Dogger Bank SCI was identified as physical abrasion of the seabed resulting from mobile demersal fishing activities (JNCC 2012). The Dogger Bank area is regularly fished by a number of UK, Dutch and Danish vessels which predominantly target plaice and sand eels using mobile bottom trawling gear (primarily beam, otter and Nephrops trawls) (JNCC 2012). Demersal fishing may result in physical damage to the seabed, and is not currently subject to prior authorisation or licensing. These activities are, therefore, considered to pose a high risk of damage to the designated feature (JNCC 2012).

[3] Activities information correct as of November 2015.

Physical damage to the seabed as the result of abrasion is listed in Table 2 of Annex III of the Marine Strategy Framework Directive (MSFD) as shown in Table 1 below**.**

**Table 1.** Extract from the OSPAR Intersessional Correspondence Group on Cumulative Effects (ICG-C) pressure list and descriptions (amended 25th March 2011).

| **OSPAR ICG-C** | | | **MSFD Annex III table 2** |
|---|---|---|---|
| **Pressure theme** | **Pressure** | **Code** | **Pressure** |
| Physical damage (Reversible Change) | Penetration and/or disturbance of the substratum below the surface of the seabed, including abrasion | D2 | Abrasion (e.g. impact on the seabed of commercial fishing, boating, anchoring) |

The JNCC have produced a recommended method for the creation of a standard UK-wide geo-data layer showing the intensity of abrasion on substrata caused by fishing activities, focusing on the area beyond 12 nautical miles (nm) from the coast (Church *et al* 2016). It is intended that this method and the parameters used (fishing gear types and associated trawl widths and speeds), might be adopted as common approaches in the future. It should be emphasised here that the spatial distribution of abrasion pressure derived using this method does not necessarily translate into a perceived footprint of direct impact on the habitat features and associated species present. Subsurface abrasion pressure (2006-2013) within the UK sector of the Dogger Bank SCI is presented in Figure 2. This figure shows the changes in the spatial distribution of abrasion pressure over time, for the years where data were available. Please see Church *et al* (2016) for a detailed description of the production of the surface and subsurface physical abrasion data layers. Subsurface abrasion (hereafter referred to as abrasion) is presented as a swept-area ratio which is an estimation of the area of seabed impacted by fishing gear within a grid cell, divided by the area of that cell to produce a comparative swept-area ratio score.

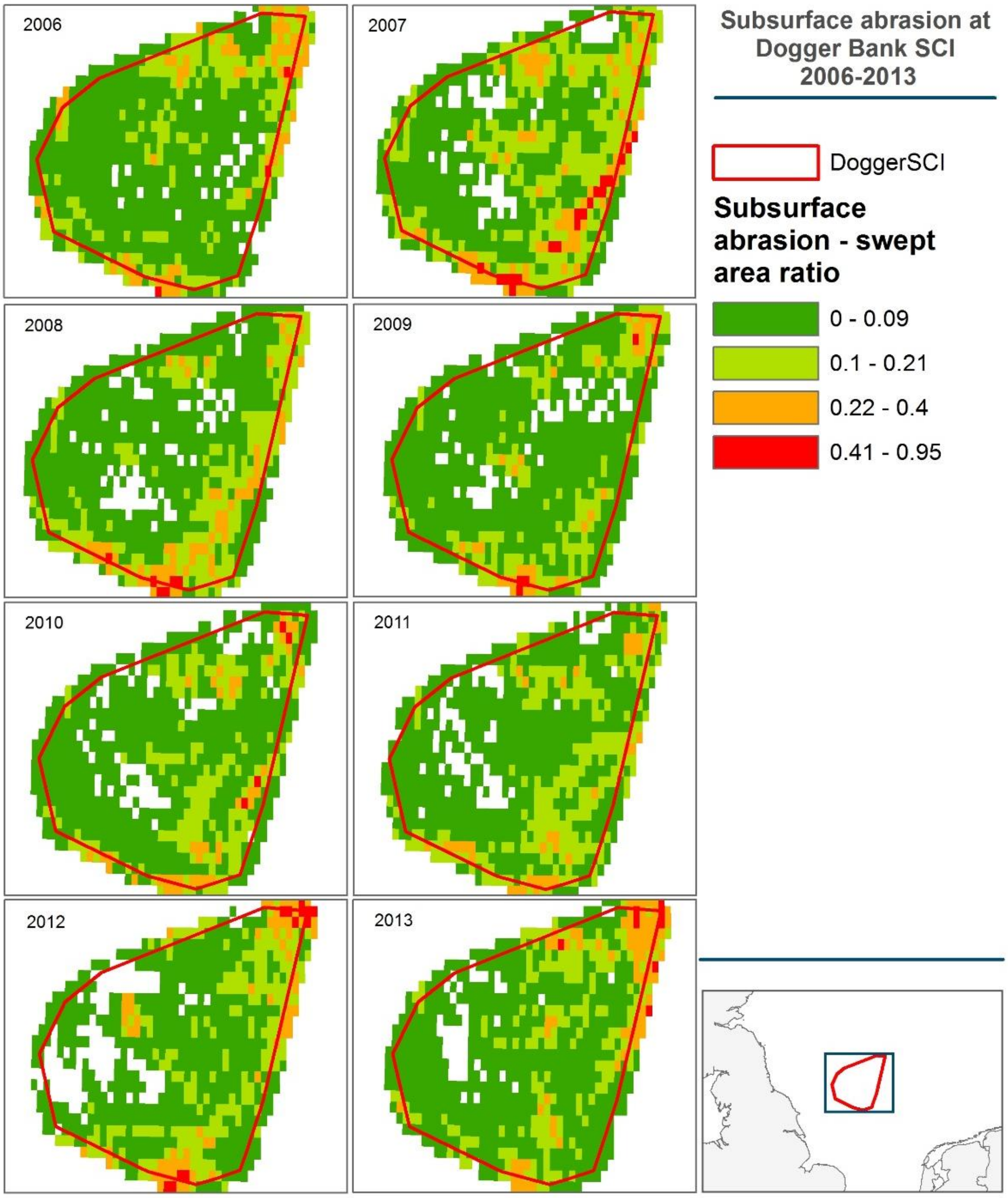



**Figure 2.** Subsurface abrasion pressure (swept area ratio) within the UK sector of the Dogger Bank SCI 2006-2013. Abrasion scores are from the UK-wide layer (Church *et al* 2016), however the categories were determined on the local scale of the Dogger Bank SCI.

The site contains a number of oil and gas developments including many fields, pipelines, wells and associated infrastructure. Four telecommunication cables also run through the site (Figure 3).

In addition, four offshore wind farms have been granted consent by the Secretary of State for development within the site (i.e. Creyke Beck A & B and Teesside A & B), each with a capacity of up to 1.2GW (Figure 3). These wind farms will individually comprise up to 200 wind turbines (depending on the size of turbines selected), offshore substations, export cables, onshore converter stations and associated infrastructure. N.B. None of the offshore windfarms had been granted consent when the current survey was designed.

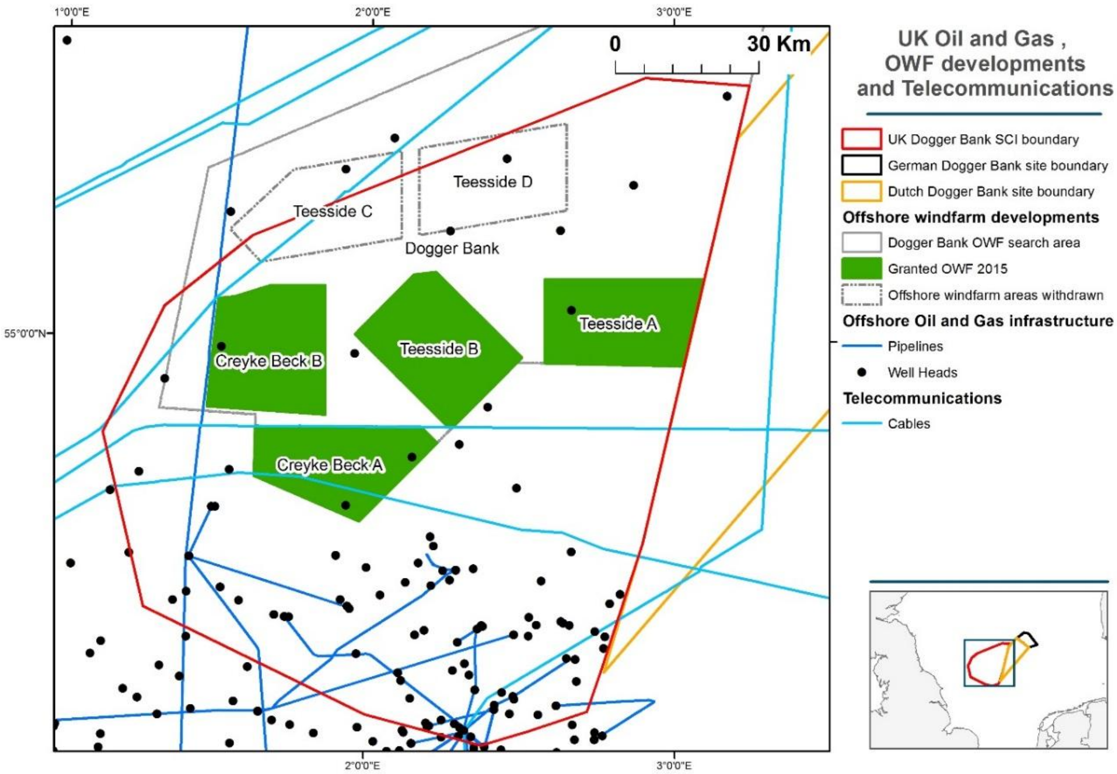



**Figure 3**. UK Oil and Gas infrastructure, offshore windfarm development areas and telecommunications cables within the Dogger Bank SCI.

### 1.2.3 Conservation Objectives

A number of long-term, historical studies conducted within the Dogger Bank site have indicated that an increase in demersal fishing effort may have resulted in modified benthic assemblages (Kröncke 2011). Kröncke (2011) compared macrofaunal data from the 1920s, 1950s, 1980s and 2000s, concluding that opportunistic species have increased whilst aggregations of the bivalves *Spisula* and *Mactra* (a key food resource for plaice) have largely disappeared. On the basis of the existing evidence, the current condition of the Annex I sandbank feature, for which the SCI was designated, is considered to be unfavourable. Therefore, the Conservation Objective proposed for the UK Dogger Bank SCI is to restore the Annex I ‘Sandbanks which are slightly covered by seawater all the time’ to favourable condition (JNCC 2012), such that:

- the natural environmental quality is maintained;
- the natural environmental processes are maintained;
- the physical structure, diversity, community structure and typical species, representative of sandbanks which are slightly covered by seawater all the time, in the Southern North Sea, are restored.

Restoration to ‘favourable condition’ will require assessment and management of activities likely to impact the natural environmental quality and environmental processes upon which the feature is dependent.

### 1.2.4 Management proposals within the site

EC Guidance (2012), concerning the trans-boundary location of the Dogger Bank feature, stated that ‘effective conservation of its benthic communities can best be achieved through the holistic view of the entire sandbank, through cooperation of the Member States concerned’. This coordination is achieved through the Dogger Bank Steering Group (DBSG), which has facilitated collaboration between Member States, and provided a forum for engagement with stakeholders. The group has produced a fisheries management proposal based on input from Member States, the fishing industry and conservation Non-Governmental Organisations (NGOs). The DBSG works to:

1) ensure a shared understanding of the conservation objectives in terms of the requirements of the Habitats Directive; and
2) identify appropriate common indicators designed to assess the effects of the fisheries closures on the sandbank habitat and its benthic communities.

In 2013 the UK, Germany and the Netherlands jointly submitted a proposal to the EC for four fisheries management zones within the UK Dogger Bank SCI based on proposals from the fishing industry, the NGO community and ICES advice, for consideration under the Common Fisheries Policy (CFP) (Figure 4). These aim to regulate fisheries in the SCI for the protection of the Habitats Directive Annex I habitat type 'sandbanks which are slightly covered by sea water all the time'.

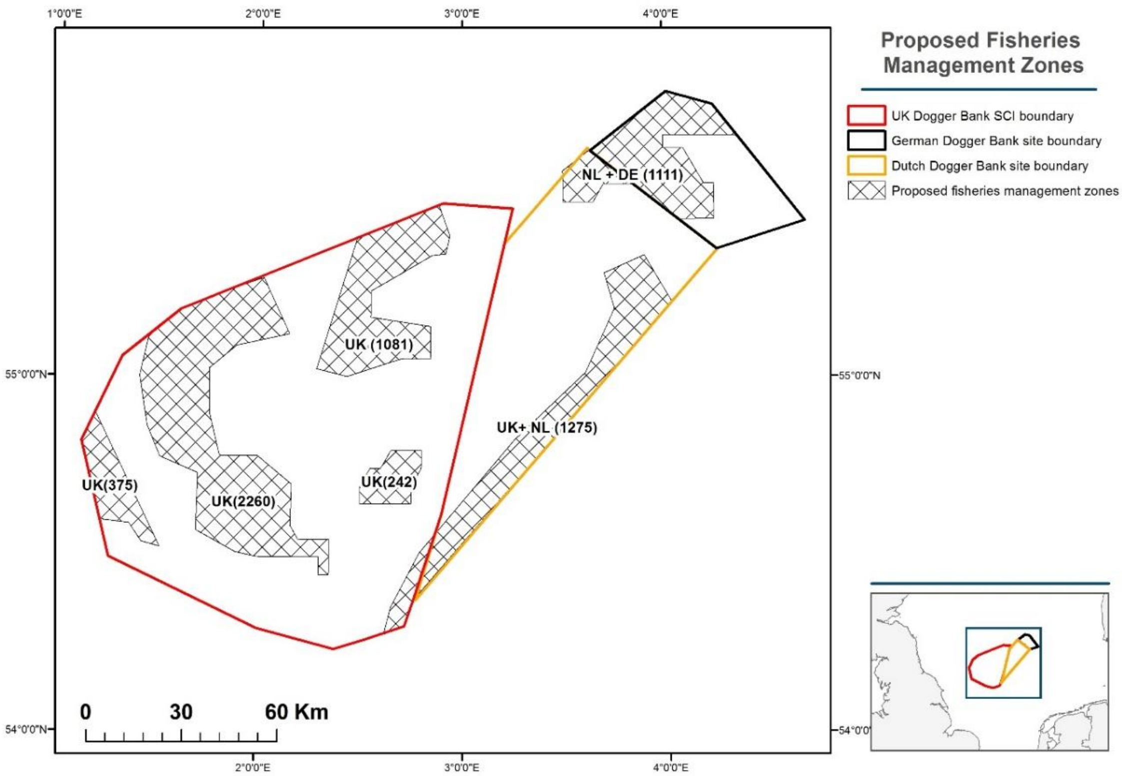



**Figure 4**. Proposed fisheries management zones for the Dogger Bank SCI (2014).

## 1.3 Survey aims and objectives

There have been several relevant surveys of the Dogger Bank in recent years. In April 2008, JNCC and Cefas conducted a characterisation survey to acquire data to support the recommendation of Dogger Bank to the EC as a Special Area of Conservation (SAC). This characterisation survey incorporated acoustic multibeam echosounder (MBES) data collection, seabed imagery and sediment sampling. A number of surveys have also been conducted in support of applications by Forewind (a consortium of four international energy companies) to develop offshore wind farms within the Dogger Bank area. These included extensive oceanographic and ecological survey work encompassing habitat mapping, hydrography, benthic ecology and fisheries. In 2014, the JNCC and Cefas planned and carried out a monitoring R&D survey of the Dogger Bank SCI. Three survey objectives were identified for the survey:

**Sentinel monitoring (Type 1):** to distinguish directional trends from short-term variability

Monitoring long-term change and *a posteriori* attributing that change to natural or anthropogenic sources is a key aim of Sentinel monitoring within the UK Marine Biodiversity Monitoring R&D Programme.

Data collection carried out during the current study will contribute an additional temporal sampling occasion to the infaunal time series dataset that exists for the Dogger Bank. Historically, a number of sentinel sampling stations across the bank feature have been visited on a regular basis by Wieking and Kröncke since the mid 1980s (Kröncke 1990; Wieking & Kröncke 2005). Therefore, in addition to allowing a temporal comparison of historical and current data, revisiting the historic sampling stations may also support the ‘Type 1’ monitoring principles; specifically elucidating long term temporal patterns in benthic faunal communities across the site and ultimately, within the overall range of comparable habitat types across the UK.

Historically, different equipment types have been used to acquire benthic samples within the various sectors of the Dogger Bank feature; in part due to variation in sediment composition across the bank. In future surveys, the three Member States also plan to use differing methodologies to meet their individual requirements for assessment and monitoring. The UK monitoring programme will acquire samples using a 0.1m$^2$ Hamon grab, whilst the German programme intends to utilise a 0.2m$^2$ Van Veen grab, and the Dutch programme will use a Reineck box corer (0.078m$^2$). The infauna data used in the temporal comparison of the Dogger Bank infauna were collected using a Van Veen grab therefore, an additional objective of this element of the survey was to obtain directly comparable samples at specified sampling points to determine if historical samples can contribute to a time-series dataset for this site. As such, a subset of 12 stations (previously visited by Wieking and Kröncke during 1985-1987 and 1997-1998 (Kröncke 1992; Wieking & Kröncke 2005)) were selected for sampling with both a 0.1m$^2$ Hamon grab (traditionally used in the UK for sampling coarse and sandy sediments) and a 0.2m$^2$ Van Veen grab (traditionally used by the German Marine Research Department). N.B. Sampling gear intended to be used by the Dutch monitoring programme was not available for the current survey.

The results of this study are intended to inform the comparability and compatibility of the datasets generated by the collective monitoring programmes implemented by individual member states and to inform the development of monitoring options for sedimentary habitats more widely.

**Null Hypothesis:**
*Benthic communities and sediment characteristics of the Dogger Bank SCI do not change over time.*

**Operational monitoring (Type 2):** to determine pressure–state relationships

Having identified seabed abrasion (resulting from mobile demersal fishing activities) as the primary pressure of concern for this site, the second objective of the survey was to conduct a pressure gradient study to develop a better understanding of how the infaunal and epifaunal communities of the Dogger Bank respond to different levels of this pressure. This element of the survey is particularly important for the ongoing development of condition indicators for sandbank features and other shallow sedimentary habitats, and also for defining meaningful thresholds of pressure beyond which the impacts on the sandbank features and associated biological communities are considered unacceptable.

As such, this element of the study is designed to improve our understanding of the relationship between seabed abrasion (attributed to demersal fishing activities) and the conservation status of benthic communities. This was achieved through the collection of targeted measurements along an abrasion pressure gradient, derived using Vessel Monitoring System (VMS) data. Acquisition of multiple samples per pressure level, along the pressure gradient, will allow testing of a number of relevant indicators currently under development to determine their sensitivity to abrasion pressure. This operational element of monitoring is intended to complement the objectives of the investigative monitoring, conducted to determine rates of recovery following exclusion of fishing (outlined below), by indicating which metrics will be most effective in determining the resultant trend in biological communities towards favourable conservation status.

**Null Hypothesis:**
*Benthic communities and sediment characteristics of the Dogger Bank SCI subject to varying levels of abrasion pressure do not differ.*

**Investigative monitoring (Type 3):** to determine the effectiveness of proposed management measures

The introduction of fisheries management zones within the Dogger Bank SAC is intended to regulate fisheries activities within the site via management zones which exclude use of beam trawl, bottom/otter trawl, dredges and semi-pelagic trawls. The establishment of a pre-closure dataset, with sufficient replication from similarly sized areas inside and outside of the management zones, is essential for testing the efficacy of the closures, and to provide evidence of causality in the relevant pressure/state relationships.

As such, the primary survey objective was to collect a set of data to comprise the ‘Before’ element of a ‘Before-After-Control-Impact’ (BACI) experimental design intended to monitor and assess changes in benthic communities in response to proposed fisheries closures within the UK Dogger Bank SCI.

**Null Hypothesis:**
*At time zero(T0), benthic communities and sediment characteristics do not differ between control and impact stations located within/out with the proposed fishery management areas.*

### 1.3.1 Selection of Candidate indicators

A major challenge in the management of the marine environment is the need to identify a simple method of assessment and monitoring which captures the inherent complexity of the ecosystem (Hering *et al* 2006; Romnouts *et al* 2013). Indicators, defined as measurable ecological parameters which effectively measure change, are frequently used as a way to distinguish between a healthy and degraded ecosystem (Van Hoey *et al* 2010). Indicators can be “descriptive” i.e. related to ecosystem structure (e.g. diversity, species composition, abundance) or “functional”, i.e. measure ecosystem activities (e.g. productivity, nutrient cycling and ecosystem metabolism) (Van Hoey *et al* 2010; OSPAR 2012). It is generally accepted that an individual biological indicator will provide an over simplified view of the environmental complexity of a marine ecosystem, and therefore a combination of indicators should be employed at a given site (Van Hoey *et al* 2010). This flexible approach to indicator selection has been adopted in the development and testing of candidate indicators to support assessment and monitoring of Good Environmental Status (GES), in relation to the benthic habitat component of the biodiversity descriptor, under the MSFD (Frost *et al* 2013; Burrows *et al* 2014; Haynes *et al* 2014; Fariñas-Franco 2014). In doing this, there is an acceptance that indicators taken forward under MSFD should, as far as possible, be compatible with those more feature specific indicators applied in the assessment and monitoring of habitats of conservation interest within MPAs, e.g. both European Marine Sites (EMS) and national MPAs. However, whilst in practice, the selection of both holistic and effective indicators as part of a comprehensive and statistically robust monitoring programme is notoriously difficult (Jenkins *et al* 2015), the use of appropriate and pressure specific indicators remains the basis for effectively detecting meaningful change attributable to human activities as part of the UK MBMP (Franco *et al* 2015). Therefore, the current study is intended to contribute to wider indicator development and operational testing to support implementation of the UK MBMP and also the specific assessment and monitoring of condition of the sandbank feature and associated sedimentary habitats within the Dogger Bank SCI.

Strong links between chronic trawling activities and observed changes in benthic communities have been reported. For example, Hinz *et al* (2009) found reduced infaunal abundances and species richness with increasing otter trawling activity at a *Nephrops* fishing ground in the Irish Sea. However, many of the traditional “descriptive” univariate metrics, such as species richness, are not necessarily a good reflection of subtle infaunal community responses to physical abrasion pressure (Jenkins *et al* 2015; Murray *et al*, in prep). For example, the magnitude of their response can vary significantly according to the type of fishing gear used, the naturally prevailing environmental regime of the habitat studied and also between the different taxa observed to be associated with the given habitat (Collie *et al* 2000). Multi-metric indices such as the Infaunal Quality Index (IQI) (Phillips *et al* 2014) which incorporates the AZTI Marine Biotic index (AMBI) (Borja *et al* 2000) have been favoured over individual metrics as they reflect both the structure and function of benthic macrofaunal assemblages. The IQI was originally developed to assess change in ecological status of soft sediment habitats, in the inshore and coastal marine environment in response to gradients in organic enrichment and sediment contamination, and has been adopted for use under the Water Framework Directive (WFD). The AMBI component within IQI, which is based on the characteristic response of species to gradients of organic enrichment as described by Pearson and Rosenberg (1978), assigns taxa to each of five ecological groups (based on their relative sensitivity to the pressure). AMBI, Simpson’s evenness (1-λ’) and taxon richness (S) are combined in the IQI to generate an Ecological Quality Ratio (EQR) ranging from 0-1 (Bad-High ecological status). The EQR value delineating the boundaries between each habitat condition (Bad-High) is shown in Table 2.

**Table 2**. EQR values delineating each ecological condition (from Phillips 2012).

| Boundary | EQR |
|---|---|
| Bad/Poor | 0.24 |
| Poor/Moderate | 0.44 |
| Moderate/Good | 0.64 |
| Good/High | 0.75 |

The IQI and AMBI have been suggested as suitable tools for assessing disturbance of benthic communities in offshore waters under the MSFD (Harrald & Davies 2009). However, it was acknowledged that for effective, wider application, the indicators would need to be adapted: 1) for application in inshore and offshore, coarse sedimentary habitats and 2) to accommodate effective assessment and monitoring of the status of biological communities in response to alternative pressure categories (e.g. physical disturbance). As such, the IQI is currently under development to expand its application in coarse and mixed sedimentary habitats in both inshore and offshore waters, and also to allow it to be effectively applied in the monitoring of infaunal community status in response to a broader range of pressure types. However, as the modified tool was not available for use at the time of the current study, the version available (IQI (v4)) was applied for analyses.

Currently, no single univariate metric or multi-metric, has proven to respond consistently across the full range of pressure-habitat combinations tested. As such, there remains a level of uncertainty around their efficacy for monitoring benthic biological community responses to abrasion pressure resulting from demersal fishing activity across the full range of both inshore and offshore sedimentary habitat features of interest. In light of this, there is the need to explore more novel approaches for detecting changes in ecosystem components in relation to abrasion pressure. Biological traits analysis (BTA) has been suggested as one of the most appropriate methods to detect benthic community response to trawling disturbance (Bremner *et al* 2003; Tillin *et al* 2006; De Juan *et al* 2007, 2009; De Juan & Demestre 2012; Lambert *et al* 2014; Jenkins *et al* 2015). This approach looks beyond taxonomic identity, focussing on aspects of a species' life history, morphology and behaviour that determine their sensitivity/resilience to specific natural or anthropogenic pressures.

Demersal trawling is known to affect benthic communities in different ways and this is hypothesised to be influenced by the predominant traits exhibited by their component taxa. For example, demersal trawling has been observed to result in:

1. **Removal of larger species from the surface and top layers of the sediment:**
   Traits such as position in sediment (e.g. epifaunal or infaunal), size and, to a lesser extent, mobility (as even the most mobile species have been caught by beam trawlers, see van Marlen *et al* 2014) may indicate sensitivity to this element of the pressure.

2. **Damage of larger benthic species through capture and release:**
   Traits that are hypothesised as potentially effective indicators of sensitivity to damage through physical abrasion include fragility, flexibility, body design (i.e. whether animals have limbs (Depestele *et al* 2014)), along with a number of additional physiological traits not previously considered, e.g. temperature change tolerance, exposure time in air, tissue damage results in physiological stress responses.

3. **Increase of food for mobile predators and scavengers:**
   Traits such as feeding type, mobility and size may indicate whether recent trawling has taken place. Dead/damaged organisms or smaller species re-suspensed during trawling may result in a short-term (days/weeks) increase of opportunistic mobile predators and scavengers taking advantage of increase food availability (Groenewold & Fonds 2000).

When using BTA as an indicator of response to a given pressure, it is essential that traits which are sensitive to that pressure are selected. In the case of physical abrasion pressure traits such as body size (i.e. smaller individuals are less affected by direct effects of trawling and have greater power to reproduce quickly, possibly thriving in an area which has had larger predators removed), position in sediment, fragility (as an indicator of resilience) mobility (speed of migration into the area after trawling) have been identified as important. Epifauna, sampled using gear such as beam trawls, are thought to be the most effective component of the benthic community to assess the direct effects of fishing impacts as the spatial extent and communities sampled represent those most vulnerable to fishing (Collie *et al* 2000).

Size-frequency based approaches have also been identified as part of the MSFD indicator development process, and specifically, a candidate indicator titled “size-frequency distribution of bivalves or other sensitive/indicator species” was proposed to measure the number and/or biomass of individuals per size class. The basis for the indicator is that benthic communities typically consist of a mixture of long-living and short-living species. The short-living species are usually small in size with low individual biomass, whilst long-lived species can reach much larger sizes, with higher individual biomass. Under natural conditions, populations of large species consist of different size-classes representing different age-groups. The natural balance between both a) the large and small species within the community and b) the large and small specimens within the population of a single species can be affected by anthropogenic influences such as physical disturbance, e.g. caused by bottom trawling or sediment extraction (Basset *et al* 2012; Hiddink *et al* 2006; Pearson & Rosenberg 1978; Tyler-Walters *et al* 2009). The proposed metric is a comparison of the current population structure with a (theoretical) natural population structure resulting in a value for the “degree of naturalness” of the population structure.

Large bivalves are of particular interest as candidate taxa for the development of size-frequency based indicators as they can play a pivotal role in ecosystem functioning (Norkko *et al* 2013) but are known to generally suffer greater mortalities following a trawl event, compared to smaller species, as they are crushed by the path of the net or are caught in the net and subsequently discarded (Jennings *et al* 2001). It should be noted that bivalves are well known for having years of ‘good’ spat fall and other years of poor recruitment which can make determining the size-frequency histogram for a particular geographical area, difficult.

Through the testing of a number of candidate indicators, this study will contribute to the evidence base required to inform the further development and validation of indicators which are most appropriate for ongoing monitoring of the Annex I sandbank feature at the Dogger Bank SCI and also in relation to the assessment and monitoring of comparable sedimentary habitats present across the wider environment.

# 2 Sentinel monitoring of long-term trends in biological communities

Null Hypothesis**:**
*Benthic communities and sediment characteristics of the Dogger Bank SCI do not change over time.*

## 2.1 Methods

### 2.1.1 Survey design

Data collected with a 0.1m$^2$ Hamon grab, for the purposes of the Sentinel, Operational and Investigative monitoring objectives, were used to gain an understanding of sediment and infaunal benthic community characteristics and variability across the SCI. As this report aims to focus on a site/habitat scale, replicates were not collected at each station to mitigate the risk of spatial autocorrelation and pseudoreplication. These data could, in the future, inform wider scale Sentinel monitoring across a fully representative range of sand and coarse sediment habitat types at the UK scale. This would allow potential changes attributable to human pressures to be better understood within the context of natural variability over larger spatial and temporal scales.

Seventeen historical sampling stations, previously surveyed by a number of institutes, namely Senckenberg Research Institute and Senckenberg Natural History Museum (Wieking & Kröncke 2001) and JNCC (Cefas 2008), were selected for sampling with both a 0.1m$^2$ Hamon grab and a 0.2m$^2$ Van Veen grab (Figure 5). In addition, ten stations within the Operational Monitoring Survey cell 0a were also sampled using both gear types (the number of stations being dictated largely by time constraints). Underlying seabed habitat maps indicated that the seabed sediments within cell 0a comprised a relatively uniform area of subtidal sand containing a small, uniform patch of coarse sediment. This area of seabed was selected intentionally to allow assessment of both the effectiveness of different sampling gears (to acquire a valid sample in different sediment habitats) and also to explore and compare the effect of different sampling gears on the metrics derived from the infaunal abundance and biomass data they generate.

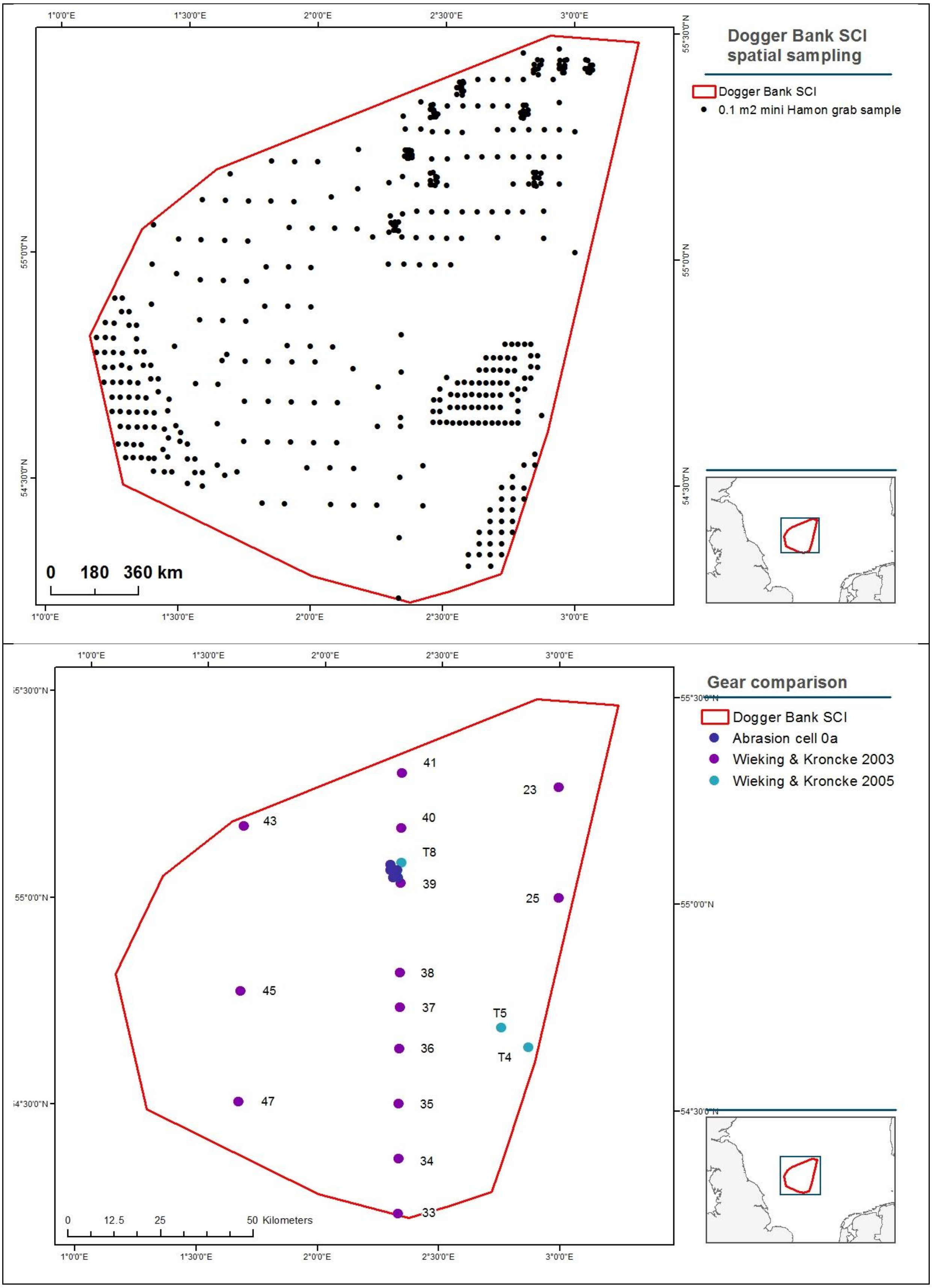



**Figure 5**. Stations selected for the spatial variability (includes all samples taken in 2014 using a a $0.1m^2$ Hamon grab) (top) and data comparison study using a $0.1m^2$ Hamon grab and a $0.2m^2$ Van Veen (bottom).

Appendix 1 and the Dogger Bank 2014 survey report (Ware & McIlwaine 2014) provide more detail on the specific methods that were used to support the data comparison objectives of this survey.

### 2.1.2 Sample acquisition and processing

**Spatial analysis**
In total, 425 stations were sampled using a $0.1m^2$ Hamon grab. Sediment sub samples (~500ml) were collected from the infaunal sample prior to sieving. In the laboratory the sediment samples were analysed at half-phi intervals using a combination of laser diffraction (<1mm fraction) and dry sieving techniques (>1mm) as described in National Marine Biological Analytical Quality Control Scheme PSA guidance (Mason 2011).

The remaining sample was processed for macrofauna (>1mm) (see Appendix 1 for detailed sample acquisition methods) following standard laboratory practices. Results were checked following the recommendations of the NMBAQC scheme (Worsfold *et al* 2010). Taxa were identified to highest taxonomic resolution and weighed. Bivalves were extracted from the samples and their valve length, height and depth (mm) were recorded.

**Temporal comparison**
For the temporal comparison of sediment particle size distribution (PSD), data, collected in 2006 and 2007, were provided by Dr Ingrid Kröncke (Senckenberg Research Institute) as % gravel, % sand and % silt/clay for nine stations located within the UK sector of the Dogger Bank SCI (Table 3).

Macrofauna data, collected using a $0.2m^2$ Van Veen grab, were also acquired from the Senckenberg Research Institute. Data were provided from 1985-1987, 1997-1998 and 2006-2007 to compare with the data collected by $0.2m^2$ Van Veen grab in 2014 (Table 3). Species abundance data (1997-1998 and 2006-2007) were provided as two separate $0.2m^2$ grab samples per station. Only the first replicate from these data was used in the temporal analysis as only one $0.2m^2$ Van Veen sample was collected at each station in 2014. The data from 1985-1987, however, were only available per $0.4m^2$ (and individuals per $m^2$).

Subsurface abrasion pressure values (swept-area ratios) were extracted for each of the temporal stations from the 2006-2013 pressure layers using ArcGIS to explore variability in fishing pressure at these positions over time.

**Table 3**. Stations within the SCI sampled (indicated by 'x') from 1985-2014. Each sampling station is also identified according to its location in relation to the infaunal communities defined by Wieking and Kröncke (2003) and whether an historical PSA sample was available. Samples where 'x' is bold were available per 0.2 $m^2$.

| Station | 1985 | 1986 | 1987 | 1997 | 1998 | 2006 | 2007 | 2014 | PSA | Infaunal Community |
|---|---|---|---|---|---|---|---|---|---|---|
| **23** | | | x | **x** | **x** | **x** | **x** | **x** | Y | Bank |
| **25** | | | x | **x** | **x** | **x** | **x** | **x** | Y | Bank |
| **34** | x | | x | **x** | **x** | **x** | **x** | **x** | Y | Bank |
| **35** | x | x | | | | | | **x** | | Bank |
| **36** | x | x | x | **x** | **x** | **x** | **x** | **x** | Y | Bank |
| **37** | x | x | | | | | | **x** | | Bank |
| **38** | x | x | x | **x** | | **x** | **x** | **x** | Y | Bank |
| **40** | | x | x | **x** | | **x** | **x** | **x** | Y | Bank |
| **41** | | x | | | | | | **x** | | North eastern |
| **43** | | | x | **x** | **x** | **x** | **x** | **x** | Y | North eastern |

| Station | 1985 | 1986 | 1987 | 1997 | 1998 | 2006 | 2007 | 2014 | PSA | Infaunal Community |
|---|---|---|---|---|---|---|---|---|---|---|
| **45** | | | x | **x** | **x** | **x** | **x** | **x** | Y | South west Patch |
| **47** | | | x | **x** | **x** | **x** | **x** | **x** | Y | South west Patch |

**Comparison of current and historical data collected within the UK part of the Dogger Bank SCI**
Twenty-four stations, successfully sampled using both a 0.1m$^2$ Hamon grab and a 0.2m$^2$ Van Veen grab were processed for macrofauna (>1mm) and particle size distribution (see Appendix 1 for detailed sample acquisition methods). Bivalves were extracted from the samples and their valve length, height and depth (mm) measurements were recorded.

### 2.1.3 Data analysis: Spatial

**Particle size**
Gradistat software (Blott & Pye 2001) was used to produce sediment statistics. Each sample was also assigned to one of four EUNIS sediment classes as defined by Long (2006). In addition, the full-resolution PSD data (at 0.5 $\phi$ intervals) were grouped using EntropyMax. This Microsoft windows based software uses non-hierarchical clustering to group large matrices of PSD datasets into a finite number of groups (Stewart *et al* 2009). EntropyMax was preferred over summary statistics such as skewness, kurtosis, mean, median, sorting coefficient (which assume unimodal distribution), as it provides a more representative analysis of the full resolution data (groups samples which are most alike, regardless of modality).

**Infaunal communities**
The DIVERSE routine in PRIMER V6 (Clarke & Gorley 2006) was used to calculate the total number of taxa and abundance for each sample (juvenile taxa were removed prior to analysis to reduce differences caused by variation in recruitment between years). Colonial organisms were included as present or absent. PRIMER was also used to calculate a Bray-Curtis similarity matrix on the square-root transformed taxon abundance data. The SIMPROF routine within CLUSTER was used to determine statistically significant infaunal groups at the 5% level. This analysis resulted in more groups than was desirable for an ecologically meaningful interpretation. Therefore, the species abundances for each group were averaged and re-run through the SIMPROF routine. This resulted in many of the groups being joined due to their similarity. The SIMPER routine was used to identify characteristic species for each group and the results plotted using ArcGIS v10.1.

**Bivalve size frequency**
Bivalve length frequency histograms were produced in SigmaPlot® for species which were represented by more than 50 individuals (from 0.1m$^2$ Hamon grab samples taken for the investigative monitoring element of this survey). This information was used to characterise the more abundant bivalve species across the Dogger Bank SCI in 2014. Other studies using bivalve size frequency as a potential indicator have set a higher minimum number of individual measurements to obtain a reliable estimate of the population's size distribution (at least 100 individiuals per meter square of *Macoma balthica*, Nygard & Jermakovs 2015). However, given the low number of individuals sampled in this study, an arbitrary value of 50 individuals was selected as a minimum for generating size frequency distribution histograms. Only nine species satisfied this criterion.

### 2.1.4 Data analysis: Temporal comparison

**Particle size**

Sediment data from nine stations, within the UK part of the SCI, sampled in 2006, 2007 and 2014 (collected by 0.2m$^2$ Van Veen) were assigned to a Folk class and to one of four EUNIS sediment classes as defined by Long (2006). No statistical analysis was undertaken due to the absence of detailed information from the historical data.

Data from 12 historically sampled stations were available for temporal analysis of macrofaunal assemblages (Figure 6).

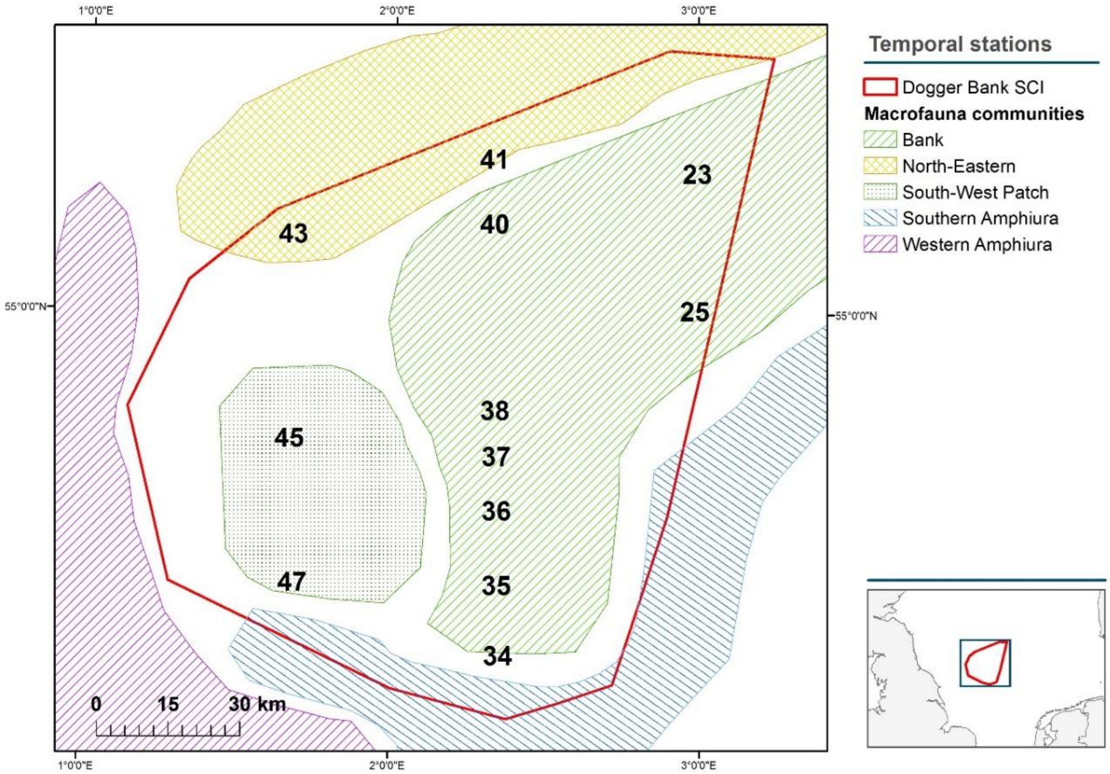



**Figure 6**. Historical station locations used in the temporal analysis overlain on the infaunal community boundaries identified by Wieking and Kröncke (2003).

**Infaunal communities**

The historical data were combined with the data from 2014 in PRIMER and species names checked using the World Register of Marine Species (WoRMS Editoral Board 2016). Several species were combined to genus level where noticeable differences in species identification were observed across the years, e.g. *Chamelea gallina* and *Chamelea striatula* were combined to *Chamelea* spp. as only one species was identified in each of the datasets. Juveniles, eggs, zoea, megalopa and epitokes were also removed from both datasets. Abundance data were standardised to m$^2$ to allow comparison with data collected in 1985-87. However, it must be noted that species richness is not directly comparable due to differences in sampling area (0.2m$^2$ v's 0.4m$^2$). Therefore, species richness values between the years are provided for illustrative purposes only.

The final combined dataset was analysed using PRIMER. The data were fourth-root transformed prior to calculation of a Bray-Curtis similarity matrix. Each station was assigned according to its location in relation to the macrofaunal communities identified by Wieking and Kröncke (2003). The univariate metrics, number of taxa, number of individuals and Hill's diversity (N1) (Hill 1973) were calculated. Box and whisker plots were produced in Minitab® Statistical Software (v15) for each metric according to year and macrofaunal community.

### 2.1.5 Data analysis: Data comparison

**Particle size**
Particle size distributions for samples collected by both $0.1m^2$ Hamon grab and $0.2m^2$ Van Veen were compared. The full-resolution particle size distribution (PSD) data (at 0.5 $\phi$ intervals) were grouped using EntropyMax software (Stewart *et al* 2009).

**Infaunal communities**
Analysis of infaunal data sampled by $0.1m^2$ Hamon grab and $0.2m^2$ Van Veen were carried out using PRIMER. Absolute values (e.g. not standardised to $1m^2$) were used to determine the affect of gear selection on the biological component of the sample. Data were square root transformed to down-weight the importance of those species which occurred in higher abundances. MDS ordination, ANOSIM and SIMPER were used to display and detect differences in infaunal community composition sampled by the two gear types. The Wilcoxon nonparametric T test was used to test for significant differences in univariate metrics between the two gear types.

## 2.2 Results

### 2.2.1 Spatial patterns in particle size distribution

Five sediment groups were determined as the best group output from Entropy when applied to the full set of PSD data derived from the $0.1m^2$ Hamon grab samples. The optimum number of clusters is achieved when the Calinski–Harabasz (C–H) statistic is at its maximum (Orpin & Kostylev 2006). In addition to this statistic, expert judgement meant that in some cases where groups were sufficiently similar, they are considered to be the same group, and suffixed with an ‘a’ or a ‘b’ to show original grouping. Sediment characteristics and profiles for each of these final groups are given in Figure 7 and Table 4a & 4b.

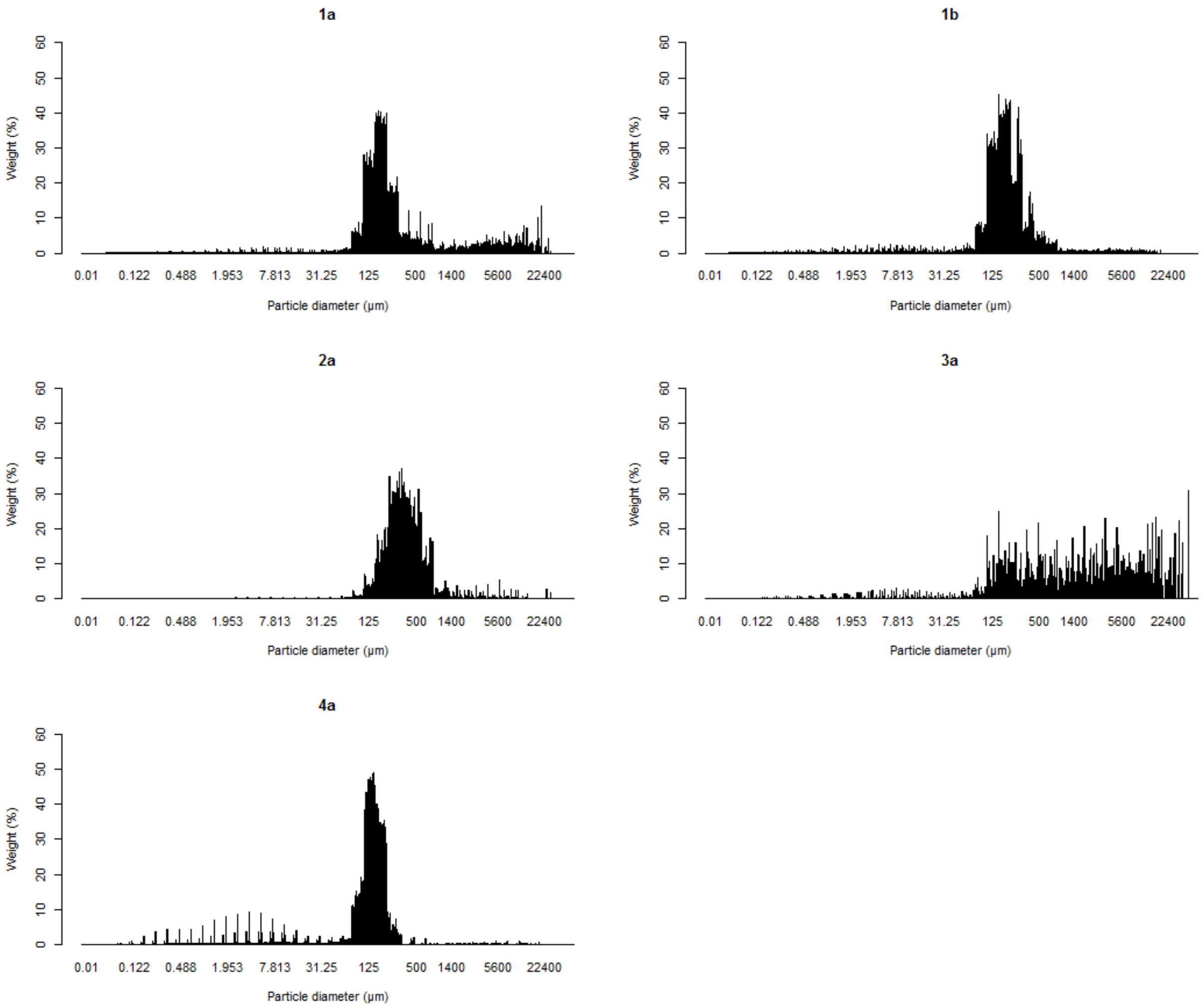



**Figure 7**. Particle size distribution histograms for each sediment group. All samples are represented within the histograms.

**Tables 4 a & b**. Sediment characteristics of the five sediment groups, produced on the average particle size distribution for each sediment group, using Gradistat (Blott & Pye 2001). Sorting for group 3a in italics as sediment is polymodal.

a)

| Sediment group | Number of samples | Sediment description | Sorting (ϕ) | Sorting description | Mode 1 (µm) | Mode 2 (µm) | Mode 3 (µm) |
|---|---|---|---|---|---|---|---|
| Group1a | 132 | Gravelly sand | 1.90 | Poorly sorted | 213.4 | | |
| Group1b | 191 | Slightly gravelly sand | 1.39 | Poorly sorted | 213.4 | | |
| Group2a | 26 | Slightly gravelly sand | 1.28 | Poorly sorted | 426.8 | | |
| Group3a | 36 | Sandy gravel | *2.86* | Very poorly sorted | 4800.0 | 213.4 | 13600.0 |
| Group4a | 43 | Slightly gravelly sand | 1.72 | Poorly sorted | 150.9 | | |

b)

| Sediment group | Gravel (%) | Very coarse sand (%) | Coarse sand (%) | Medium sand (%) | Fine sand (%) | Very fine sand (%) | Silt/clay (%) |
|---|---|---|---|---|---|---|---|
| Group1a | 8.90 | 1.64 | 5.24 | 18.73 | 57.38 | 5.32 | 2.80 |
| Group1b | 1.36 | 0.51 | 4.63 | 22.28 | 62.22 | 5.44 | 3.55 |
| Group2a | 2.77 | 2.24 | 27.57 | 50.78 | 14.14 | 1.05 | 1.46 |
| Group3a | 50.02 | 9.93 | 12.25 | 10.68 | 11.08 | 1.92 | 4.11 |
| Group4a | 0.68 | 0.18 | 0.19 | 4.23 | 72.13 | 13.42 | 9.16 |

The majority of sediments present across the Dogger bank SCI are unimodal sands, with sandy gravel in patches mainly concentrated on the western edge of Dogger Bank as shown in Figure 8 – Figure 10. There are also a few muddy sediments in the central north area. As most of the sediments are unimodal, the sorting co-efficient values can be considered as reliable. The sorting gives an indication of the variability of the sediment sizes present. If a sediment is bimodal, then it may be composed of two well sorted sediment sizes, and the sorting coefficient calculated from such a sample may give a misleading interpretation. Therefore, it is important to check modality of sediment distributions, and investigate sediment distributions before calculating sediment statistics in general, as most of these are designed assuming a unimodal distribution. However, in a broad sense, the more polymodal the sediment, the more variable the sediment sizes present, so the less well sorted the sediment will be. Most sediments are considered as poorly sorted for all the sediment groups presented here.

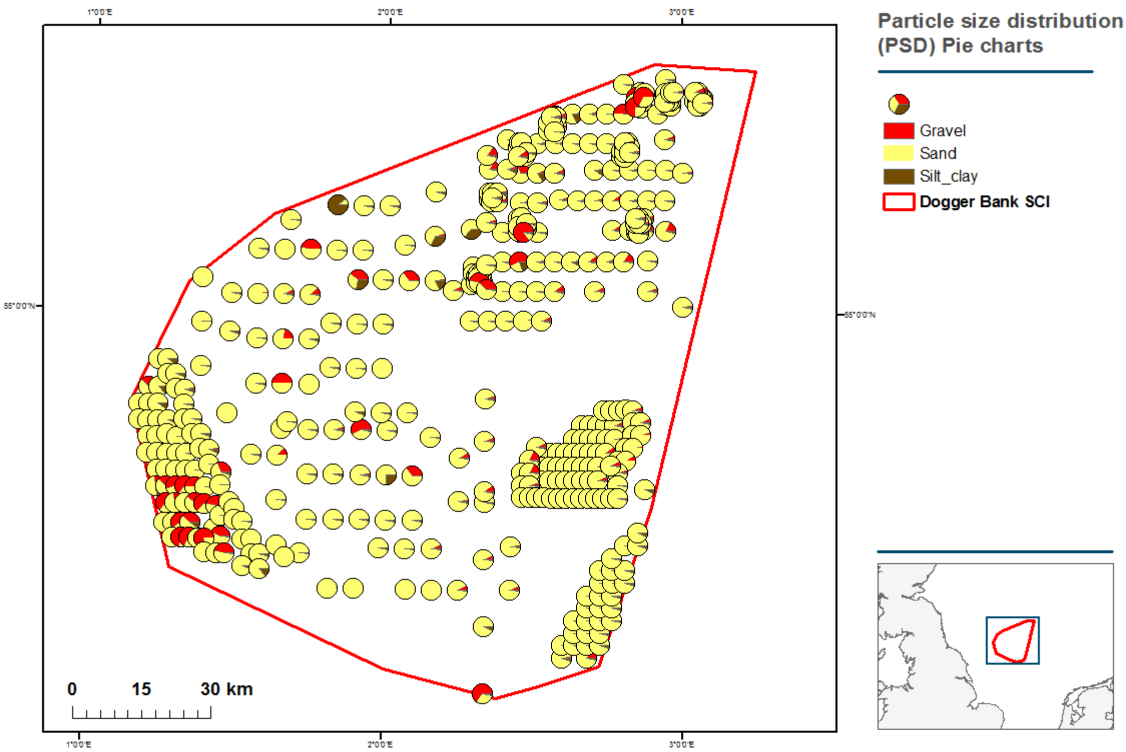



**Figure 8**. Particle size pie charts showing gravel, sand and mud fractions for each sample.

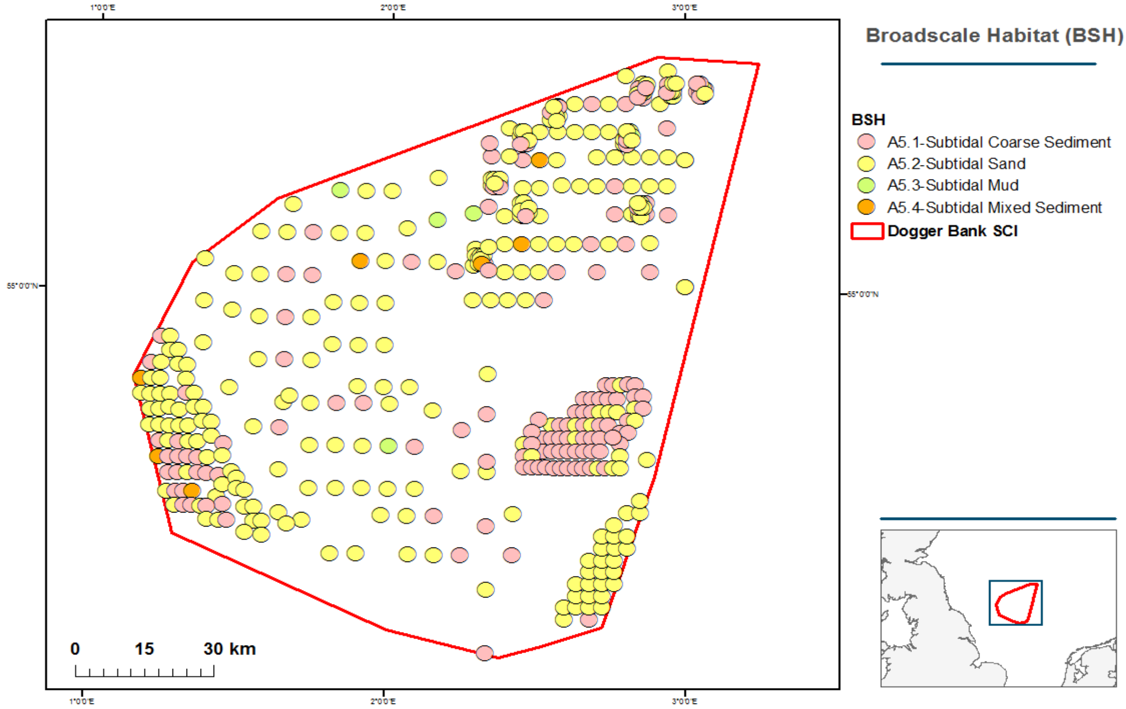



**Figure 9**. Broadscale habitat (BSH) sediment classification for each sample.

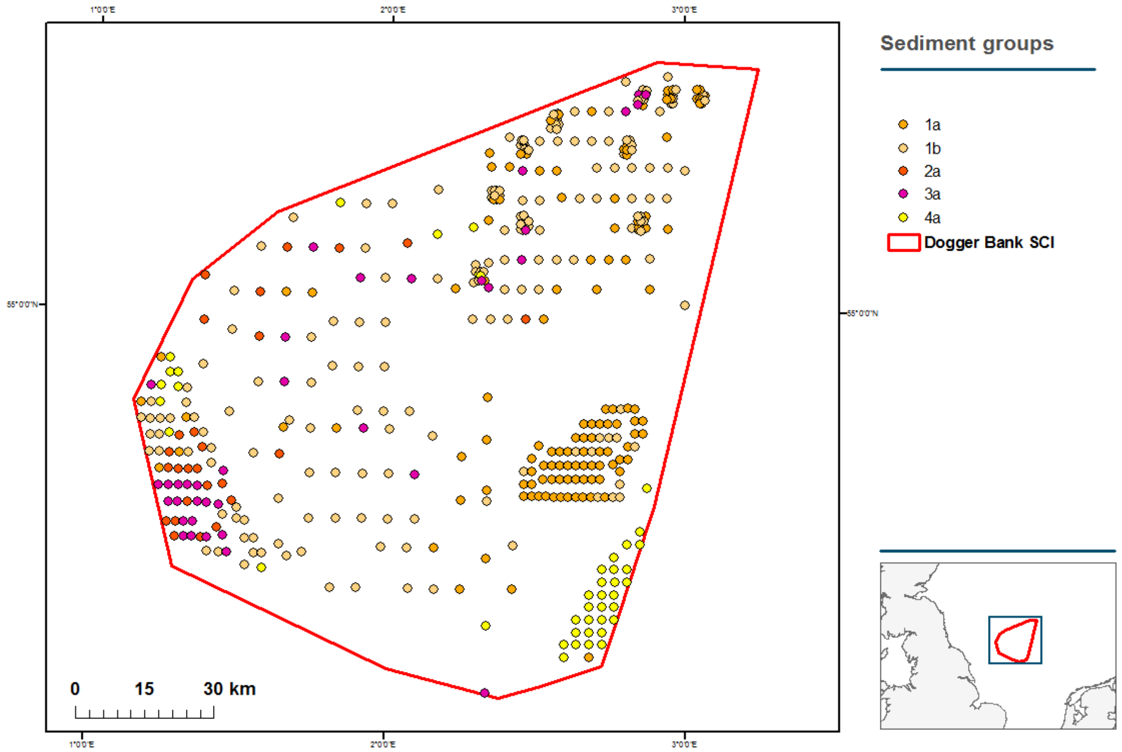



**Figure 10**. Sediment groups based on half-phi resolution particle size distributions for each sample.

## 2.2.2 Spatial patterns in Macrofauna

In total, 424 taxa and 20,886 individuals were identified in the 425 Hamon grab samples collected across the Dogger Bank SCI in 2014. The most commonly occurring species are shown in Table 5. Rare taxa (only present at one station) were represented by 131 taxa (30% of total).

**Table 5**. Most commonly sampled taxa across the Dogger Bank SCI (occurring at more than 50% of stations).

| Phylum | Taxa | % Occurrence | Total abundance |
|---|---|---|---|
| Annelida | *Spiophanes bombyx* | 76.70 | 1954 |
| Mollusca | *Tellina fabula* | 62.82 | 944 |
| Annelida | *Magelona filiformis* | 58.82 | 635 |
| Annelida | *Goniada maculata* | 57.65 | 468 |
| Annelida | *Sigalion mathildae* | 55.53 | 481 |
| Crustacea | *Bathyporeia elegans* | 54.12 | 2044 |
| Annelida | *Owenia borealis* | 53.18 | 630 |
| Crustacea | *Bathyporeia guilliamsoniana* | 51.53 | 548 |
| Echinodermata | *Echinocyamus pusillus* | 50.82 | 809 |

Figure 11 and Figure 12 highlight the spatial variability in number of taxa and their abundance observed across the SCI. The area corresponding with, and to the north of, Wieking and Kröncke's 'South-West patch community' is generally sparsely populated in comparison with the other areas of the bank sampled during 2014, although small scale variability in the number of taxa and individuals is apparent across the whole site.

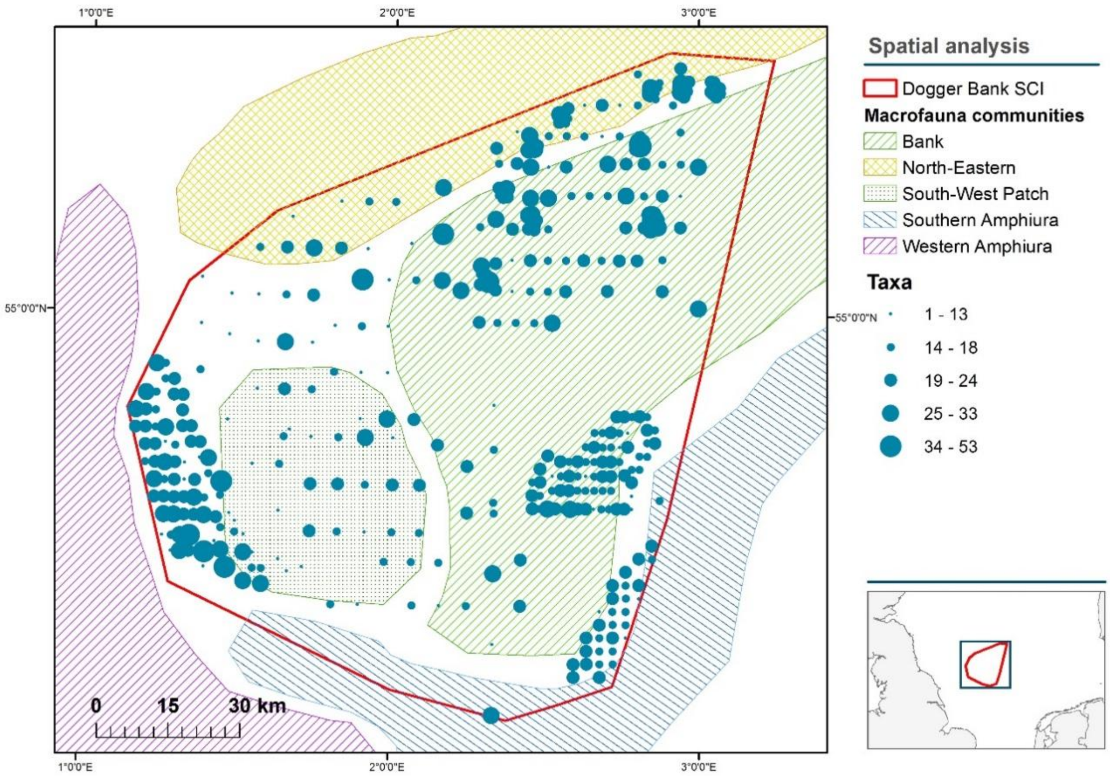



**Figure 11**. Number of taxa present in samples collected by $0.1m^2$ Hamon grab during the 2014 survey. Macrofauna communities as defined by Wieking and Kröncke 2003.

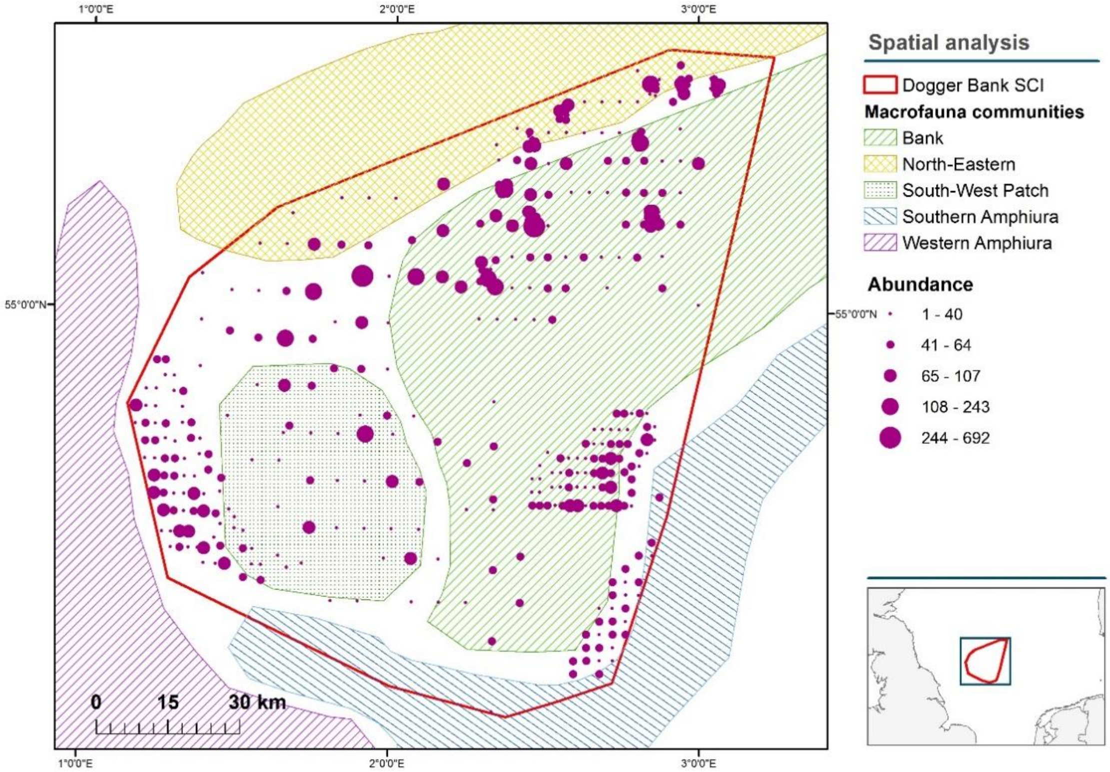



**Figure 12**. Number of individuals present in samples collected by 0.1m$^2$ Hamon grab during the 2014 survey. Macrofauna communities as defined by Wieking and Kröncke 2003.

Infaunal community analyses further highlight the small scale variability across the SCI (Figure 13). Twenty significantly ($p<0.05$) different groups were identified using a second stage SIMPROF analysis. SIMPER analysis also showed that many of the groups could be combined further due to their similarity in the main characterising species. *Spiophanes bombyx* was present across the majority of the SCI, and was a characteristic species of many of the SIMPROF groups. However, this species was not characteristic of the *Fabulina/Magelona* group located in the South East of the SCI nor within the *Notomastus/Glycera* group located in the South West of the SCI. The most commonly represented group was located mainly in the southern part of the 'Bank' and across and to the north of the South West Patch communities previously identified by Wieking and Kröncke (2003) and was characterised by *Bathyporeia* spp (in addition to *S. bombyx*). The northern part of the 'Bank' community was highly variable and comprised a large number of groups characterised by higher abundances of species such as the polychaetes *S. bombyx* and *Chaetozone christei,* the echinoderms *Echinocyamus pusillus* and *Acrocnida brachiata,* and the bivalve mollusc *Kurtiella bidentata*. The latter two species were generally absent from samples taken in the southern part of the 'Bank'. (SIMPER analysis detailing species contributing to 50% of the within group similarity is provided in Appendix 5.

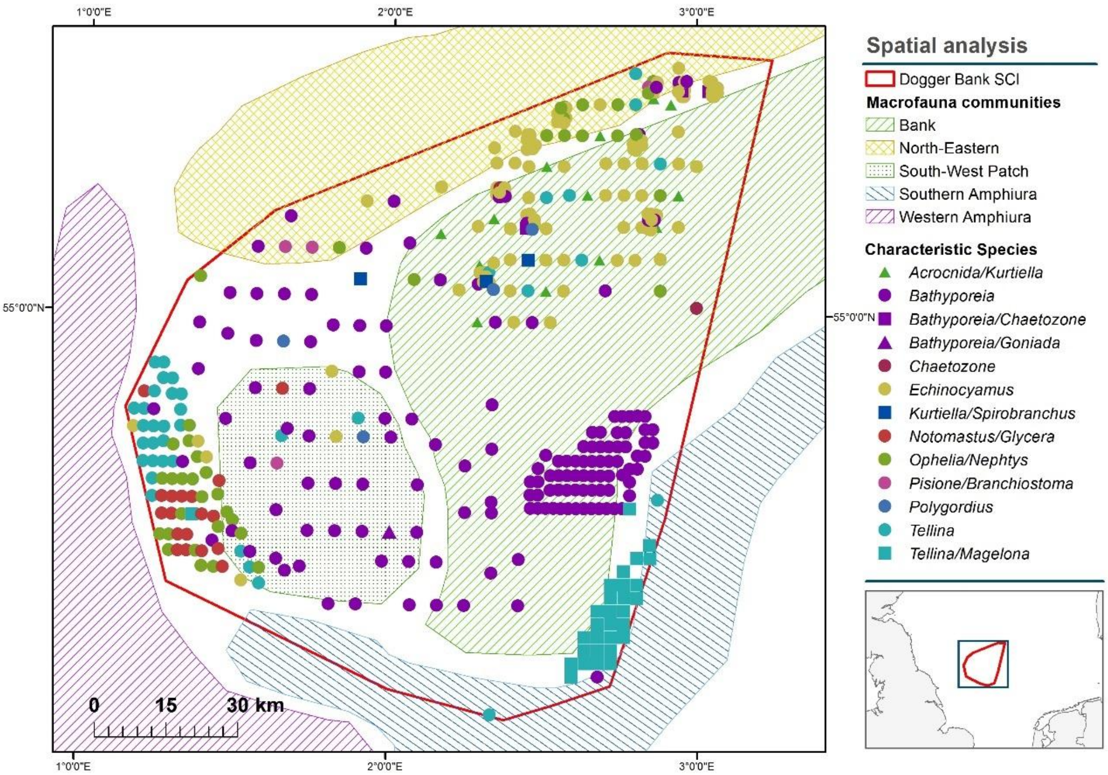



**Figure 13**. Spatial distribution of significantly different assemblages across the UK sector of the Dogger Bank SCI. Outliers are represented by small grey circles. Macrofauna communities as defined by Wieking and Kröncke 2003.

## 2.2.3 Bivalve size frequency distribution

The size frequency distribution of the nine most abundant bivalve species collected across the Dogger Bank SCI are shown in Figure 14. *Kurtiella bidentata, Donax vittatus, Tellina fabula and Thracia gracilis* follow a Gaussian distribution with a single size cohort while *Ensis ensis* follows a polymodal distribution with two defined size cohorts. The distribution of the remaining species is less defined although it should be noted that abundances within each size category are generally low with the exception of *Donax vittatus* and *Tellina fabula*. Highest abundances in these two species relate to young age classes (based on information of maximum size recorded for each species: *D. vitattus* = 35mm, *T. fabula* = 19mm). This is generally true for all species, with the exception of *Kurtiella bidentata* (maximum size 3-6mm) where highest abundances are found in the adult range (2-3mm). Large bivalves were infrequently observed in grab samples and were generally specimens of *Polititapes rhomboides, Dosinia exeolata/lupinus* and *Acropagia crassa.*

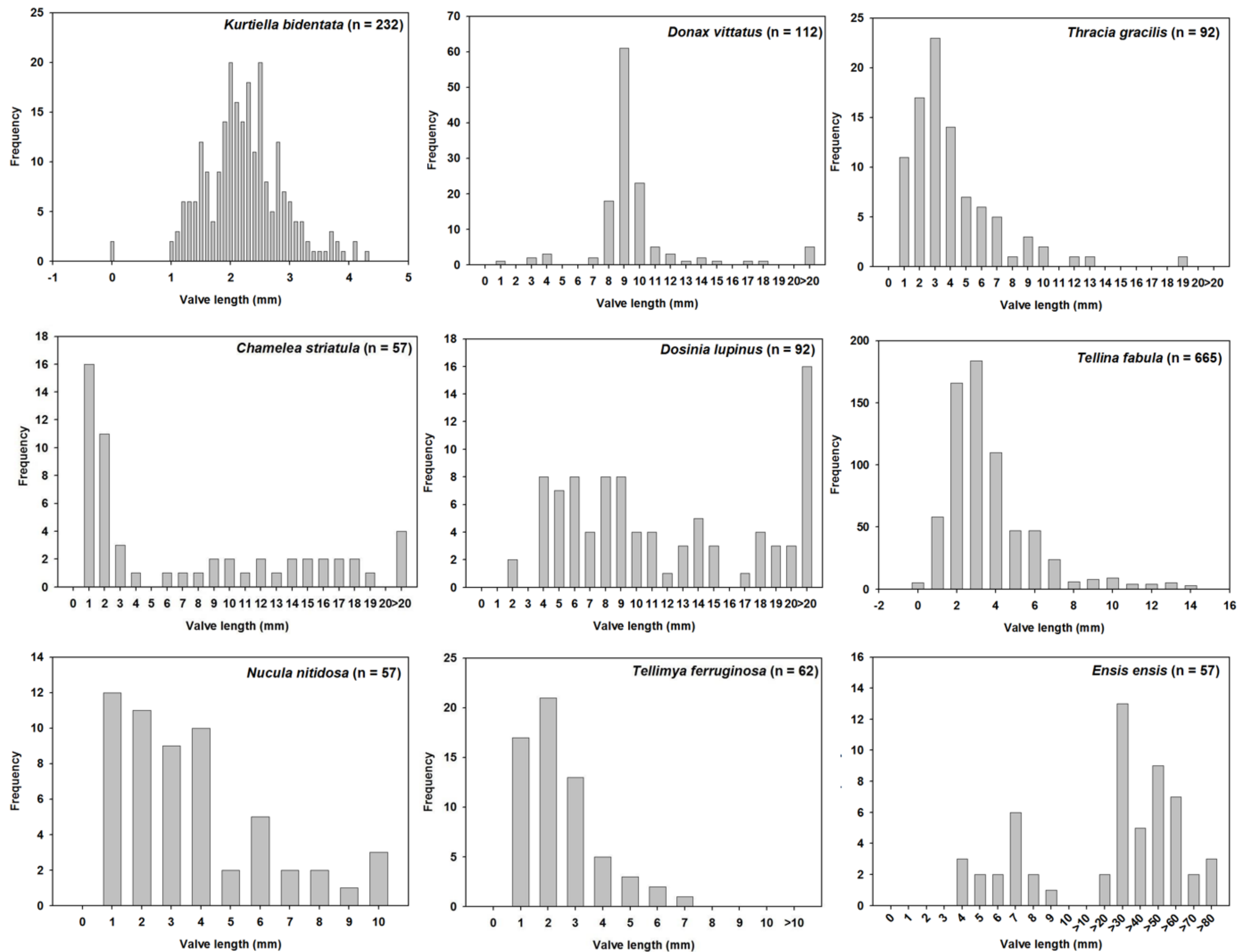



**Figure 14**. Length (in mm) frequency distribution of the nine most abundant (>50 individuals) bivalves collected (using a 0.1m$^2$ Hamon grab) within the Dogger Bank SCI in 2014.

### 2.2.4 Temporal comparison: Particle size distribution

Broad sediment types are similar across the temporal sampling stations (Table 6). More detailed analyses were not possible due to the different sediment analysis methods used to generate the current and historical PSD data sets.

**Table 6**. Summary table comparing Folk classification and EUNIS groups for temporal sites between 2006, 2007 and 2014. Cells are coloured according to classification as coarse sediment (pink) or sand and muddy sand (yellow)

| Original station | 2006 Folk symbol | 2007 Folk symbol | 2014 Folk symbol | 2006 EUNIS groups | 2007 EUNIS groups | 2014 EUNIS groups |
|---|---|---|---|---|---|---|
| 23 | S | (g)S | (g)S | sand and muddy sand | sand and muddy sand | sand and muddy sand |
| 25 | gS | gS | (g)S | coarse sediment | coarse sediment | sand and muddy sand |
| 34 | S | S | S | sand and muddy sand | sand and muddy sand | sand and muddy sand |
| 36 | S | (g)S | gS | sand and muddy sand | sand and muddy sand | coarse sediment |
| 38 | (g)S | (g)S | (g)S | sand and muddy sand | sand and muddy sand | sand and muddy sand |
| 40 | (g)S | S | gS | sand and muddy sand | sand and muddy sand | coarse sediment |
| 43 | S | (g)S | S | sand and muddy sand | sand and muddy sand | sand and muddy sand |
| 45 | S | S | S | sand and muddy sand | sand and muddy sand | sand and muddy sand |
| 47 | S | S | S | sand and muddy sand | sand and muddy sand | sand and muddy sand |

### 2.2.5 Temporal comparison: Macrofauna communities

Figure 15 – Figure 17 show the variability in three univariate metrics over time according to macrofaunal community boundaries identified by Wieking and Kröncke (2003). Variability in numbers of species was apparent both within ‘communities’ and between years. Median values were relatively consistent across the years (excluding 1985-87 Van Veen samples which represent 0.4m$^2$ sediment surface sampling area) within each of the community areas. However, the number of individuals representing the ‘Bank’ community was considerably lower in 2014. High abundances within the ‘Bank’ community in 2007 were largely due to elevated numbers of the polychaete *Lanice conchilega*, particularly at station 40 (>3000 per m$^2$) in the northern area of the ‘Bank’, although high abundances of this species were observed at several other stations within the ‘Bank’ area. This species was absent from the ‘Bank’ in 1985-87 and present in low numbers in 1998, 2006 and 2014. The polychaete *Spiophanes bombyx* was also more abundant, particularly in 1997 (total of ~3000 per m$^2$ within the ‘Bank’) but also in 1998, 2006, 2007, compared to 1985-87 and 2014. In 2014, *Bathyporeia* spp. represented the most abundant species within the ‘Bank’ (~1000 individuals per m$^2$). Numbers of species, individuals and diversity were considerably reduced at stations during all years within the ‘South-West Patch’ in comparison with the ‘Bank’ stations. Only one sample represented the ‘North Eastern’ community from 1986-2007, however the number of species from samples representing 0.2m$^2$ were consistent with those from 2014. Numbers of individuals were slightly more variable within this area from year to year, with highest abundances observed in 1987 (>2200 Syllidae at station 43).

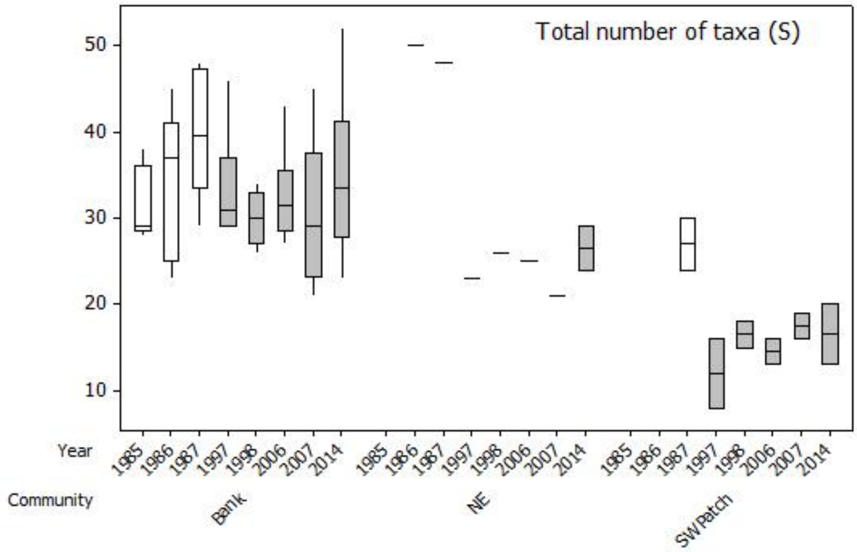



**Figure 15.** Box and whisker plots of the number of taxa representing the 'Bank', North Eastern (NE) and 'South-West (SW) Patch' community boundaries identified by Wieking and Kröncke (2003) from 1985-2014. N.B. Data from 1985-87 (open boxes) were only available per $0.4m^2$ whereas data from 1997-2014 was per $0.2m^2$. (Boxes represent the interquartile range (middle 50% of the data), horizontal line represents the median, the vertical lines (whiskers) represent the data range).

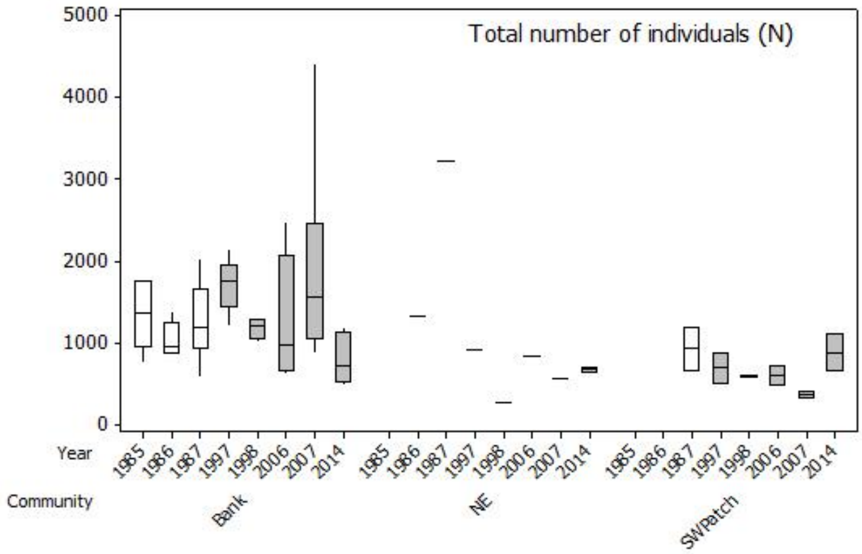



**Figure 16**. Box and whisker plots of the number of individuals (per $m^2$) representing the 'Bank', North Eastern (NE) and 'South-West (SW) Patch' community boundaries identified by Wieking and Kröncke (2003) from 1985-2014. N.B. Open boxes represent data (1985-87) from an original sampling area of $0.4m^2$. (Boxes represent the interquartile range (middle 50% of the data), horizontal line represents the median, the vertical lines (whiskers) represent the data range).

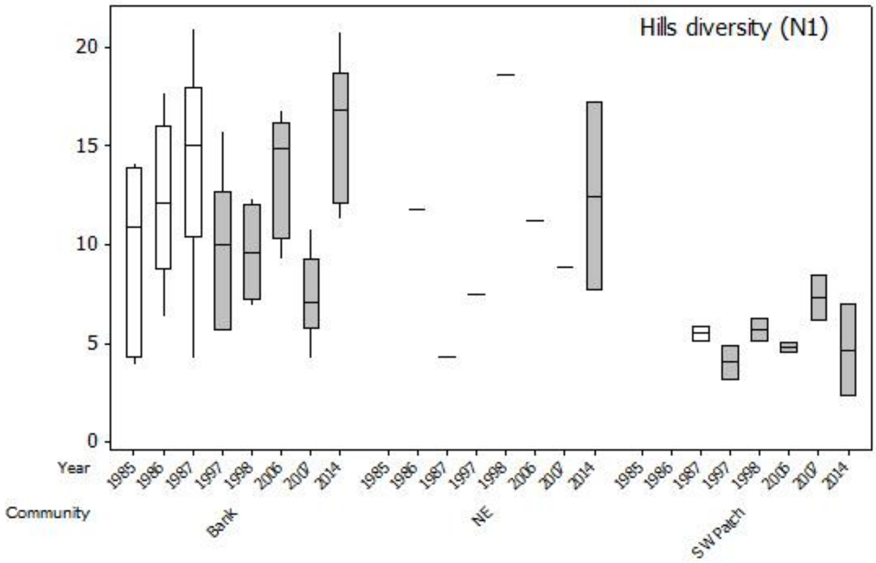



**Figure 17**. Box and whisker plots of the Hills diversity (N1) representing the 'Bank', North Eastern (NE) and 'South-West (SW) Patch' community boundaries identified by Wieking and Kröncke (2003) from 1985-2014. N.B. Data from 1985-87 (open boxes) was only available per $0.4m^2$ whereas data from 1997-2014 was per $0.2m^2$. (Boxes represent the interquartile range (middle 50% of the data), horizontal line represents the median, the vertical lines (whiskers) represent the data range).

Multivariate analysis suggests high overlap in species composition across the years, with the exception of 1987 which clusters away from the main group (Figure 18). SIMPER analysis revealed the absence of a significant number of species from the 1987 dataset despite the data representing a larger surface sampling area of $0.4m^2$. Species absent from 1987 include *Magelona* spp., *Tellina fabula*, *Euspira nitida* (formerly *Polinices pulchellus*), *Urothoe poseidonis*, *Owenia* spp. which were present in high abundances during all other years. However, the polychaete family Syllidae, *Cheirocratus assimilis* and *Minuspio cirrifera,* were present in high abundances in 1987, in addition to numerous other species of lower abundances, which were absent from all other years (see Appendix 5). High temporal similarity in species composition was apparent for samples located within the 'South-West Patch' (stations 45 and 47). The majority of temporal samples located within the 'Bank' also clustered together (including those from 1985 and 1986). SIMPER analysis showed that *Bathyporeia* sp.*, Spiophanes bombyx* and *Magelona* were the numerically dominant species in all years except 1987. In 2007 and 1997 high abundances of the polychaete *Lanice conchilega* were also characteristic of the Bank community (see Appendix 5). *Bathyporeia* sp. was characteristic of the community similarity within the South West Patch in all years sampled. *S. bombyx* was also a characteristic species in 1998-2014 but was completely absent from samples collected in 1987 despite the larger sampling area.

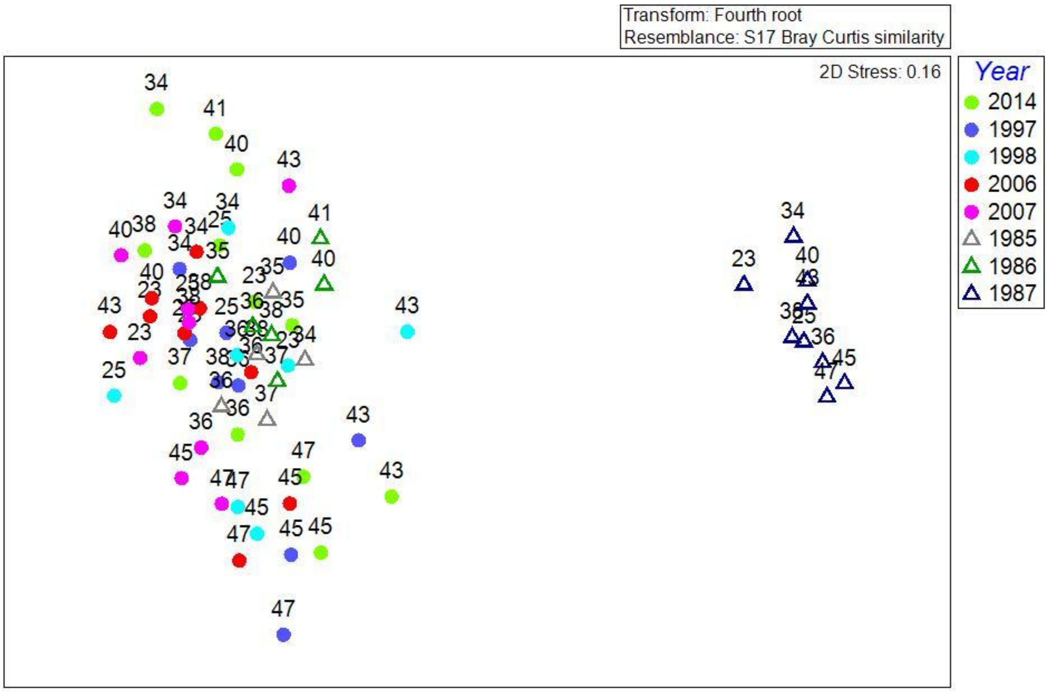



**Figure 18**. nMDS ordination of fourth root transformed data from 1985 – 2014 labelled according to station. N.B. samples from 1985-87 represent 0.4m$^2$, samples from 2006-2014 represent 0.2m$^2$.

## 2.2.6 Abrasion pressure

Abrasion pressure has remained consistently low over time at stations 43, 45 and 47 located in the western part of the SCI and at station 38 located in the centre of the SCI. Stations recently (2013) coincident with an abrasion pressure were 36 and 41, located in the south and the north of the SCI respectively. Station 23 had sustained the highest levels of abrasion pressure over time (Table 7).

**Table 7**. Subsurface abrasion pressure values (swept area ratio) (2006-2013) for temporal station positions. Cells are coloured according to pressure categories displayed in Figure 2.

| | Station | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year** | **23** | **25** | **34** | **35** | **36** | **37** | **38** | **40** | **41** | **43** | **45** | **47** |
| **2006** | 0.31 | 0.16 | 0.02 | 0.017 | 0.0006 | 0.017 | 0.039 | 0.076 | 0.122 | 0.0007 | 0.0019 | 0.017 |
| **2007** | 0.15 | 0.25 | 0.14 | 0.153 | 0.0585 | 0.1 | 0.053 | 0.212 | 0.088 | 0.0188 | 0.0006 | 0.049 |
| **2008** | 0.26 | 0.16 | 0.18 | 0.051 | 0.0538 | 0.009 | 0.034 | 0.174 | 0.053 | 0.0013 | 0.0025 | 0.024 |
| **2009** | 0.16 | 0 | 0.05 | 0.05 | 0.1039 | 0.07 | 0.024 | 0.129 | 0.001 | 0.0038 | 0.0008 | 0.029 |
| **2010** | 0.16 | 0.01 | 0.18 | 0.092 | 0.1245 | 0.061 | 0.086 | 0.147 | 0.103 | 0 | 0.0027 | 0.003 |
| **2011** | 0.12 | 0.09 | 0.14 | 0.127 | 0.1157 | 0.055 | 0.029 | 0.173 | 0.001 | 0 | 0 | 0.039 |
| **2012** | 0.15 | 0.07 | 0.16 | 0.056 | 0.1319 | 0.1 | 0.083 | 0.001 | 0.008 | 0 | 0 | 0.031 |
| **2013** | 0.18 | 0.12 | 0.1 | 0.174 | 0.2237 | 0.089 | 0.077 | 0.044 | 0.248 | 0.0013 | 0 | 0.019 |

## 2.2.7 Data comparison: Particle size distribution

Analysis of the PSD data from both gears (0.1m$^2$ Hamon grab and 0.2m$^2$ Van Veen grab), indicated seven sediment groups as the best group output from Entropy analyses. The optimum number of clusters is achieved when the Calinski–Harabasz (C–H) statistic is at its maximum (Orpin & Kostylev 2006). In addition to this statistic, expert judgement meant that in some cases where groups were sufficiently similar, they are considered to be the same group, and suffixed with an ‘a’ or a ‘b’ to show original grouping. Sediment characteristics and profiles for each of these final groups are given in Figure 19 and Tables 8a & 8b.

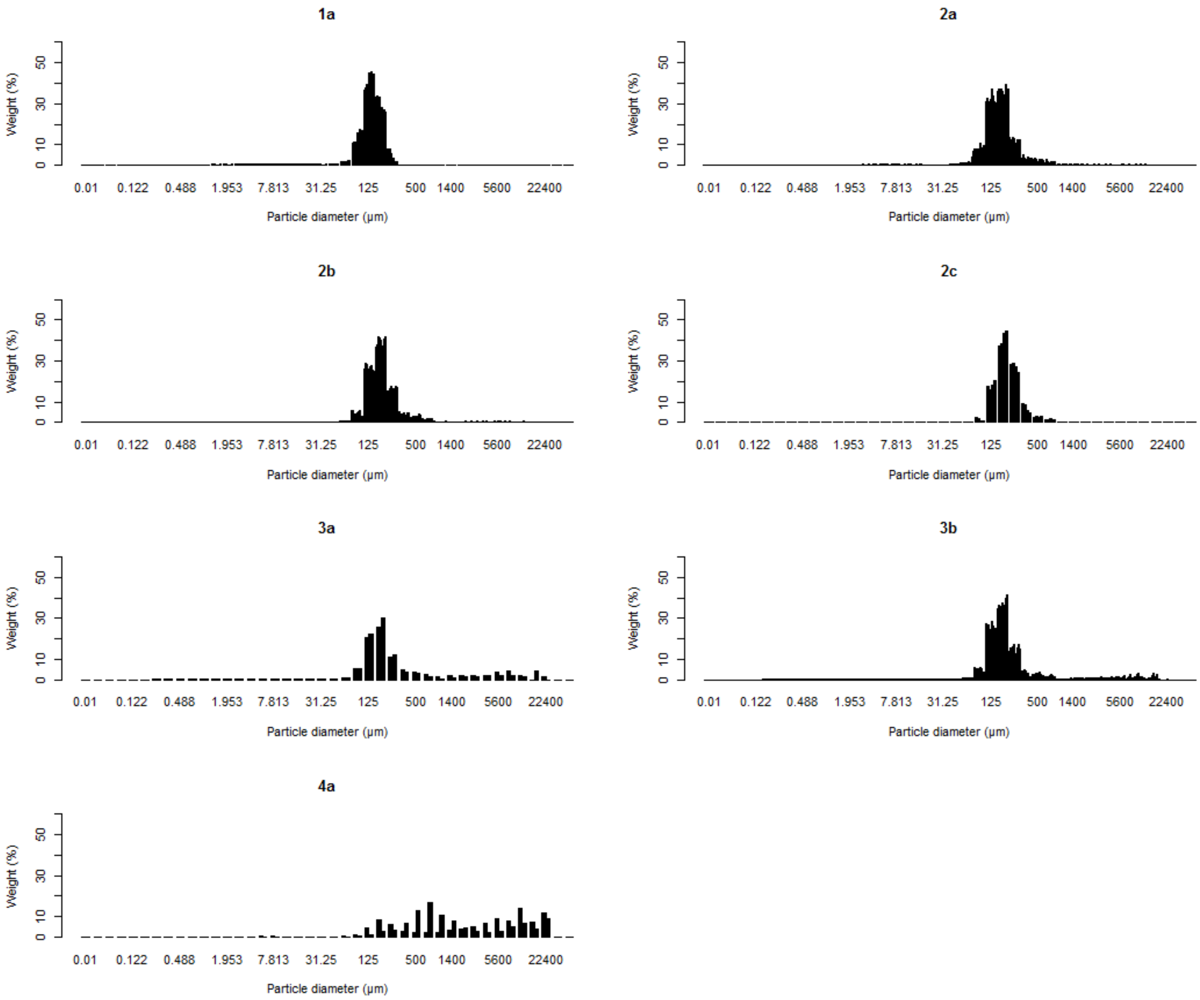



**Figure 19.** Particle size distribution histograms for each sediment group. All samples are represented within the histograms.

**Table 8 a & b** Sediment characteristics of the five sediment groups, produced on the average particle size distribution for each sediment group, using Gradistat (Blott & Pye 2001).

a)

| Sediment group | Number of samples | Sediment description | Sorting (ϕ) | Sorting description | Mode 1 (µm) | Mode 2 (µm) | Mode 3 (µm) |
|---|---|---|---|---|---|---|---|
| Group1a | 7 | Slightly Gravelly Sand | 1.46 | Poorly sorted | 150.9 | | |
| Group2a | 16 | Slightly Gravelly Sand | 1.42 | Poorly sorted | 213.4 | | |
| Group2b | 10 | Slightly Gravelly Sand | 1.27 | Poorly sorted | 213.4 | | |
| Group2c | 4 | Slightly Gravelly Sand | 0.84 | Moderately well sorted | 213.4 | | |
| Group3a | 2 | Gravelly Sand | 2.43 | Very poorly sorted | 213.4 | | |
| Group3b | 12 | Gravelly Sand | 1.76 | Poorly sorted | 213.4 | | |
| Group4a | 2 | Sandy Gravel | *2.60* | Very poorly sorted | 26950.0 | 13600.0 | 853.6 |

b)

| Sediment group | Gravel (%) | Very coarse sand (%) | Coarse sand (%) | Medium sand (%) | Fine sand (%) | Very fine sand (%) | Silt/clay (%) |
|---|---|---|---|---|---|---|---|
| Group1a | 0.70 | 0.25 | 0.02 | 4.50 | 71.83 | 15.84 | 6.86 |
| Group2a | 1.25 | 0.66 | 3.53 | 14.85 | 66.50 | 8.93 | 4.28 |
| Group2b | 1.61 | 0.57 | 4.49 | 19.97 | 65.86 | 5.18 | 2.32 |
| Group2c | 0.17 | 0.17 | 4.20 | 34.34 | 58.72 | 1.69 | 0.71 |
| Group3a | 16.50 | 2.59 | 5.40 | 15.81 | 49.43 | 6.29 | 3.97 |
| Group3b | 6.59 | 0.97 | 4.49 | 17.79 | 62.25 | 5.37 | 2.54 |
| Group4a | 50.86 | 11.71 | 16.84 | 9.58 | 8.34 | 1.07 | 1.59 |

**Table 9**. Summary table comparing results of the particle size analysis for 0.2m$^2$ Van Veen and 0.1m$^2$ Hamon grab sample collection methods. Cells are coloured according to classification as coarse sediment (pink) or sand and muddy sand (yellow).

| Sample Code | HG Sediment group | VV Sediment group | Different sediment group comment | HG Gravel (%) | VV Gravel (%) | HG Folk symbol | VV Folk symbol | HG EUNIS groups | VV EUNIS groups |
|---|---|---|---|---|---|---|---|---|---|
| B031 | 3a | 2b | Lower gravel content in VV. | 17.81 | 1.62 | gS | (g)S | coarse sediment | sand and muddy sand |
| B060 | 2a | 2a | | 1.31 | 0.73 | (g)S | S | sand and muddy sand | sand and muddy sand |
| B063 | 2a | 2a | | 1.09 | 0.93 | (g)S | S | sand and muddy sand | sand and muddy sand |
| B099 | 2a | 2a | | 0.11 | 0.51 | S | S | sand and muddy sand | sand and muddy sand |
| B100 | 1a | 2a | Very slightly lower gravel content in VV. Profiles very similar. | 1.57 | 0.65 | (g)S | S | sand and muddy sand | sand and muddy sand |
| B101 | 2a | 2a | | 1.05 | 1.58 | (g)S | (g)S | sand and muddy sand | sand and muddy sand |
| B102 | 2a | 2a | | 2.48 | 2.46 | (g)S | (g)S | sand and muddy sand | sand and muddy sand |
| B103 | 2a | 2a | | 1.93 | 1.46 | (g)S | (g)S | sand and muddy sand | sand and muddy sand |
| B104 | 1a | 1a | | 1.10 | 0.40 | (g)S | S | sand and muddy sand | sand and muddy sand |
| WK01_33 | 4a | no VV core | | 65.16 | n | sG | n | coarse sediment | n |
| WK02_35 | 3b | 2b | Lower gravel content in VV | 6.33 | 2.11 | gS | (g)S | coarse sediment | sand and muddy sand |
| WK03_37 | 3b | 2b | Lower gravel content in VV | 6.05 | 2.16 | gS | (g)S | coarse sediment | sand and muddy sand |
| WK04_39 | 4a | no VV core | | 36.57 | n | sG | n | coarse sediment | n |
| WK05_41 | 3a | 3b | Lower gravel content in VV | 15.18 | 8.17 | gS | gS | coarse sediment | coarse sediment |
| WK06_23 | 2b | 2b | | 0.57<br>2.63 | 0.69 | S<br>(g)S | S | sand and muddy sand<br>sand and muddy sand | sand and muddy sand |
| WK07_25 | 2b | 3b | Higher gravel content in VV | 2.49<br>2.98 | 7.02 | (g)S<br>(g)S | gS | sand and muddy sand<br>sand and muddy sand | coarse sediment |
| WK08_34 | 1a | 1a | | 0.86 | 0.88 | S | S | sand and muddy sand | sand and muddy sand |
| WK09_36 | 3b | 3b | | 10.82 | 4.85 | gS | (g)S | coarse sediment | sand and muddy sand |
| WK10_38 | 3b | 2a | Lower gravel content in VV | 4.76 | 1.07 | (g)S | (g)S | sand and muddy sand | sand and muddy sand |
| WK11_40 | 3b | 3b | | 5.27 | 6.24 | gS | gS | coarse sediment | coarse sediment |
| WK12_43 | 2b | 2b | | 0.41 | 0.45 | S | S | sand and muddy sand | sand and muddy sand |
| WH13_45 | 2c | 2c | | 0.02 | 0.05 | S | S | sand and muddy sand | sand and muddy sand |
| WK14_47 | 2c | 2c | | 0.23 | 0.36 | S | S | sand and muddy sand | sand and muddy sand |
| WK15_T4 | 1a | 1a | | 0.04 | 0.07 | S | S | sand and muddy sand | sand and muddy sand |
| WK16_T5 | 3b | 3b | | 6.91<br>8.72 | 4.00 | gS<br>gS | (g)S | coarse sediment<br>coarse sediment | sand and muddy sand |
| WK17_T8 | 2a | 2a | | 1.01 | 1.66 | (g)S | (g)S | sand and muddy sand | sand and muddy sand |

Samples collected from a given station using both 0.2m$^2$ Van Veen and 0.1m$^2$ Hamon grab were generally assigned to the same broadscale habitat and sediment group (Table 9). However, the Van Veen grab was not able to acquire valid samples in coarser sediments containing large proportions of gravel (>36% gravel).

### 2.2.8 Data comparison: Macrofauna

Univariate metrics were calculated for the number of taxa, number of individuals, Hills diversity (N1) and total biomass for samples collected by 0.1m$^2$ Hamon grab (MHN) and 0.2m$^2$ Van Veen grab (VV). Figure 20 shows the variability of these metrics along with the variability in abundance and biomass of bivalves collected by each gear type. Significant differences ($p>0.01$) were observed in all metrics between the two gear types with the 0.2m$^2$ Van Veen samples expressing larger values (see Table 10 andTable 11).

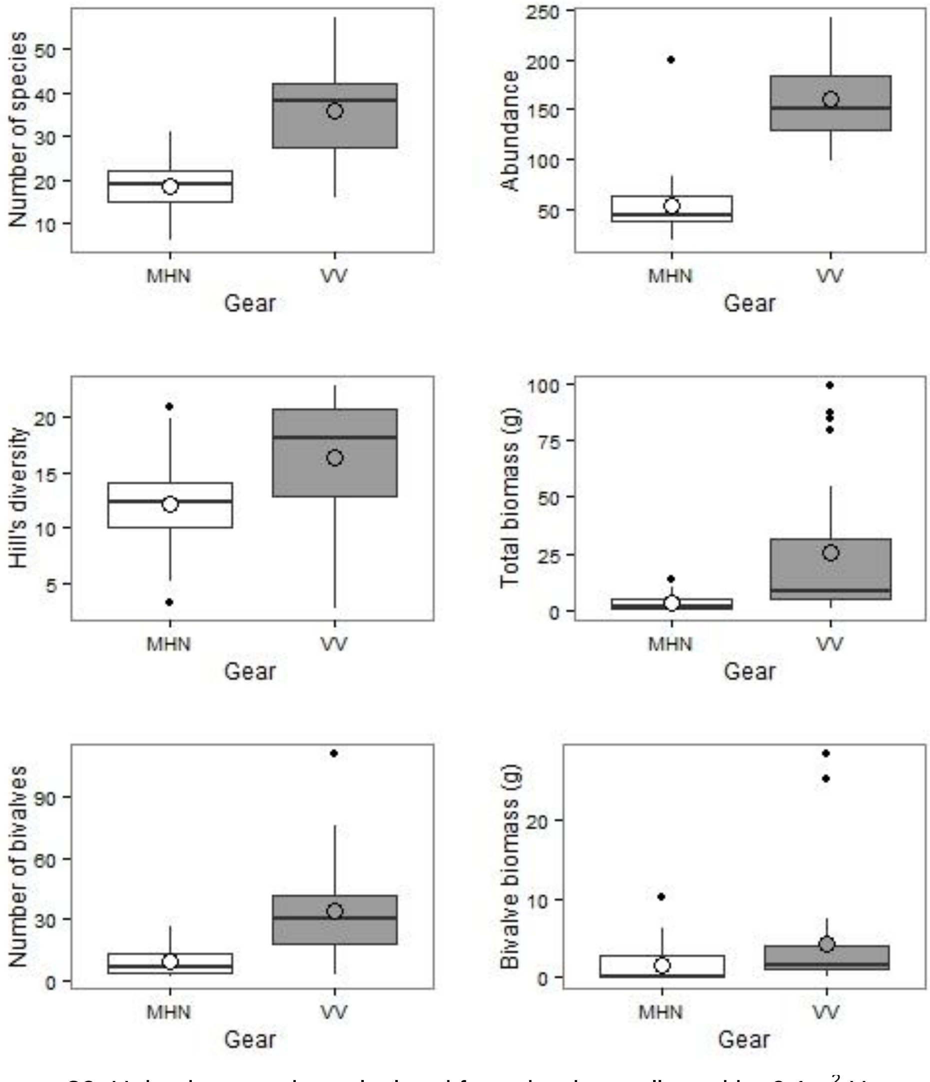



**Figure 20**. Univariate metrics calculated from the data collected by 0.1m$^2$ Hamon grab (MHN) and 0.2m$^2$ Van Veen (VV).

Figure 21 shows how the frequency distribution in these metrics differ according to gear types. The distribution of all univariate metric values were observed to be skewed towards the higher end of the x axes in the samples taken using the 0.2m$^2$ Van Veen grab.

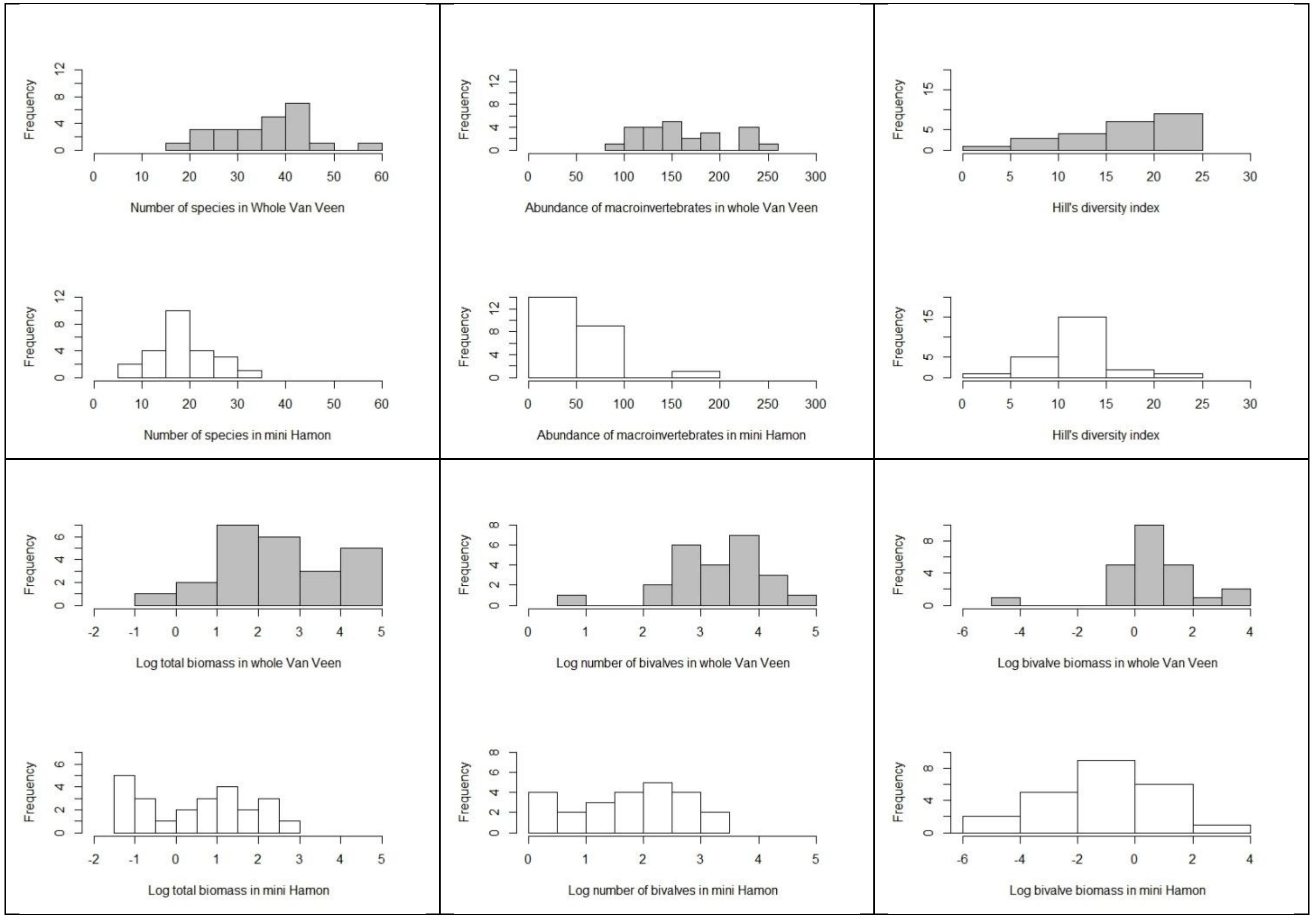



**Figure 21**. Frequency distribution in the number of species, number of individuals, Hills diversity (N1), total biomass, bivalve abundance and bivalve biomass according to gear type. $0.1m^2$ Hamon grab samples are presented as open bars and $0.2m^2$ Van Veen grab samples are presented as shaded bars.

Summary statistics showing the range, median, mean, variance and standard deviation of the univariate metrics calculated from samples collected using a 0.1m$^2$ Hamon grab and 0.2m$^2$ Van Veen grab are provided in Table 10 and Table 11.

**Table 10**. Summary statistics for each of the metrics calculated from the 0.1m$^2$ Hamon grab (HG) samples.

| 0.1m$^2$ HG | **S** | **N** | **Hill's** | **N.Bivalves** | **Bivalve biomass (g)** | **Total biomass (g)** |
|---|---|---|---|---|---|---|
| Range | 6 – 31 | 17 - 199 | 3.2 – 20.8 | 1 – 26 | 0.0002 – 10.2702 | 0.2836 – 13.4817 |
| Median | 19.00 | 43.00 | 12.25 | 6.5 | 0.19915 | 1.8016 |
| Mean | 18.67 | 53.75 | 12.14 | 9.0 | 1.56419 | 3.3347 |
| Variance | 38.84 | 1259.41 | 17.19 | 53.61 | 6.73 | 13.62 |
| SD | 6.23 | 35.49 | 4.45 | 7.32 | 2.59 | 3.69 |

**Table 11.** Summary statistics for each of the metrics calculated from the 0.2m$^2$ Van Veen grab (VV) samples.

| 0.2m$^2$ VV | **S** | **N** | **Hill's** | **N.Bivalves** | **Bivalve biomass (g)** | **Total biomass (g)** |
|---|---|---|---|---|---|---|
| Range | 16 - 57 | 98 – 242 | 2.6 – 22.7 | 2 – 111 | 0.0132 – 28.3636 | 0.6645 – 98.5853 |
| Median | 38.00 | 151.00 | 18.00 | 30.50 | 1.5356 | 8.2948 |
| Mean | 36.00 | 160.10 | 16.28 | 34.08 | 4.4264 | 25.5871 |
| Variance | 89.13 | 1962.90 | 30.36 | 591.73 | 52.4136 | 973.0306 |
| SD | 9.44 | 44.30 | 5.51 | 24.33 | 7.2397 | 31.19344 |

Multivariate analysis (using nMDS ordination) of the square root transformed infaunal data highlight differences in community composition indicated by samples collected using a 0.1m$^2$ Hamon grab compared with those collected using a 0.2m$^2$ Van Veen grab (Figure 22). ANOSIM analysis suggested small but significant differences in faunal composition between the two gear types ($R = 0.27$, $p<0.001$). SIMPER analysis showed that within gear variability in community composition was high (0.2m$^2$ Van Veen: 39.53% and 0.1m$^2$ Hamon grab: 31.03%). Average dissimilarity between communities sampled using the different gear types was also high (69.80%). Seventy-eight taxa were absent from the 0.1m$^2$ Hamon grab samples and present in the 0.2m$^2$ Van Veen samples. Conversely, 19 taxa were absent from the 0.2m$^2$ Van Veen samples and present in the 0.1m$^2$ Hamon grab samples (Appendix 5).

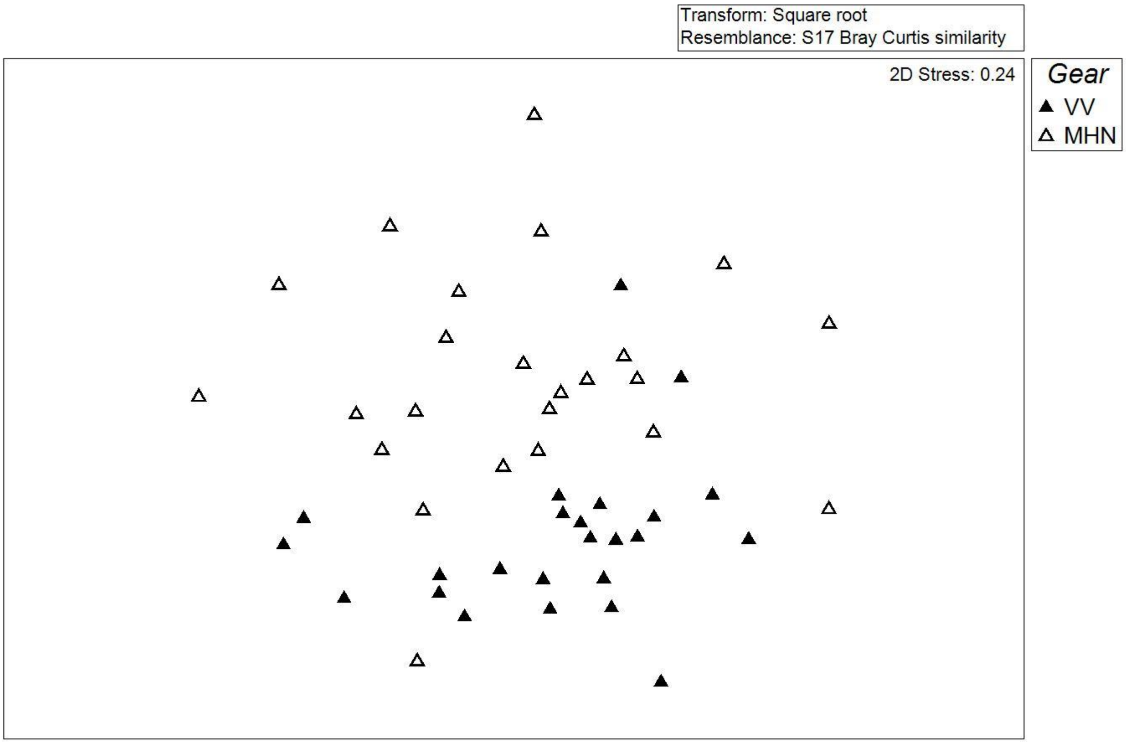



**Figure 22**. nMDS of infaunal communities sampled using a 0.1m$^2$ Hamon grab (MHN) (open triangles) and 0.2m$^2$ Van Veen grab (VV) (closed triangles).

## 2.3 Discussion

Spatial variability in both sediments and biological communities are apparent across the Dogger Bank SCI. The spatial variability in sediments was assessed using three methods to better understand the consequences of applying different classifications to the sediment samples collected.

- Percentage composition of mud, sand and gravel
- EUNIS level 3 classification
- Statistical groupings based on half-phi sediment classifications using EntropyMax.

All three methods indicate spatially variable sediment groups exist across the Dogger Bank. However, the application of Entropy utilises the full-resolution PSD data (at 0.5 ϕ intervals) and is therefore suggested as more comprehensively describing the sediment characteristics.

It is not fully understood which method of sediment classification is most meaningful from an ecological perspective and, thus, is most appropriate for exploring changes in their associated biological communities. Sediment samples taken during the current study ranged from slightly gravelly sand to sandy gravel, with a number of samples also containing a high mud content. This observed variability in the sediment composition of the Dogger Bank SCI is hypothesised to be due to its unique geological history and is therefore thought to be more physically stable than other offshore sandbanks formed by hydrological, rather than geological, processes (Kröncke & Knust 1995; Diesing *et al* 2009).

Unlike other, more dynamic, coastally located sandbanks in the North Sea, macrofaunal communities on the Dogger Bank are characterised by higher overall abundance of individuals, numbers of species and total biomass (DTI 2001). This is largely due to the heterogeneity of available habitats within the Dogger Bank SCI coupled with increased food availability resulting from hydrodynamic processes (Rees *et al* 2007; Wieking & Kröncke 2001). Large areas of heterogenous sediments are often characterised by species typical of sandy sediments, such as *Bathyporeia* spp. and *Spiophanes bombyx*. However multivariate analysis of the 2014 infaunal community indicates a north/south divide in the benthic communities present within Wieking and Kroncke's 'Bank' community. For instance, *Acrocnida brachiata* and *Kurtiella bidentata* are only present in samples collected in northern region of the 'Bank'. This supports previous studies which have described the Dogger Bank as a 'transitional zone' between Northern and Southern North Sea hydrodynamic regimes (Rees *et al* 2007) with Atlantic inflow dominating to the north and coastal-water influences governing the south (MAFF 1981).

Bivalves are under consideration as a candidate indicator as part of MSFD indicator development (OSPAR 2012). The assumption is that benthic communities typically consist of a mixture of long-living and short-living species. The short-living species are usually small with low individual biomass whilst the long-living species can reach much larger sizes and higher individual biomass. The natural balance between large and small species within a community and large and small specimens within a single species population can be affected by anthropogenic pressure. The most abundant bivalve species collected across the SCI were generally small sized and were typical of sandy sediments. However even the most abundant species were not present in sufficient numbers to allow robust size frequency distribution analysis. For example, the development of *Macoma balthica* as a state indicator within Baltic waters highlighted a minimum of 100 adult individuals per square metre to provide a reliable estimate of the population size distribution. Low abundances of large long-lived bivalves collected in this study may be the result of the small footprint and shallow penetration depth of the gear used and/or due to naturally low occurences of these species on the Dogger Bank. A bivalve size structure indicator may therefore not be appropriate for monitoring status of highly dynamic, sedimentary habitat features.

Broad sediment types present across the SCI appear to be temporally stable. However analyses were limited due to the resolution of and methods used to generate the historical data. Temporal comparisons of the benthic infaunal communities, using the new survey data combined with the historical data, indicates that the total number of taxa and total abundance of macroinvertebrates is highly variable with no clear temporal trend. A number of factors may contribute to the observed variability across the data sets, including differences in sampling technique and gear type employed, along with the population dynamics of species typical of the Dogger Bank. However, abrasion scores were generally and consistently low at the temporal stations and are therefore unlikely to be linked to the observed variability in benthic community structure.

Surveys conducted on the Dogger Bank have historically employed a variety of sampling techniques (e.g. Van Veen Grabs, Hamon grabs) with different units of quantification (ranging from 0.1-0.2m$^2$ surface area sampled). When comparing the datasets derived from the 0.1m$^2$ mini Hamon grab and the 0.2m$^2$ Van Veen grab, all of the macrofaunal derived metrics were significantly greater when the larger Van Veen grab was employed. The observed differences in community structure were mainly attributable to higher abundances and increased occurrence of rarer species in the larger grab type. Although this may appear self-evident, it highlights the limitations and consequences of selecting a certain gear type over another when designing sampling strategies for ongoing monitoring programmes, especially when conservation features span different international jurisdictions as is the case for the Dogger Bank SCI.

Despite the limitations detailed above, making use of historic datasets when evaluating specific monitoring strategies can provide information on any temporal variability in environmental conditions and faunal communities. To facilitate the use of a combined time series dataset, the collection and processing methods of any historic datasets must be aligned with the current robust quality assurance criteria associated with those acquired for more recent, bespoke surveys. In comparing metrics derived from faunal data acquired using variable sampling techniques a number of limitations were encountered. For example, in relation to the IQI, an EQR value cannot be produced using the publically available IQI workbook v4 due to restrictions on the size of grab permitted (unable to select $0.2m^2$ gears). As a consequence, assessment of change in the benthic community over time may be masked by the variability in the datasets which results from the use of different types of sampling gear. Furthermore, indicators that make use of the population parameters (e.g. size-frequency) of particular species collected using sediment grabs, such as bivalves, are constrained by the ability of the gear to adequately sample fauna which typically occur deeper in the sediment. These differences in 'gear success' have practical consequences when developing monitoring strategies specific to an area such as the implications of missing entire functional groups which are not adequately sampled by the selected sampling gear.

Analysis of the time series data available indicated that the benthic community as a whole does not exhibit any discernible temporal trend and suggests a level of temporal stability at the site. However, one historic infaunal dataset (1987) used to determine temporal variation in benthic macroinvertebrates formed a separate cluster to both the historic and contemporary samples. The reasons for this separation appear to be due to the absence of certain species which were present in high numbers during other sampling occassions. Wieking and Kröncke (2001, 2003) suggest that the macrofaunal communities on the Dogger Bank can be explained, in part, by measured environmental variables (depth and sediment variables). However, it is suggested that further understanding is required regarding the wider influences of food availability and hydrodynamic processes on the Dogger Bank as no single variable was identified to be an obvious driver for differences in the overall patterns observed.

A change in the North Atlantic Oscillation (NAO) was demonstrated to alter the macrobenthic community structure of the Dogger Bank in the period between 1980-1990, providing further evidence of the natural variability within the SCI (Wieking & Kröncke 2001). A number of other environmental factors have been hypothesised as drivers of the observed spatial and temporal patterns in biological communities in the North Sea, including the Dogger Bank (Künitzer *et al* 1992; Snelgrove & Butman 1994). Sediment grain size has traditionally been used as a proxy for investigations into patterns in the distribution of benthic infaunal communities. Similarly, North Sea macrofauna communities have also been shown to vary with water depth (Künitzer *et al* 1992; Heip *et al* 1992; Rees *et al* 2007), suggesting stratification based on temperature variability. However, the taxa which inhabit the Dogger Bank SCI are dominated by cosmopolitan species with an ability to tolerate a wide thermal range implying that sediment characteristics or water depth alone does not fully explain the observed variability in community structure (Rees *et al* 2007; Diesing *et al* 2009). As such, it is important to understand the contribution of additional factors (e.g. trophic interactions) in determining the observed spatial patterns in biological communities (Snelgrove & Butman 1994). For example, a combination of environmental parameters (such as sediment type and depth) along with hydrodynamic regime alters food supply to the benthos, as evidenced by differences in the trophic structure of the Dogger Bank macrobenthic communities (Wieking & Kröncke 2003). In this context a better understanding of the role of food availability and subsequent population structure is required for highly variable sites such as the Dogger Bank SCI. Whilst such investigations would require a more targeted and comprehensive study of food web dynamics, and were thus beyond the scope of the current study, it is suggested that additional factors such as total organic carbon in the sediment, would aid interpretation of results and should be considered in future monitoring.

The disappearance of extensive populations of the bivalve species *Spisula* and *Mactra* described by Davis 1923 and 1925 (cited in Wieking & Kröncke 2003) has been hypothesised to be attributable to certain anthropogenic influences (e.g. eutrophication and high sediment contamination in the 20µm fraction) (Kröncke & Knust 1995). However, this has not been tested empirically due to the lack of available associated environmental parameters (Kröncke 1991). Bivalves play an important role in nutrient cycling and are often the dominant functional group with regards to filter feeding. Bivalves are also an important dietary component for a number of commercially important fish species (Gibson 2004). Therefore, changes in the prevalence of given functional roles in the infauna can result in ecosystem wide changes which may or may not permanently alter historic equilibria (Link 2002). As such, even in the absence of a known causative factor for the decline of *Spisula* and *Mactra*, their perceived decrease implies potential long-term changes in the ecosystem of the Dogger Bank.

# 3 Operational monitoring to determine pressure-state relationships

Null Hypothesis:
*Benthic communities and sediment characteristics of the Dogger Bank SCI, subject to varying levels of abrasion pressure, do not differ.*

## 3.1 Methods

### 3.1.1 Survey design

Targeted sampling for the operational 'pressure-state' relationship monitoring element of this study was planned along a subsurface abrasion pressure gradient, informed using spatial distribution of both UK and non UK demersal fishing effort acquired from Vessel Monitoring System (VMS) data following the methods detailed in Church *et al* (2016). It is suggested that faunal communities typically associated with sandbank features are able to recover within 100 days (Collie *et al* 2000). Therefore, the subsurface abrasion layer derived from VMS data reported from the year preceding the 2014 survey only (2013) was used to inform on the pressure gradient across which sampling stations were positioned. It should also be noted that no VMS data from 2014 were available at the time of survey planning, therefore it could not be used to inform the sampling strategy. A gridded (0.05dd) subsurface abrasion pressure layer from 2013 was created to identify areas across the site that have potentially been exposed to varying levels of physical abrasion pressure as a result of demersal trawling activities. Table 12 details the subsurface abrasion pressure (swept area ratio) within each of the pressure cells identified. Figure 23 shows how the pressure cells are distributed across the study area chosen for this element of the investigation. Data from 2006 – 2012 (not used in survey planning) were classified according to the same categories as 2013 and are presented in Appendix 2 to demonstrate the variability in abrasion pressure within a cell over time.

**Table 12**. Subsurface abrasion pressure (swept area ratio) due to fishing activity within the abrasion cells identified from the 2013 pressure layer.

| | 0a | 0b | 1a | 1b | 2a | 2b | 3a | 3b | 4a | 4b |
|---|---|---|---|---|---|---|---|---|---|---|
| 2013 | 0 | 0 | 0 - 0.09 | 0 - 0.09 | 0.1 - 0.21 | 0.1 - 0.21 | 0.22 - 0.4 | 0.22 - 0.4 | 0.41 - 0.95 | 0.41 - 0.95 |

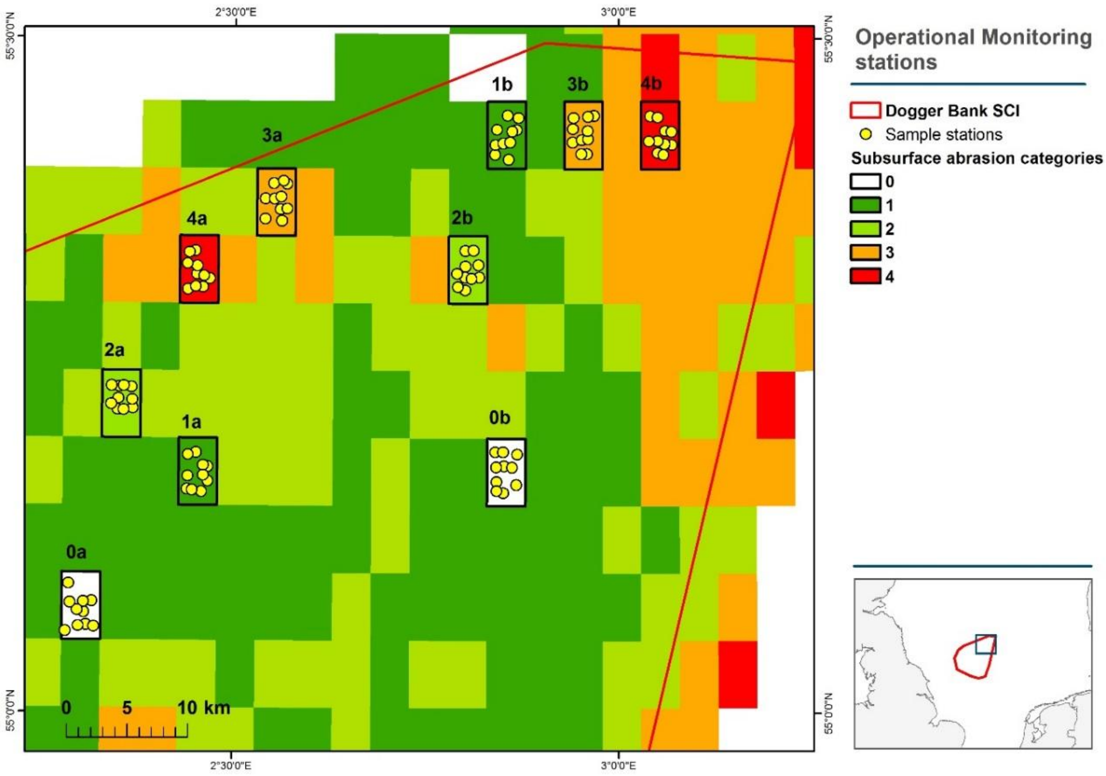



**Figure 23.** Operational monitoring 'pressure gradient' study planned sampling locations. Subsurface abrasion, quantified as swept area ratio, was clipped to the SCI boundary (with a 0.05dd buffer) and classified into four categories using Jenks natural breaks. Areas where no VMS data were present were excluded from the classification and are displayed in white. These effectively serve as the 5$^{th}$ category and represent null values. Projection used is WGS 1984 UTM Zone 31N.

Analysis of infaunal univariate metrics (infaunal abundance and species number) calculated using existing data did not show any significant relationship with physical abrasion pressure (see Appendix 3). It was not therefore possible to carry out a meaningful power analyses to inform the sampling density required for this element of the study.

The 2013 subsurface abrasion layer was split into five pressure categories (0-4), the values of which are shown in Table 13. Two replicate cells ('a' and 'b') were identified for each category resulting in 10 cells in total (Figure 23). The number of categories and replicates was based on available time for this element of the survey along with experience derived from similar 'pressure-response' studies applied at comparable feature types (Jenkins *et al* 2015). These cells were chosen primarily based on their location, as practical consideration was given to achieving multiple survey objectives with limited vessel time. Cells were located within Management Area B (see Section 3), which was originally planned to be the first area visited, to enable parallel objectives to be achieved simultaneously and mitigate against the risk of unforeseen circumstances (such as adverse weather or equipment downtime) affecting the ability to succesfuly sample. Care was also taken to ensure cells of the same pressure category were not within a cell's width (0.05dd) of one another to avoid the effects of spatial autocorrelation and pseudoreplication. Each cell (0.05dd x 0.05dd in size), was selected to be representative of the same water depth (-40m to -30m).

**Table 13**. Subsurface abrasion pressure (swept area ratio) cell values calculated from VMS data for UK and non-UK fishing vessels for 2013.

| Cell code | Fishing pressure (swept area ratio) |
|---|---|
| 0a | Null |
| 0b | Null |
| 1a | 0.047 |
| 1b | 0.0013 |
| 2a | 0.1 |
| 2b | 0.171 |
| 3a | 0.323 |
| 3b | 0.288 |
| 4a | 0.446 |
| 4b | 0.423 |

Ten samples per cell were randomly allocated using ETGeowizard's 'Random points in polygon' tool with a minimum distance between samples, and from cell boundaries, of 0.005dd as a precaution to mitigate against the risk of spatial autocorrelation. In total, 100 sampling points were planned for this element of the survey. Any sample points that lay within a 500m buffer of oil and gas wells and pipelines were relocated to the closest suitable location. The Dogger Bank 2014 survey report (Ware & McIlwaine 2014) provides further detail on how the sample points were selected for this element of the study.

### 3.1.2 Indicator selection and testing

A range of candidate indicators were selected for testing in this element of the study to help inform future monitoring of the impacts of physical abrasion on comparable offshore sandbank features present in the wider environment. The candidate indicators include: species richness, abundance and diversity measures for infauna and epifaunal communities, the Infaunal Quality Index (IQI) and its component metric AMBI, size-frequency of epifaunal taxa biomass, bivalve morphometrics and BTA as a tool to detect changes in the benthic epifauna that could be attributed to abrasion.

### 3.1.3 Sample acquisition and processing

In total, ten 0.1m$^2$ Hamon grab samples, three camera sledge video tows and three 2m beam trawl samples were collected from within five paired abrasion pressure boxes (0–4, a,b), positioned along the identified gradient of pressure. The number of video tows and beam trawl samples to be taken was pre-determined based on available survey time. Detailed sample acquisition methods are provided in Appendix 1 and within the survey report (Ware & McIlwaine 2014).

**Sediment Particle Size Analysis (PSA)**
Sediment sub samples (~500ml) were collected from the infaunal sample prior to sieving. (see Appendix 1 for detailed sample acquisition methods) and were analysed at half-phi intervals using a combination of laser diffraction (<1mm fraction) and dry sieving techniques (>1mm) as described in National Marine Biological Analytical Quality Control Scheme PSA guidance (Mason 2011).

**Infaunal sample processing**
Processing of the infaunal samples collected using the 0.1m$^2$ Hamon grab (see Appendix 1 for detailed sample acquisition methods) followed standard laboratory practices. Results were checked following the recommendations of the NMBAQC scheme (Worsfold *et al* 2010). Taxa were identified to highest taxonomic resolution and weighed.

**Bivalve size frequency distribution**
Morphometric measurements for all bivalves species present were taken. Metrics recorded for each individual included: 1) maximum valve width (mm) per individual as well as whole body biomass (blotted wet weight in g) per individual.

**Epifauna assemblage analysis**
A total of 30 camera deployments (three tows per abrasion cell) were collected producing 30 x ten minute videos and 494 still images. Observations were made within a fixed field of view and over a standard distance. Videos and stills images were processed following guidance documents developed by Cefas and the JNCC for the acquisition and processing of video and still images (Coggan & Howell 2005). Each video transect was analysed to determine faunal counts and SACFOR scores. Identification of anthropogenic activities such as the presence of trawl scars, fishing gears and litter was also recorded at each station.

In addition, 60 x 2m beam trawls were collected from 30 stations within the abrasion pressure boxes (two five minute replicate tows at three stations within each pressure cell, equating to a total swept area of $600m^2$ per station). Fauna were identified and categorised as belonging to one of 15 $\log_2$ body size categories as per Jennings *et al* (2001)(Table 14). The total number of individuals and their summed wet weight was recorded for each taxa at every size class. Pagurids were removed from their gastropod shell prior to weighing. Colonial taxa were weighed and a total wet weight obtained for each species encountered per tow. Fauna allocated to the smallest size class were removed from the analysis as they either represented infaunal species or juveniles.

**Table 14**. Epifauna size class bins used on survey to categorise beam trawl catch.

| Size class | Range (wet weight g) |
|---|---|
| 1 | <0.1 |
| 2 | 0.2 |
| 3 | 0.3-0.5 |
| 4 | 0.6-1.0 |
| 5 | 1.1-2 |
| 6 | 2.1-4 |
| 7 | 4.1-8 |
| 8 | 8.1-16 |
| 9 | 16.1-32 |
| 10 | 32.1-64 |
| 11 | 64.1-128 |
| 12 | 128.1-256 |
| 13 | 256.1-512 |
| 14 | 512.1-1024 |
| 15 | >1025 |

### 3.1.4 Data analysis

**Infauna assemblages**

Univariate metrics calculated, using PRIMER v6, for each infaunal sample included: number of species (S), total abundance (N) and Hill's (1973) taxon diversity index (N1). Juvenile taxa were removed prior to calculations.

Multimetric indices including Infaunal Quality Index (IQI), and one of its component metrics the AZTI Marine Biotic Index (AMBI), were calculated using both the infauna community and sediment PSD data within the publically available MS Excel macro based 'IQI Workbook UKTAG v01 20150311.xlsm' accessed from the Water Framework Directive UK TG website.[4] Forty-eight taxa were initially rejected when calculating the IQI workbook due to their not being assigned an ecological group. Amendments to their taxonomic resolution and/or use of different synonyms resulted in the inclusion of all 48 previously unassigned taxa as 46 distinct taxa. Particle size distribution information was reduced from 42 variables (percentage contribution at half-phi size classes) to nine class ranges (ranging from <63µm to ≥8000µm) for inclusion into the IQI metric.

Multivariate analyses were undertaken in PRIMER v6 using square-root transformed species abundance matrix (excluding juvenile and colonial taxa). A Bray-Curtis similarity matrix was calculated on the transformed data and displayed using nMDS ordination to explore community patterns with respect to abrasion pressure. The SIMPROF routine was used to determine statistically significant infaunal groups at the 5% level. Species contributing to the within group similarity were determined using SIMPER.

Boxplots were produced in R for each of the metrics. A Mann Kendall trend analysis was performed on each variable using the 'mannkendall' function from the library *emon* in R.[5]

Spatial autocorrelation analyses (semi-variogram plots) were carried out in R (R Core Team 2015) to ensure sample locations were independent of each other. A plot was generated for each metric being considered using the linear distance between sample locations, calculated from the coordinates of the actual sampling event. There was no evidence of spatial autocorrelation for any of the metrics tested (see Appendix 4).

**Epifaunal assemblages**
For video and 2m beam trawl samples, univariate metrics calculated for each sample included: total number of individuals (N), total number of taxa (S), and Hill's (1973) taxon diversity index (N1). Boxplots were produced in SigmaPlot® for each of the metrics. Multivariate analyses were undertaken to explore patterns in epifaunal assemblages along the gradient of fishing pressure. Results were displayed using nMDS ordination. The SIMPER routine was used to identify the taxa contributing to the similarity within and between the defined groups. Beam trawl samples were also used to generate size frequency histograms showing the frequency of each size class for stations combined by fishing pressure.

**Biological traits**
Five biological trait categories, with 23 modalities, were selected to investigate the functional composition and perceived vulnerability to demersal trawling of benthic epifaunal communities collected using the 2m beam trawl within each of the abrasion pressure boxes (Table 15). Trait information was extracted from a pre-existing and pre-coded trait database developed within Cefas under Defra funded project ME5301 and EU FP7 project BENTHIS. Where trait information for a species was absent from the database, information was sourced from published literature and internet searches. Where no information could be found, the traits from conspecifics or closely related taxa were assigned. This allowed all taxa to be included in the analysis. The trait modalities within each category were specifically chosen to closely align with the known responses of benthic macrofauna to trawling disturbance. The maximum size trait modalities were derived from literature. Note, these categories are discrete from the size bins used to categorise beam trawl catch on survey.

[4] http://www.wfduk.org/resources%20/coastal-and-transitional-waters-benthic-invertebrate-fauna [accessed July 2015].
[5] https://r-forge.r-project.org/projects/emon/ [Accessed February 2016]

**Table 15.** Five trait categories and their associated modalities used in the present study. Corresponding code (in brackets) given in results.

| Trait category | Modality (code) |
|---|---|
| **Sediment Position** | Surface (S)<br>0-5 cm (S)<br>6-10 cm (SS)<br>>10 cm (SS) |
| **Feeding Type** | Suspension (Other)<br>Surface deposit (Other)<br>Subsurface deposit (Other)<br>Predator/Scavenger (PRED/SCAV) |
| **Maximum Size**<br>(from literature) | >10mm (S)<br>11-20mm (S)<br>21-50mm (M)<br>51-100mm (L)<br>101-200mm (L)<br>201-500mm (L)<br>>500mm (L) |
| **Fragility**<br>(degree of damage inflicted by trawl) | Fragile shell/structure (3)<br>No protection (3)<br>Strong/flexible (2)<br>Robust/vermiform (1) |
| **Mobility**<br>(ability to move into recently trawled area) | Sessile (None)<br>Creep, climb (Low)<br>Crawl (Medium)<br>Swim (High) |

Trait modalities were assigned to individual taxa using a 'fuzzy coding' approach (Chevene *et al* 1994) according to the extent to which they displayed the modalities of each trait. Fuzzy coding allows taxa to exhibit categories to different degrees, avoiding the obligate assignment of a taxon to a single category which can lead to inaccurate characterisation of biological or ecological taxa profiles (Usseglio-Polatera *et al* 2000). In order to classify a taxon according to its affinity for more than one modality within a trait, each modality was given a score between 0 and 3, where 0 conveys that the taxon has no affinity for that modality, 1 or 2 express partial affinity and 3 indicates total and exclusive affinity for that modality (Bolam *et al* 2014).

In reality, certain traits such as sediment position, feeding type and longevity were predominantly expressed as partial affinities for most taxa. This reflected 1) variability of the trait within a particular taxon, 2) variability in the trait for a taxon from different published sources, and 3) variability displayed between different species within a genus. In contrast, entries for other traits, e.g. mobility and size, were often represented by a total affinity for one particular modality. The maximum size of species with appendages reflects to total size of the animal, not just carapace length or disc diameter, and Pagurid size was increased to accommodate an estimate of living accommodation (i.e. mollusc shell).

In order to determine if the highly trawled areas contained a greater number of scavenging species, the feeding type of certain species known to scavenge in recently (days/weeks) trawled areas was weighted to reflect this opportunistic trait (Groenewold & Fonds 2000). For example, *Buccinum undatum* is known to suspension feed, deposit feed and scavenge, however studies (e.g. Evans *et al* 1996) have shown that this species has been observed to opportunistically feed on dead and injured fauna that have been impacted by a trawl.

Organisms present in few incidences and identified only to lower taxonomic levels i.e. Polychaeta and Nemertea were removed prior to analysis, as were species such as *Neanthes fucata* (a commensal of hermit crabs).

When all taxa had been coded for the species by traits matrix, the codes were converted to proportions (i.e. *affinity* scores) for each taxon so that the total score for each trait category = 1. For example, for the trait ‘feeding mode’, if a species was assigned a ‘3’ for suspension feeding, a ‘3’ for surface-deposit feeding and a zero for the remaining categories; this was subsequently standardised to 0.5 and 0.5, respectively.

To look for a response to trawling disturbance, each trait modality was weighted according to its perceived vulnerability to trawling following methods detailed in De Juan and Demestre, 2012, as follows:

0 = Not affected by trawling or advantaged by trawling
1 = Low vulnerability to trawling
2 = Moderate vulnerability to trawling
3 = High vulnerability to trawling

For instance, organisms living on the surface or within the top 5cm of sediment were classified as highly vulnerable to trawling (based on evidence of trawl gear penetration (Paschen *et al* 2000; Kaiser & Spencer 1994) and therefore, their trait affinity score would be multiplied by 3. Smaller organisms are assumed to suffer lower direct mortality as they are pushed aside by the pressure wave in front of the fishing gear (Gilkinson *et al* 1998) and are therefore assigned a lower score. Organisms living greater than 10cm deep in the sediment were assumed to be affected less by trawling and therefore their trait affinity score was multiplied by 1 (they were not considered as completely unaffected, as trawl gear may turn over the sediment making deeper dwelling organisms susceptible to subsequent trawling episodes). Any organism with maximum potential size greater than 50mm was considered vulnerable to capture by the trawl based on beam trawler cod end mesh sizes of 80mm (see Van Marlen *et al* 2014).

Vulnerability scores were assigned to each of the modalities within three trait categories used in the overall vulnerability assessment as shown in Table 16:

**Table 16**. Trait modalities in relation to their vulnerability to trawling scores (eight traits).

| Score | Position in sediment | Size (mm) | Fragility |
|---|---|---|---|
| **0** | | <10 | Robust shell/vermiform |
| **1** | >10cm | 11--20 | Strong/flexible |
| **2** | 6-10cm | 21-50 | No protection |
| **3** | Surface – 5cm | >50 | Fragile |

Mobility and feeding type were considered separately to the other traits as they were used to assess scavenger immigration. The scores within each trait category were summed for each species and combined with the abundance data. All analyses were conducted within R (R Core Team 2015). Plots displaying vulnerability scores according to pressure gradient were produced for each of the trait categories. Overall vulnerability of a species was assessed by combining the total scores for the trait categories 'Size', 'Position in sediment' and 'Fragility'. The maximum possible score was 9, representing taxa most vulnerable to trawling.

To determine whether any differences in scavenging behaviour were apparent between the areas affected by different levels of trawling, the information from 'Size', 'Position in sediment', Mobility' and 'Feeding type' were combined as a trait string. For instance, a large surface dwelling (classified as surface to 5cm) highly mobile predator/scavenger would be assigned LSHIGHPRED/SCAV, whilst a small surface dwelling organism with no ability to move into an area affected by trawling and which is not a predator or scavenger would be assigned SSNONEOther. The abundances of species with the same trait string were summed for samples taken within each of the pressure boxes. Colonial organisms were considered as unit occurrence and therefore may be under represented.

## 3.2 Results

### 3.2.1 Particle size distribution

Samples were analysed at half-phi intervals using a combination of laser diffraction (<1mm fraction) and dry sieving techniques (>1mm) as described in National Marine Biological Analytical Quality Control Scheme PSA guidance (Mason 2011). Gradistat software (Blott & Pye 2001) was used to produce sediment statistics. The variability in sediment type in each of the treatment boxes is indicated in Figure 24. Sediments present across the pressure gradient (boxes 0-4a,b) are predominantly comprised of sands and gravelly sands. One sample in treatment box 0a contains higher proportions of both gravel and silt/clay resulting in the assignment of a mixed sediment classification for this sample. The sediments in treatment boxes 1a, and particularly in 1b, are more gravelly, while some sediments in treatment box 2b are muddier than sediments in other treatment boxes.

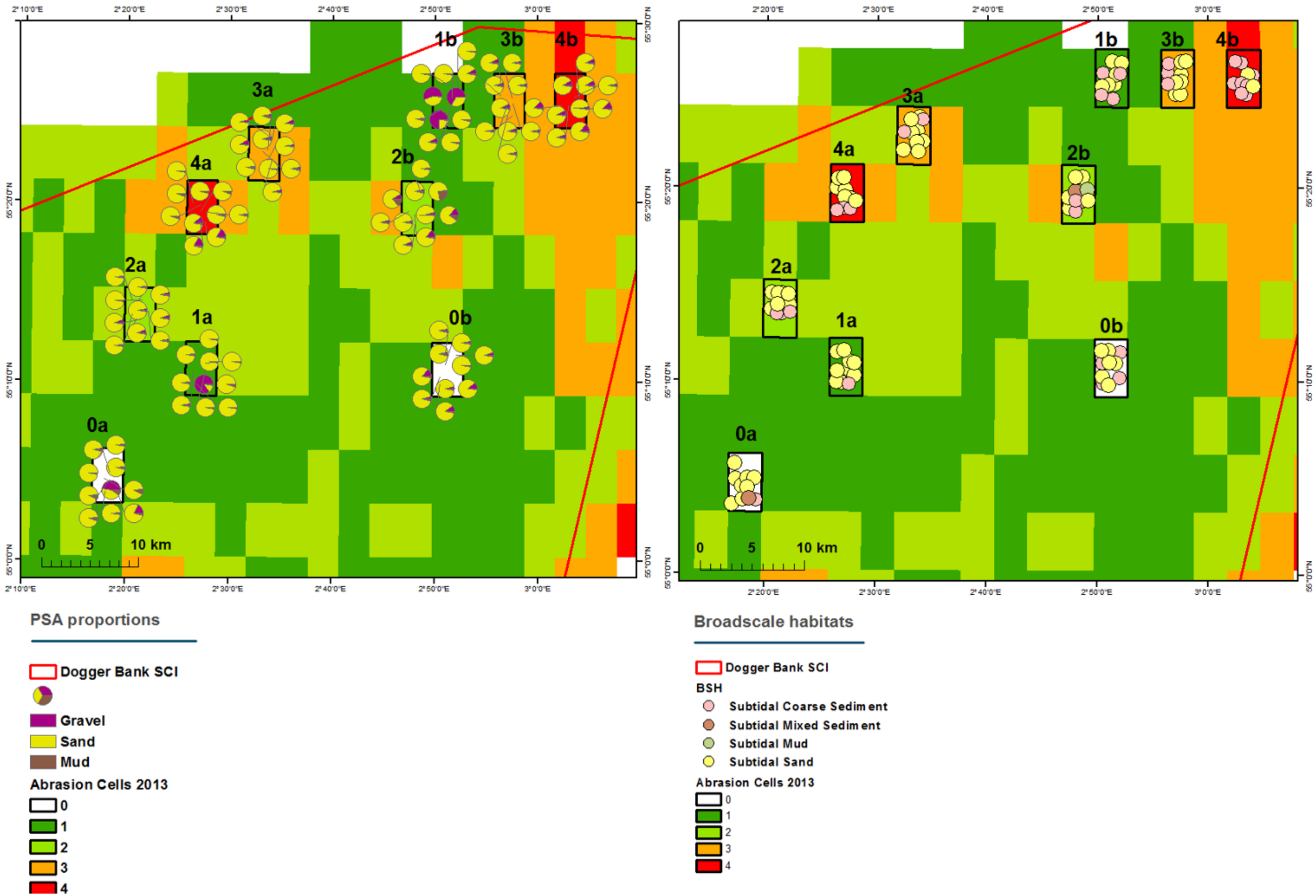



**Figure 24.** Proportion of gravel, sand and silt/clay (left) and EUNIS Level 3 classification (right) assigned to each sampling stations within the treatment boxes.

### 3.2.2 Infauna assemblages

Univariate metrics calculated using the infaunal data matrix are presented in Figure 25 – Figure 30. The median, mean (open circles) and interquartile ranges of the variables derived from samples collected within each category of known abrasion pressure are shown. Initially, all samples from each pressure score 0–4 were investigated before the samples were split by the pressure cell (‘a’ or ‘b’) and analysed to explore variability within and between each pressure category. The Mann-Kendall p value is presented in Table 17. No significant trends were observed across the pressure gradient in relation to the univariate metrics explored (Figure 25). AMBI and EQR values represent slightly disturbed communities and good-high ecological status, respectively, regardless of pressure. One sample in abrasion Cell 1a was classified as Moderate ecological status, however this was due to the presence of only one individual *S. bombyx*. The EQR of five stations exceeded 1 (1 corresponds to specific reference conditions set for each habitat represented in the IQI), indicating that the observed values exceed those expected under reference conditions defined for that habitat.

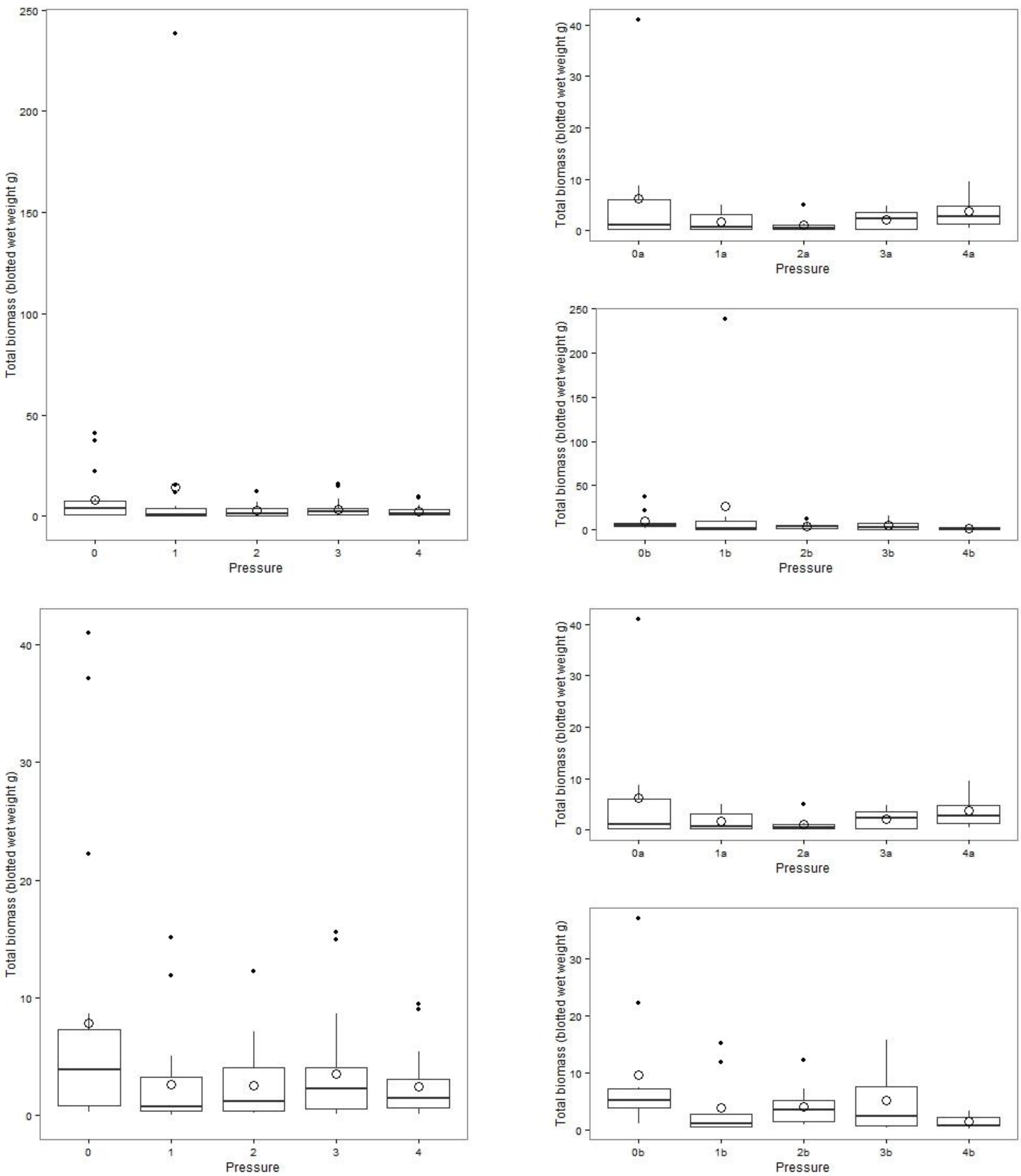



**Figure 25.** Biomass boxplots with (top) and without (bottom) station B139 included in analysis. The boxplots display results of pooled data (left) and ‘a’ and ‘b’ cells separately (right) according to pressure cell. (Boxes represent the interquartile range (middle 50% of the data), horizontal line represents the median, open circles represent the mean, the vertical lines (whiskers) represent the data range and the closed circles are outliers).

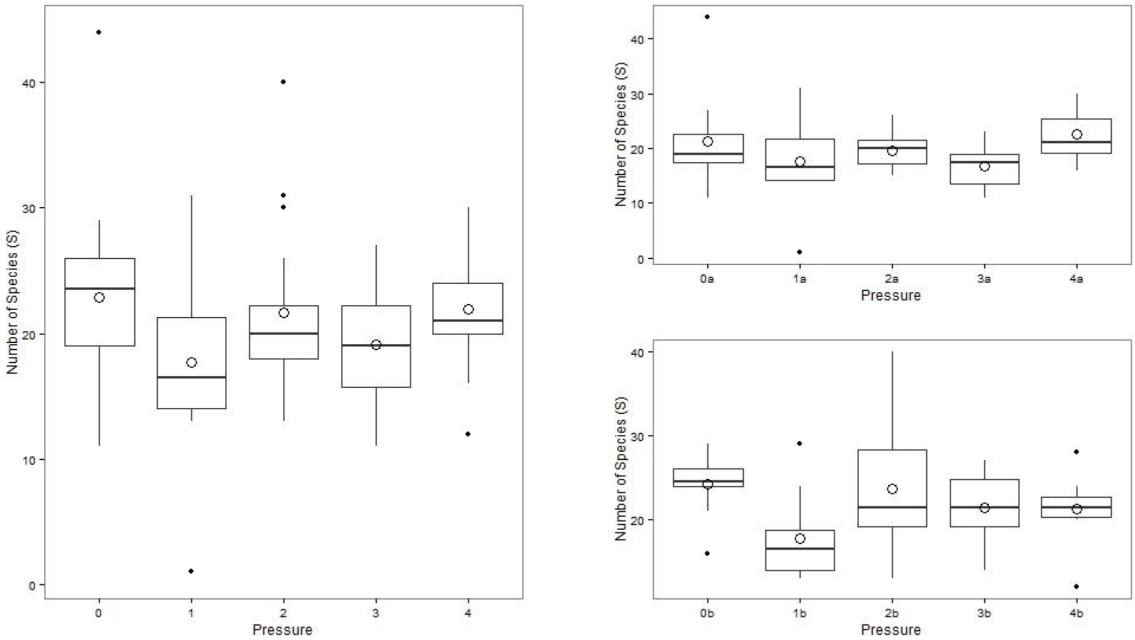



**Figure 26**. Boxplots showing the number of species (S) collected from stations within an area of known fishing pressure. Left – ‘a’ and ‘b’ cells combined for each pressure category. Right – ‘a’ and ‘b’ cells displayed separately (Boxes represent the interquartile range (middle 50% of the data), horizontal line represents the median, open circles represent the mean, the vertical lines (whiskers) represent the data range and the closed circles are outliers).

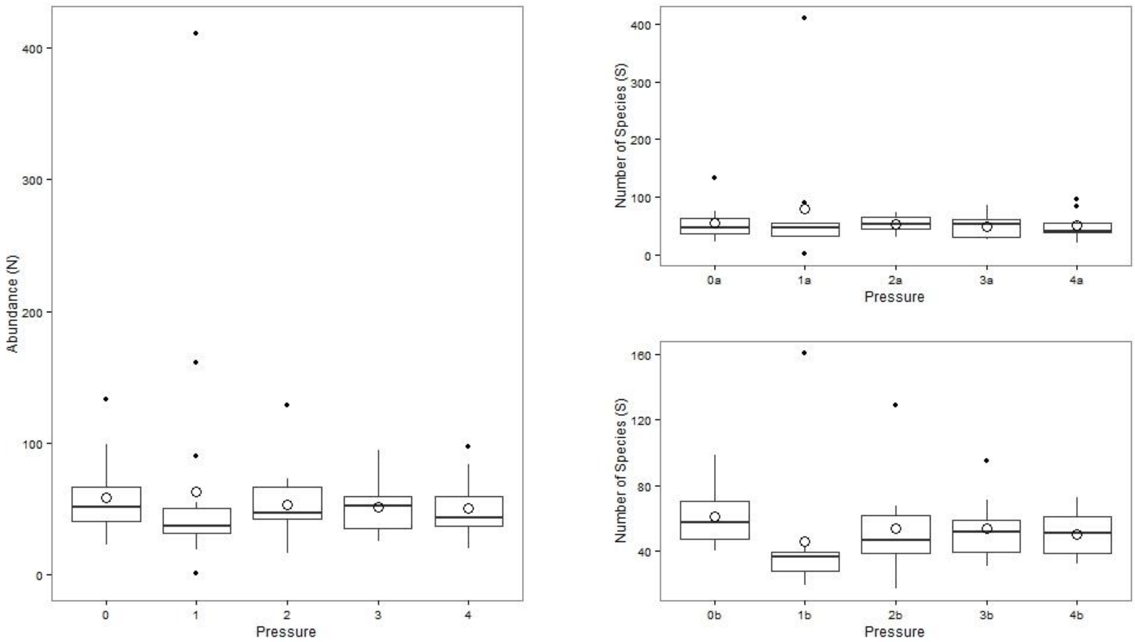



**Figure 27**. Boxplots showing the total abundance (N) of invertebrates collected from stations within an area of known fishing pressure. Left – ‘a’ and ‘b’ cells combined for each pressure category. Right – ‘a’ and ‘b’ cells displayed separately. (Boxes represent the interquartile range (middle 50% of the data), horizontal line represents the median, open circles represent the mean, the vertical lines (whiskers) represent the data range and the closed circles are outliers).

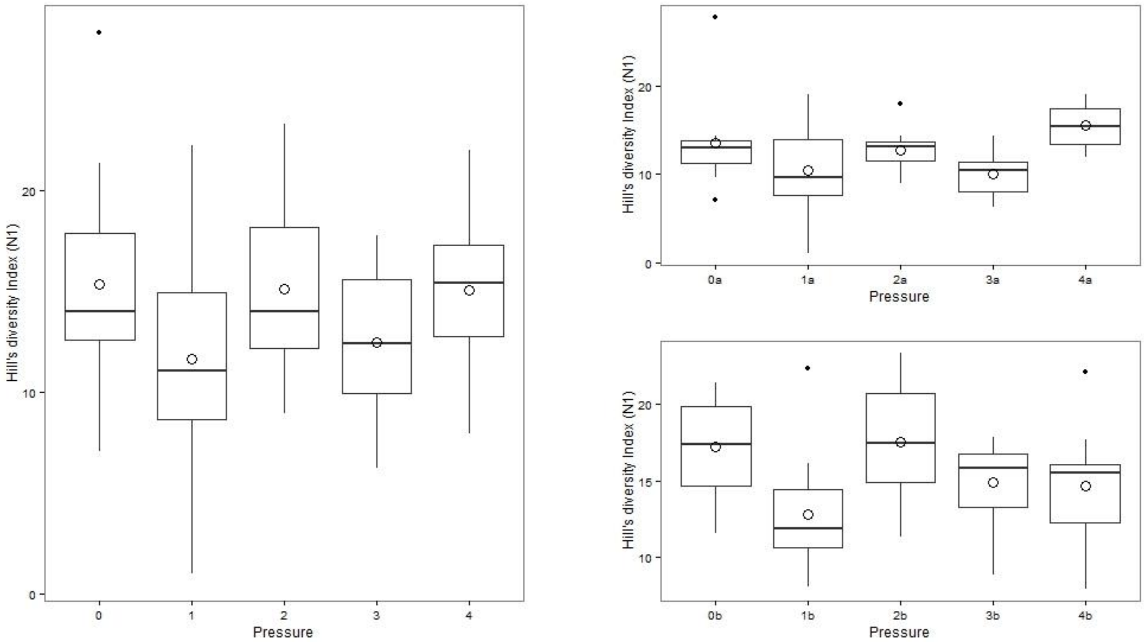



**Figure 28**. Boxplots showing the Hill diversity (N1) of invertebrates collected from stations within an area of known fishing pressure. Left – 'a' and 'b' cells combined for each pressure category. Right – 'a' and 'b' cells displayed separately. (Boxes represent the interquartile range (middle 50% of the data), horizontal line represents the median, open circles represent the mean, the vertical lines (whiskers) represent the data range and the closed circles are outliers).

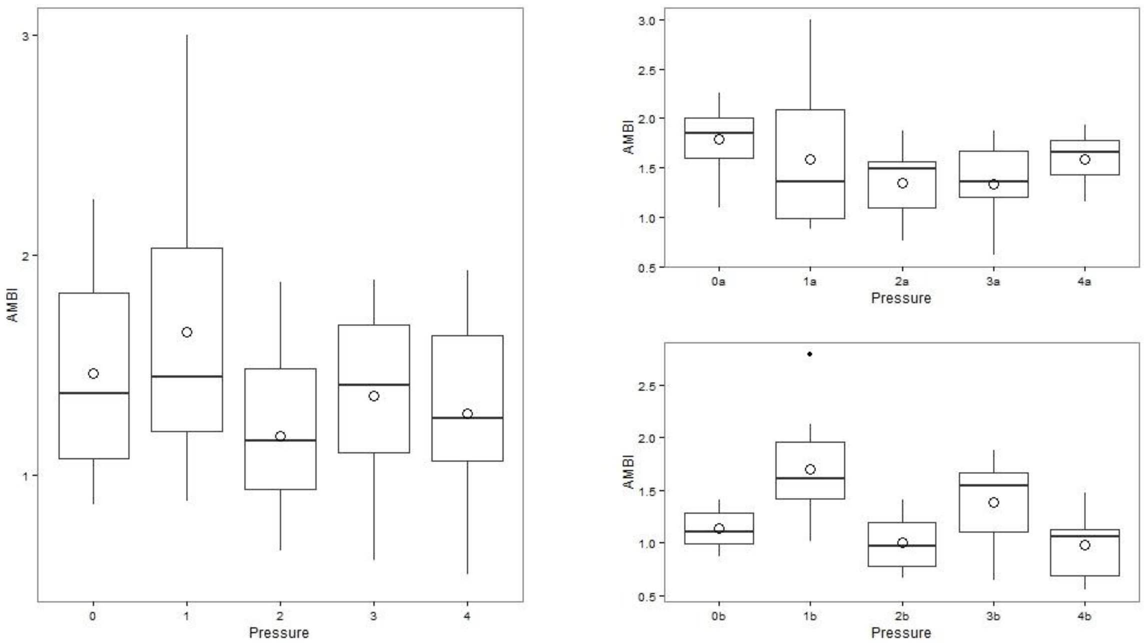



**Figure 29.** Boxplots showing the AMBI metric of invertebrates collected from stations within an area of known fishing pressure. Left – 'a' and 'b' cells combined for each pressure category. Right – 'a' and 'b' cells displayed separately. (Boxes represent the interquartile range (middle 50% of the data), horizontal line represents the median, open circles represent the mean, the vertical lines (whiskers) represent the data range and the closed circles are outliers).

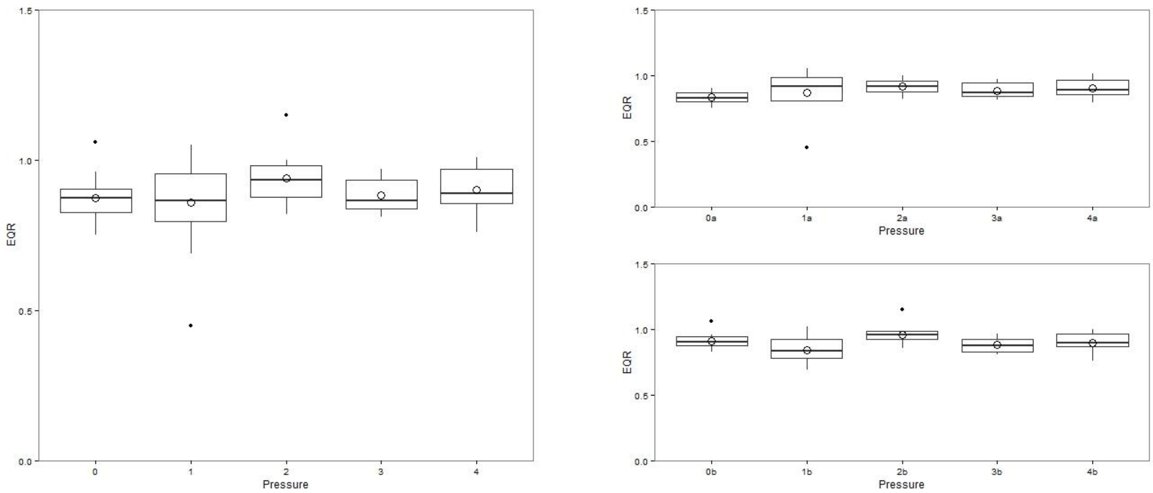



**Figure 30**. Boxplots showing the Ecological Quality Ratio (EQR) of invertebrates collected from stations within an area of known fishing pressure. Left – ‘a’ and ‘b’ cells combined for each pressure category. Right – ‘a’ and ‘b’ cells displayed separately. (Boxes represent the interquartile range (middle 50% of the data), horizontal line represents the median, open circles represent the mean, the vertical lines (whiskers) represent the data range and the closed circles are outliers).

**Table 17**. Significance (p) values using the Mann-Kendall test, values in bold text indicate a value of p <0.05.

| Pressure category | Biomass | S | N | N1 | AMBI | IQI |
|---|---|---|---|---|---|---|
| 0–4 | 0.254 | 0.78 | 0.791 | 0.73 | 0.163 | 0.187 |

The abundances of infaunal taxa present within each abrasion pressure category were combined according to major taxonomic groups (Annelida, Crustacea, Echinodermata, Mollusca, and ‘Others’). The relative proportions of these groups in each pressure category were calculated to test the hypothesis that increasing abrasion can lead to a change in the structure of benthic assemblages (Figure 31). Annelida represented the greatest proportion of infaunal assemblages across all pressure categories and no clear changes in taxonomic structure were observed in relation to the abrasion gradient.

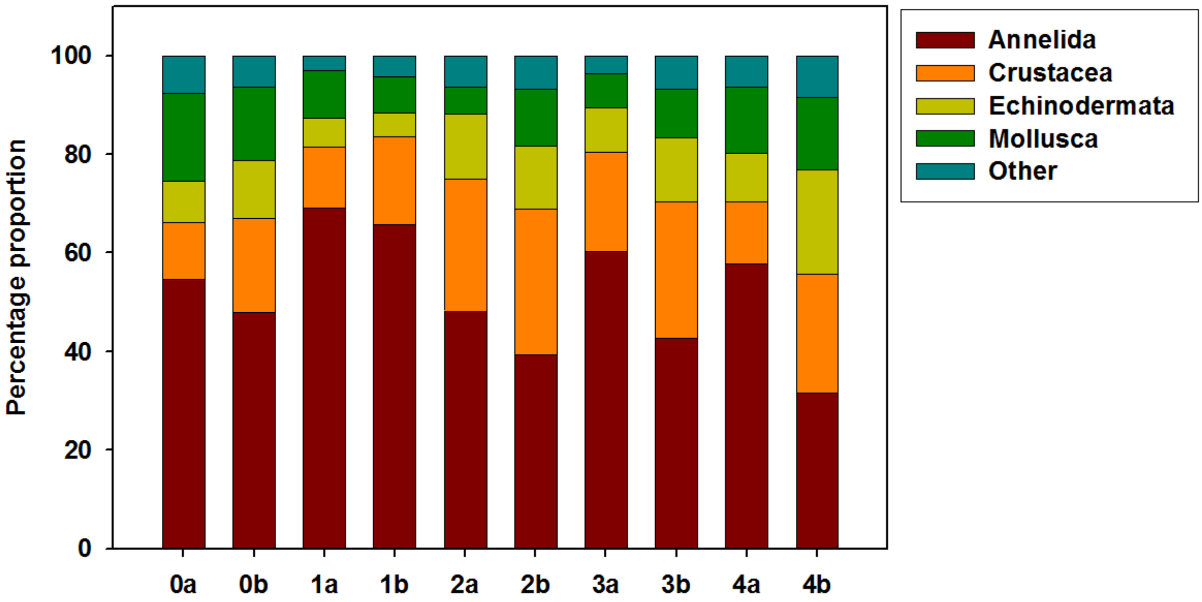



**Figure 31.** Relative proportions of infaunal abundance according to major taxonomic group within cells located along the gradient of abrasion pressure.

Multivariate analysis of infaunal communities across the abrasion pressure gradient was also explored and is presented in Figure 32. The high 2-dimensional stress value (0.2) indicates that the MDS solution is a relatively poor fit to the data and no clear patterns of infaunal assemblages within the boxes of differing abrasion pressure are evident. Abrasion pressure category 1 has the most widely distributed samples across the plot while the intermediate and highest abrasion categories (2, 3 and 4) are more tightly clustered in the centre. Figure 32 shows infaunal samples tagged with Folk sediment classification. Four outliers from abrasion pressure 1a and b were classified as gravel or sandy gravel and one sample from abrasion pressure category ‘0’, which is positioned outside the central cluster, was classified muddy sandy gravel. Samples within the main cluster were predominantly classified as sand. Multivariate analysis including the colonial taxa was also undertaken using presence absence transformed data. The results are not presented here as the multivariate pattern was unchanged.

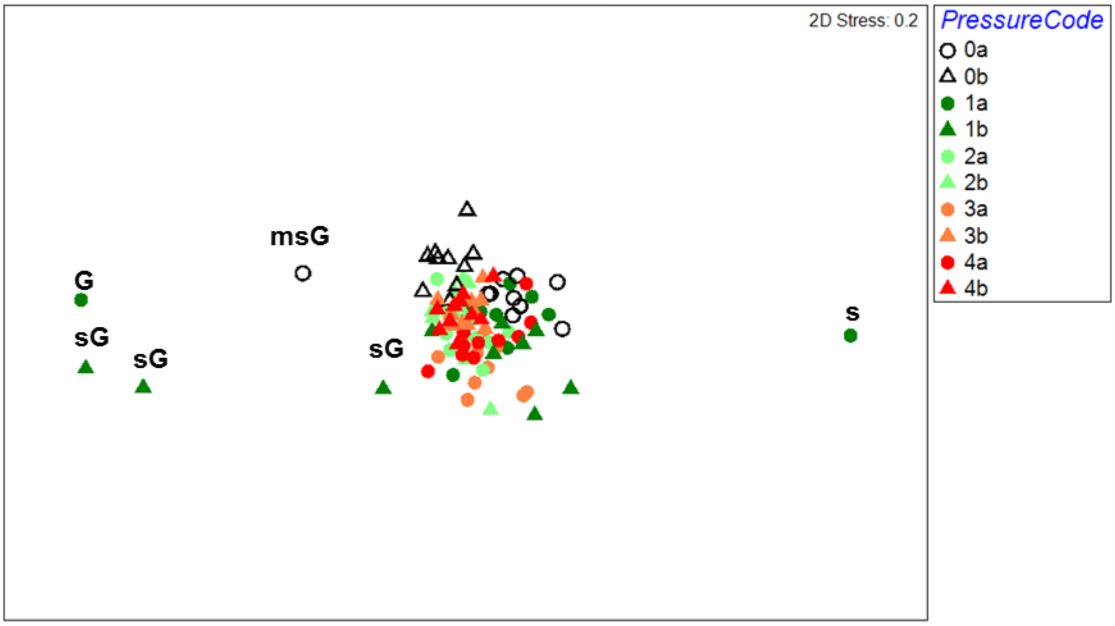



**Figure 32.** nMDS ordination of infaunal assemblages collected along the gradient of abrasion pressure (outlying stations are displayed with the associated folk classification).

SIMPER analysis revealed high within-treatment variability across all pressure categories (average similarity for samples within categories: 0 = 36.84%; 1 = 24.94%; 2 = 45.03%; 3 = 42.95%; 4 = 43.25%). Average dissimilarity between categories ranged from 56.84% between pressure categories 2 and 4, to 73.22% when comparing categories 0 and 1. Average dissimilarity between the lowest pressure category (0) and the highest (4) was 64.11% with 21 species accounting for 50% of the dissimilarity between treatments. The polychaete worms, *Spiophanes bombyx* and *Ophelia borealis*, the amphipod *Bathyporeia elegans* and the urchin *Echinocyamus pusillus* were higher in abundance in the highest abrasion category (4) while the molluscs *Kurtiella bidentata* and *Tellina fabula* were higher in abundance in the lowest abrasion pressure category. Differences were observed within each of the pressure categories when analysed separately. Table 18 shows the species characteristic of the ‘a’ and ‘b’ cells within each pressure category.  Most notable differences are observed for the areas where there was no abrasion in 2013. Average dissimilarity between the communities in 0a and 0b was 68%.

**Table 18**. SIMPER results of taxa contributing to top 50% of the community similarity within each pressure cell.

| Taxa | 0a | 0b | 1a | 1b | 2a | 2b | 3a | 3b | 4a | 4b |
|---|---|---|---|---|---|---|---|---|---|---|
| *Spiophanes bombyx* | 3.33 | | 2.37 | 1.63 | 3.04 | 1.53 | 3.11 | 2.93 | 2.99 | 1.76 |
| *Echinocyamus pusillus* | 1.34 | | 1.45 | 0.81 | 2.28 | 1.87 | 1.67 | 1.91 | 1.66 | 2.85 |
| *Bathyporeia elegans* | | 1.41 | 1.62 | | 2.52 | 2.12 | | 2.17 | | 2.18 |
| *Chaetozone christiei* | 1.39 | 1.71 | 1.41 | | 1.35 | 1.57 | | | 1.53 | 1.34 |
| *Ophelia borealis* | | | | 0.96 | | 1.6 | 2.89 | | 2.24 | |
| *Urothoe poseidonis* | | | | | | 1.79 | | 1.69 | | 1.43 |
| *Goniada maculata* | 1.17 | | | 0.99 | | 1.08 | | | 1.11 | |
| *Bathyporeia guilliamsoniana* | | | | 0.89 | | | | 1.66 | | 1.15 |
| *Kurtiella bidentata* | | 2.05 | | | | | | | | |
| *Fabulina fabula* | | 1.82 | | | | | | | | |
| *Magelona filiformis* | | 1.55 | | | | | | | | |
| *Acrocnida brachiata* | | 1.52 | | | | | | | | |
| *Sigalion mathildae* | | 1.48 | | | | | | | | |

ANOSIM suggested there were small but significant differences between the infaunal assemblages observed along the abrasion pressure gradient (Global R=0.279, p=<0.01). Greatest differences were observed between samples from cell 3a and 0b, however large differences were also observed between assemblages sampled in both the control cells (0a and 0b). ANOSIM Pairwise results of the greatest differences are shown in Table 19.

**Table 19**. ANOSIM pairwise results of groups with greatest differences (R>0.5) in infaunal assemblages.

| **ANOSIM Pairwise test** | | |
|---|---|---|
| Groups | R statistic | Significance level % |
| 3a, 0b | 0.772 | 0.01 |
| 0a, 4b | 0.707 | 0.01 |
| 2a, 0b | 0.598 | 0.01 |
| 3a, 4b | 0.54 | 0.01 |

Cluster analysis of infaunal assemblages revealed 12 distinct groupings (a–l) at the 5% significance level (Figure 33) although it should be noted that 3 groups (a, b and k) were comprised of only one sample and were therefore classified as outliers. Variability within the remaining groups was high, with average within group similarity ranging from between 34.62% to 47.76%. Only 17 species contributed to 50% of the similarity within the groups. The urchin *E. pusillus* was most commonly observed across the groups and were present in 6 of the 9 groups. *Dipolydora caulleryi, Edwardsiidae, Glycera lapidum, Glycinde nordmanni, Kurtiella bidentata, Magelona filiformis, Notomastus, Protodorvillea kefersteini* were all present in only one group (Table 20).

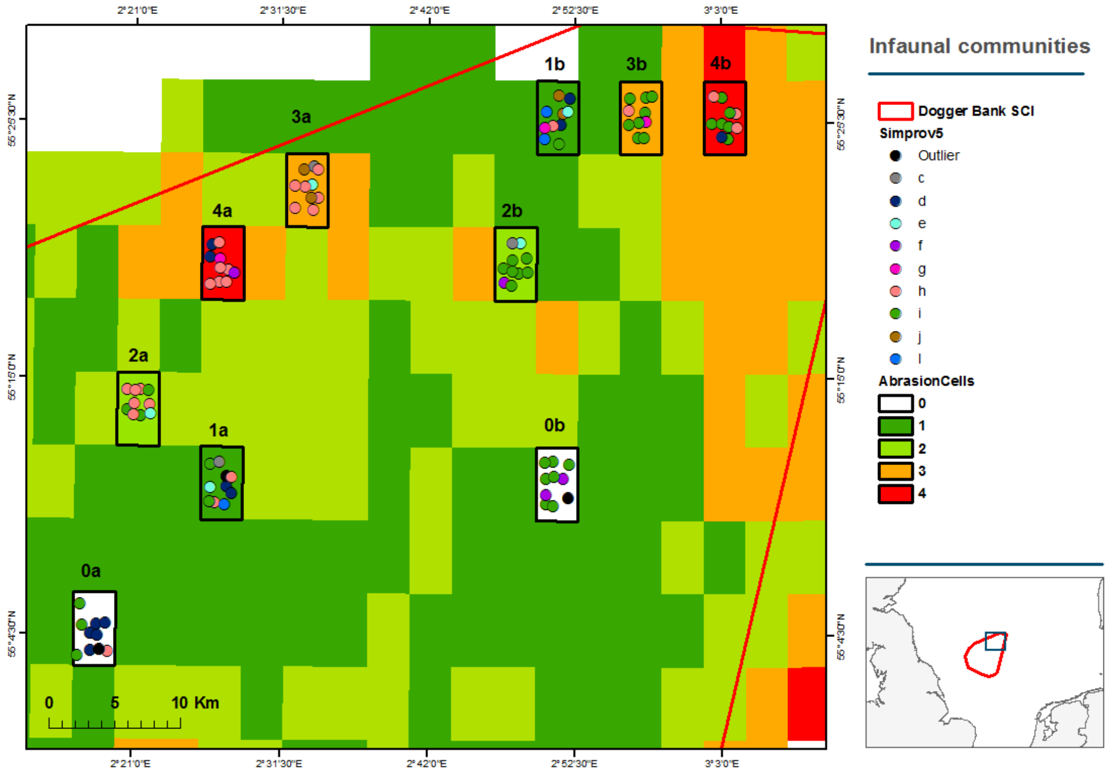



**Figure 33.** Cluster analysis of the infaunal assemblages showing the geographic location of the 12 distinct groupings (a–l) at the 5% level, across the abrasion pressure gradient.

**Table 20**. Species contributing to 50% of similarity of infaunal groups based on cluster analysis (5%).

| Species | Groups where present |
|---|---|
| *Bathyporeia elegans* | e, h, i |
| *Bathyporeia guilliamsoniana* | c, e |
| *Chaetozone christiei* | d, f, i |
| *Dipolydora caulleryi* | l |
| *Echinocyamus pusillus* | c, d, f, g, h, i |
| Edwardsiidae | g |
| *Tellina fabula* | f, i |
| *Glycera lapidum* | l |
| *Glycinde nordmanni* | f |
| *Goniada maculata* | c, d, f, j |
| *Kurtiella bidentata* | i |
| *Magelona filiformis* | l |
| Notomastus | g |
| *Ophelia borealis* | c, e, h |
| *Protodorvillea kefersteini* | l |
| *Spiophanes bombyx* | d, g, h, l, j |
| *Urothoe poseidonis* | g, i |

### 3.2.3 Bivalve size frequency distribution

Nine hundred and seventy individual bivalves, representing 34 different species, were extracted from the infaunal samples and the maximum valve width (mm) and whole body biomass (blotted wet weight in g) per individual were measured (Table 21 and Table 22). The highest number of individuals were in samples collected from the lowest abrasion pressure categories 0a (171 individuals) and 0b (170 individuals). The fewest number of individuals were measured in 2a. The number of different species present within each abrasion pressure cell was variable, ranging from 14 different species in 4b to 28 different species in 2b. Six individuals of the bivalve species of conservation interest *Arctica islandica* were present, 1 adult in box 1b and 5 juveniles recorded in boxes 0a (1), 1a (3) and 2b (1).

**Table 21**. Presence and abundance of bivalve species (including juveniles) collected in 0.1m$^2$ Hamon grab samples within pressure cells 0-4 (samples classified as gravel were removed).

| Species | 0a | 0b | 1a | 1b | 2a | 2b | 3a | 3b | 4a | 4b |
|---|---|---|---|---|---|---|---|---|---|---|
| *Abra* | 9 | 1 | 8 | | | 2 | 2 | 1 | 2 | |
| *Abra* (j) | 33 | 1 | 42 | 2 | 6 | 1 | 2 | 1 | 3 | |
| *Abra alba* | 2 | | | | | | | | | |
| *Abra prismatica* | 4 | | 3 | 3 | 6 | 1 | 1 | 1 | 4 | |
| *Abra prismatica* (j) | | | 2 | | | 1 | 5 | | 3 | |
| *Arctica islandica* | | | | 1 | | | | | | |
| *Arctica islandica* (j) | 1 | | 3 | | | 1 | | | | |
| Bivalvia | 2 | 1 | 1 | | | 1 | 1 | 2 | 1 | 1 |
| Bivalvia (j) | 2 | 1 | 1 | 2 | | | | | | 1 |
| Cardiidae | 1 | | | | | | | | 1 | |
| Cardiidae (j) | 5 | 1 | 5 | 3 | 1 | | 1 | | 1 | |
| *Chamelea striatula* | | 3 | | 2 | | | | | 6 | |
| *Chamelea striatula* (j) | 2 | | 1 | 1 | | 2 | 2 | 1 | 1 | |
| *Cochlodesma praetenue* | | 2 | 1 | 1 | 1 | 1 | 8 | 6 | 5 | 5 |

| Species | 0a | 0b | 1a | 1b | 2a | 2b | 3a | 3b | 4a | 4b |
|---|---|---|---|---|---|---|---|---|---|---|
| *Cochlodesma praetenue* (j) | | 1 | | | 2 | 3 | | | | 5 |
| *Corbula gibba* | 3 | | 1 | | | 2 | | | | 1 |
| *Dosinia* | | | | | | | | | 1 | |
| *Dosinia* (j) | 6 | 3 | 3 | 5 | 2 | 4 | 1 | 1 | 1 | 2 |
| *Dosinia exoleta* | | | | 1 | | 1 | | | 1 | |
| *Dosinia lupinus* | 2 | 3 | 2 | | 3 | 6 | 5 | 2 | 13 | 7 |
| *Ensis* | | | 1 | | | | | | | |
| *Ensis ensis* | 4 | 3 | 1 | | 2 | 3 | | 2 | | |
| *Ensis ensis* (j) | | 2 | | | | 1 | | | | |
| *Gari fervensis* | | | | 1 | | 1 | 1 | | 2 | 3 |
| *Hiatella arctica* | 1 | | | | | | | | | |
| *Kurtiella bidentata* | 15 | 77 | 6 | 4 | 22 | 18 | 16 | 31 | 9 | 9 |
| *Lucinoma borealis* | | | | | | | 1 | | | |
| *Mactra stultorum* | | 2 | | 2 | | 1 | | | | |
| *Mya* (j) | | | | 1 | | | | | | |
| *Mysia undata* | 1 | | | | 2 | 1 | 1 | 1 | | |
| *Mysia undata* (j) | | 1 | | | | | | | | |
| *Nucula nitidosa* (j) | | 1 | | | | | | | | |
| Pharidae | | | | | 1 | | | | | |
| Pharidae (j) | 9 | | 4 | 3 | | | 1 | 2 | 4 | |
| *Phaxas pellucidus* | 18 | 1 | 21 | 1 | 2 | | | 1 | 5 | |
| *Spisula* (j) | | | 1 | | | | | | | |
| *Tapes rhomboides* | | | | 1 | | | | | | |
| *Tellimya ferruginosa* | 3 | 16 | 1 | 1 | | 1 | | | 2 | |
| *Tellina fabula* | 17 | 46 | 9 | 5 | 7 | 21 | 3 | 18 | 10 | 40 |
| *Thracia* | | | | | 1 | | | | 1 | |
| *Thracia* (j) | 2 | | 2 | | 1 | 2 | 1 | 2 | 2 | 1 |
| *Thracia gracilis* | | | 4 | 2 | | 1 | 3 | 1 | 4 | 4 |
| *Thracia gracilis* (j) | | 2 | 1 | | | 1 | | | | |
| *Thyasira* | | | | | | 1 | | | | |
| *Thyasira* (j) | 13 | 1 | 4 | | | 1 | | | | 1 |
| *Thyasira flexuosa* | 14 | | 13 | | 2 | 3 | | 1 | 6 | |
| *Thyasira flexuosa* (j) | | | | | | | | | 1 | 1 |
| Thyasiridae | | | | 1 | | | | | | |
| Veneridae (j) | 2 | 1 | | | | 2 | | 1 | | |
| **Total no. individuals** | **171** | **170** | **141** | **43** | **61** | **84** | **55** | **75** | **89** | **81** |
| **Total no. species** | **25** | **22** | **26** | **21** | **16** | **28** | **18** | **18** | **25** | **14** |

A total of 34 bivalve taxa were present in the 0.1m$^2$ Hamon grab samples collected across the abrasion pressure gradient. However, only two species *Tellina fabula* and *Kurtiella bidentata* were represented by 50 or more individuals, therefore a cut of 40 individuals was considered for analysis in this section and included *Dosinia lupinus* and *Phaxas pellucidus* in addition to *Tellina fabula* and *Kurtiella bidentata.* Juvenile size classes were most frequently observed in individual measurements of the species *D. lupinus, P. pellucidus, T. fabula* while a more classic size frequency distribution was observed for *K. bidentata* based on adult size range of 3-6mm. Table 22 details a number of bivalve size metrics from all individuals measured for the four species with over 40 individual measurements including mean valve length (mm) and mean biomass (g wwt). Data shown in Table 22 suggest no clear changes in size frequency distribution in comparison with data collected across the SCI (Figure 14), with the exception of *T.fabula* which was represented by the smaller size classes and exhibited the lowest mean valve length for this species.

**Table 22**. Comparison of bivalve size metrics from all individuals identified in grab samples collected across the abrasion pressure gradient which had over 40 individual measurements.

| Species | Cell | No. Individuals | Mean valve length (mm) | Valve length range (mm) | Standard deviation in valve length (mm) | Mean biomass (g wwt) | Standard Deviation in biomass (g wwt) |
|---|---|---|---|---|---|---|---|
| *Kurtiella bidentata* | **0a** | 15 | 1.989 | 1.58 – 2.5 | 0.5394 | 0.0009 | 0.0008 |
| | **0b** | 77 | 2.156 | 1.06 – 3.66 | 0.4303 | 0.0012 | 0.0013 |
| | **1a** | 6 | 2.073 | 1.92 – 2.34 | 0.2318 | 0.0003 | 0.0002 |
| | **1b** | 4 | 2.675 | 2 – 3.7 | 0.7932 | 0.0032 | 0.0033 |
| | **2a** | 22 | 1.880 | 1 – 2.84 | 0.4881 | 0.0014 | 0.0009 |
| | **2b** | 18 | 2.202 | 1.42 – 3.18 | 0.5760 | 0.0012 | 0.0013 |
| | **3a** | 16 | 2.402 | 1.96 – 4.21 | 0.6539 | 0.0013 | 0.0029 |
| | **3b** | 31 | 2.169 | 1.34 – 4.45 | 0.5920 | 0.0007 | 0.0005 |
| | **4a** | 9 | 1.926 | 1.52 – 2.24 | 0.2932 | 0.0011 | 0.0004 |
| | **4b** | 9 | 2.355 | 1.75 – 2.66 | 0.4187 | 0.0012 | 0.0006 |
| *Dosinia lupinus* | **0a** | 2 | 5.400 | 4.3, 6.5 | 1.5556 | 0.0493 | 0.0364 |
| | **0b** | 3 | 12.573 | 8.42 – 19.74 | 6.2326 | 0.7967 | 1.0675 |
| | **1a** | 2 | 9.720 | 6.48, 12.96 | 4.5821 | 0.3197 | 0.3287 |
| | **1b** | | | | | | |
| | **2a** | 3 | 7.580 | 6.7 - 9 | 1.2415 | 0.1127 | 0.0586 |
| | **2b** | 6 | 9.865 | 6.18 – 15.06 | 3.1138 | 0.3008 | 0.2877 |
| | **3a** | 5 | 12.378 | 2.28 – 23.93 | 7.8818 | 1.3837 | 1.4273 |
| | **3b** | 2 | 31.105 | 28.23, 33.98 | 4.0659 | 8.5948 | 5.7795 |
| | **4a** | 13 | 11.162 | 5.36 – 17.58 | 4.2462 | 0.4200 | 0.4116 |
| | **4b** | 7 | 8.319 | 5.2 – 12.68 | 2.7930 | 0.1818 | 0.1559 |
| *Tellina fabula* | **0a** | 17 | 7.452 | 1.62 – 14.9 | 4.2048 | 0.0480 | 0.0590 |
| | **0b** | 46 | 3.831 | 1.34 – 7.56 | 1.5192 | 0.0054 | 0.0060 |
| | **1a** | 9 | 4.384 | 1.22 – 9.18 | 2.9515 | 0.0151 | 0.0171 |
| | **1b** | 5 | 5.800 | 2.4 – 9.6 | 3.2987 | 0.0155 | 0.0190 |
| | **2a** | 7 | 6.509 | 2.5 – 10.58 | 3.2147 | 0.0207 | 0.0195 |
| | **2b** | 21 | 3.828 | 0.76 – 8.88 | 2.4356 | 0.0078 | 0.0124 |
| | **3a** | 3 | 7.107 | 2.35 – 16.09 | 7.7843 | 0.0815 | 0.1394 |
| | **3b** | 18 | 5.547 | 2.45 – 9.9 | 2.6200 | 0.0135 | 0.0133 |
| | **4a** | 10 | 5.938 | 1.78 – 9.14 | 2.7029 | 0.0314 | 0.0417 |
| | **4b** | 40 | 2.612 | 1.42 – 5.64 | 0.9787 | 0.0016 | 0.0014 |
| *Phaxas pellucidus* | **0a** | 18 | 3.968 | 2.28 – 5.26 | 0.8684 | 0.0008 | 0.0013 |
| | **0b** | 1 | 2.320 | | | 0.0008 | |
| | **1a** | 21 | 4.596 | 1.96 – 23.32 | 4.3503 | 0.0097 | 0.0401 |
| | **1b** | 1 | 4.140 | | | 0.0001 | |
| | **2a** | 2 | 2.920 | 2.36, 3.48 | 0.7920 | 0.0008 | 0.0008 |
| | **2b** | | | | | | |
| | **3a** | | | | | | |
| | **3b** | 1 | 3.430 | | | 0.0001 | |
| | **4a** | 5 | 4.234 | 2.22 – 9.31 | 2.8730 | 0.0004 | 0.0002 |
| | **4b** | | | | | | |

Twenty-one individual bivalves present in 2m beam trawl samples were extracted and the maximum valve width (mm) and whole body biomass (blotted wet weight in g) per individual measured. Only nine different bivalve species were collected in beam trawl samples and none were collected from within abrasion boxes 0a and 1b (Table 23). Further analysis of size frequency distribution was not possible due to the low number of occurences in 2m beam trawl samples.

**Table 23**. Presence and abundance of bivalve species collected in 2m beam trawl samples within each pressure cell.

| | **0a** | **0b** | **1a** | **1b** | **2a** | **2b** | **3a** | **3b** | **4a** | **4b** |
|---|---|---|---|---|---|---|---|---|---|---|
| *Aequipecten opercularis* | | | | | | | 2 | | | |
| *Chamelea striatula* | | 1 | | | | 1 | | | | |
| *Dosinia exoleta* | | | 1 | | | | | | | |
| *Dosinia lupinus* | | | | | | 1 | | | | |
| *Ensis ensis* | | | | | | 1 | | 1 | | 1 |
| *Mactra stultorum* | | | 1 | | | | | | | |
| *Mytilus edulis* | | | | | | 2 | | | | |
| *Spisula solida* | | | 1 | | | | 1 | | | |
| *Spisula subtruncata* | | | 2 | | 1 | | | 1 | 1 | 2 |
| **Total no. individuals** | 0 | **1** | **5** | **0** | **1** | **5** | **3** | **2** | **1** | **3** |
| **Total number of species** | 0 | **1** | **4** | **0** | **1** | **4** | **2** | **2** | **1** | **2** |

### 3.2.4 Epifauna assemblages

Twenty-five different taxa were recorded in video and still image analysis. The most commonly observed taxonomic group was Asteroidea (starfish) with 108 individuals recorded across 30 video tows followed by hermit crabs (91 individuals) and the masked crab, *Corystes cassivelaunus* with 59 individuals recorded. Analysis of univariate metrics (Figure 34) revealed that pressure boxes 1b, 2b and 3a had the highest mean number of species (S) and 2b had the highest mean number of individuals (N) per video tow (Figure 34). However, no significant trend was observed using a Mann Kendall test across the pressure gradient for any of the metrics explored (S, N, N1) (Table 24).

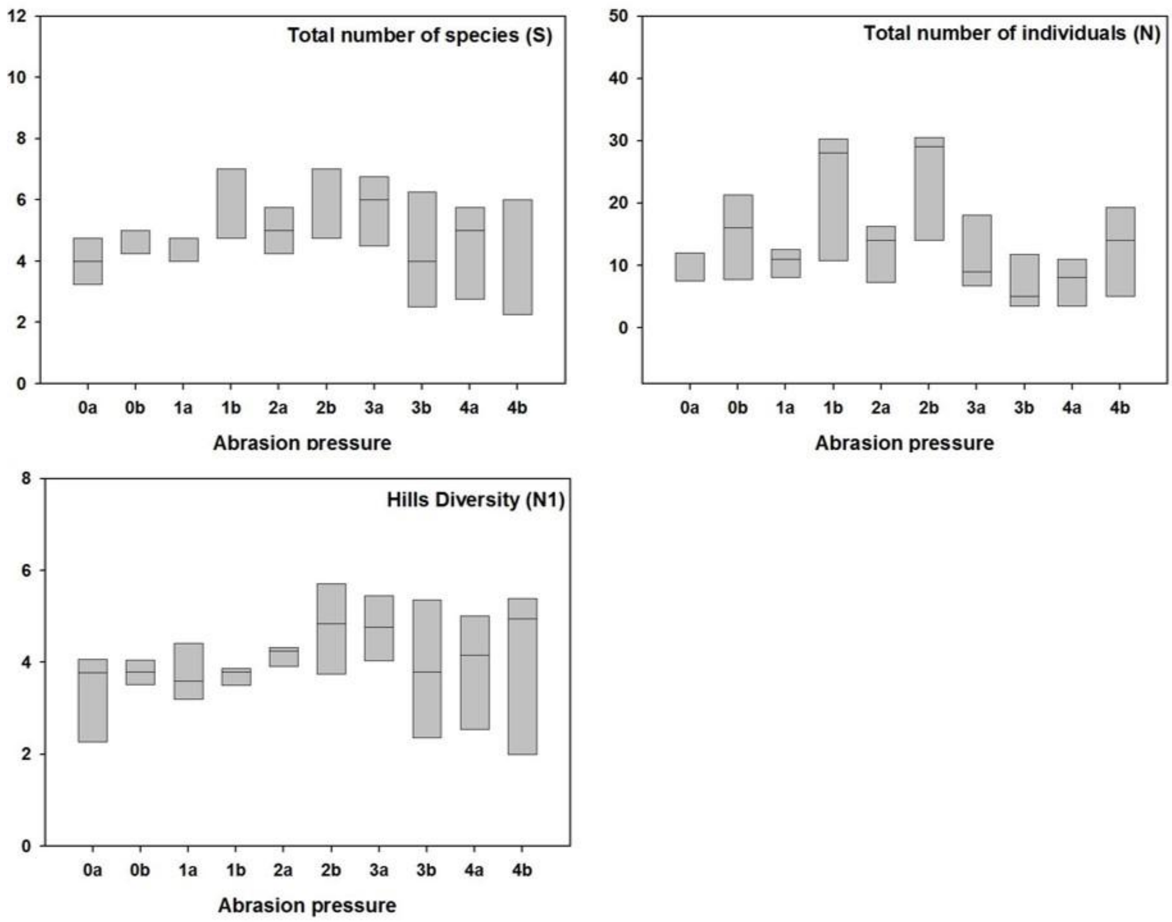



**Figure 34.** Mean number of taxa (S), Mean number of individuals (N) and Hill's Diversity (N1) calculated from observations from seabed imagery analysis.

**Table 24.** Mann Kendall text statistic and p value calculated for number of species (S), abundance (N) and diversity (N1) of epifaunal communities sampled by video across the pressure gradient.

| Univariate metric | P value | Mann Kendall statistic |
|---|---|---|
| S | 1 | 0 |
| N | 0.374 | -45 |
| N1 | 0.392 | 50 |

Multivariate patterns in epifaunal communities derived from video tows collected across the abrasion pressure gradient were explored. Samples collected from within the pressure cells were highly variable, and while not statistically significant, there was an observed pattern moving across the X axis from right to left on the nMDS plots (Figure 35). Taxa contributing to the within category similarity are shown in Table 25.

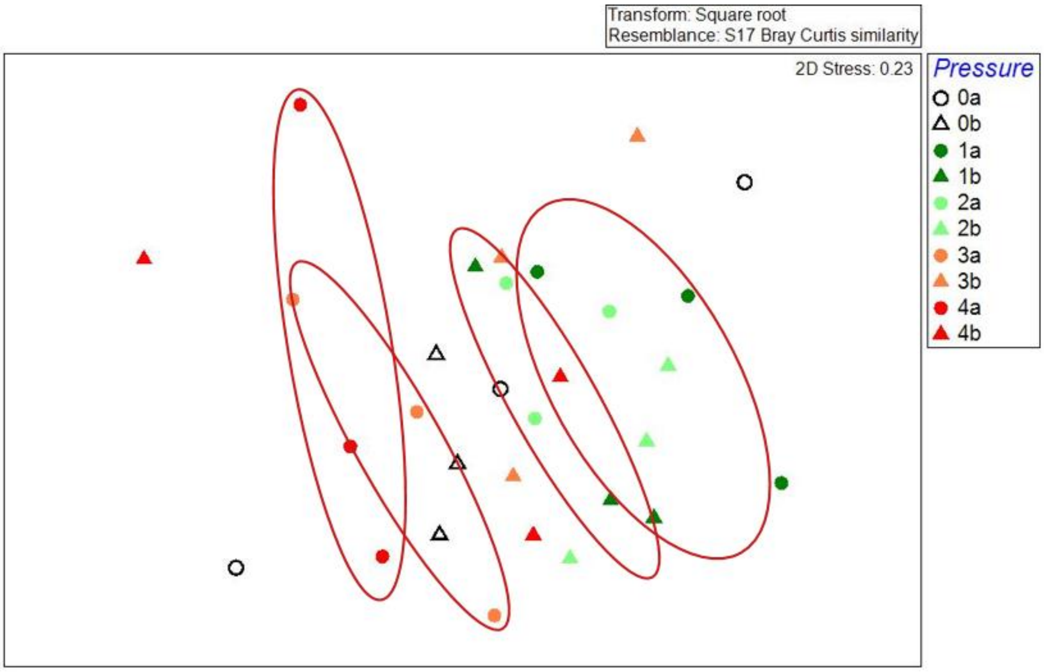



**Figure 35.** nMDS ordination of epifaunal assemblages observed in videos within each of the pressure cells. Red  circles highlighting observed pattern across the X axis from right to left with increasing pressure category.

**Table 25.** Taxa contributing to the epifaunal community similarity (sampled by video) within each pressure category (values are square-root transformed average abundances).

| Taxa | 0a | 0b | 1a | 1b | 2a | 2b | 3a | 3b | 4a | 4b |
|---|---|---|---|---|---|---|---|---|---|---|
| ASTEROIDEA | | | 1.76 | 3.04 | 1.8 | 2.52 | 1.94 | 1.38 | | |
| Paguridae | 1.08 | 2.37 | | 2.23 | | | | | 1.66 | 1.52 |
| *Corystes cassivelaunus* | | | | | 1.55 | 2.4 | | 1.38 | | |
| *Liocarcinus* sp. | 0.8 | 1.9 | | | | | | | | |
| *Asterias rubens* | 1.53 | | | | | | | | | |
| *Astropecten irregularis* | | | | | | | 1.38 | | | |

Epifaunal species observed in video tows were grouped into major taxonomic groups to explore the relative abundance in each pressure cell (Figure 36). Five major groups were present across all abrasion pressure boxes and included Annelida, Crustacea, Echinodermata, Cnidaria and Bryozoa. Crustacea and Echinodermata represented the greatest proportion of epifaunal assemblages across all pressure categories. No clear changes in higher taxonomic structure were observed in relation to the abrasion gradient. Sessile fauna (within the bryozoa and cnidaria), which are assumed to be more vulnerable to trawling, are still represented within the higher abrasion categories.

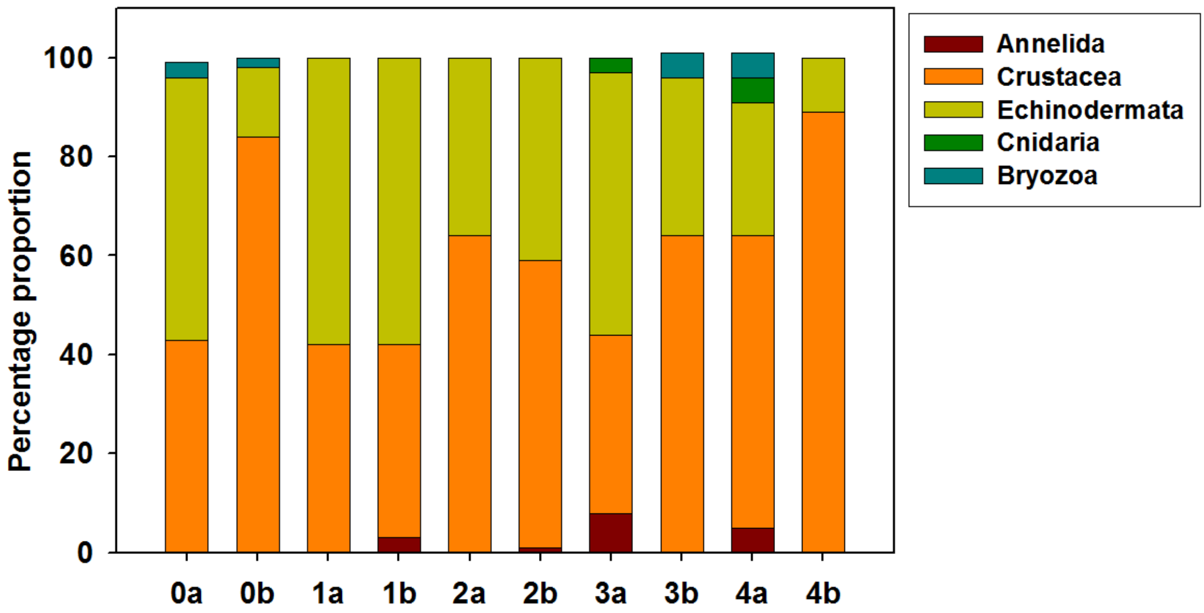



**Figure 36**. Relative abundance of the major taxonomic groups observed in videos taken from within each of the pressure categories.

Forty-three taxa, excluding fish species, were recorded (within size classes 2-11) from the 2m beam trawl samples (representing 600m$^2$ swept area per sampling station) acquired from within the abrasion pressure categories. The most commonly observed taxon was the hermit crab, *Pagurus bernhardus* with 168 individuals recorded across the 30 tows, followed by the crabs, *Corystes cassivelaunus* (160 individuals) and *Liocarcinus holsatus* (159). Twenty-one taxa had only one individual recorded from the 30 tows. Analysis of univariate metrics calculated revealed that pressure category 1a contained the highest number of taxa and number of individuals (Figure 37). However, there was also a high level of variability (8-17 taxa and 24-126 individuals) across the 3 beam trawl stations within category 1a, which is partly reflective of a significant amount of gravelly sediment retained in the trawls at one station (B079). Stations B075 and B076 within category 1a were also characterised by the brittlestar *Ophiothrix fragilis*, and represented the only stations where this species was present. Lowest number of taxa were present within the unfished category (0a and 0b) and category 1b. Category 1b also contained the lowest average abundances along with one of areas subjected to highest abrasion (4a). No significant trend was observed along the pressure gradient for any of the metrics tested using a Mann Kendall (S, N, N1) (Table 26).

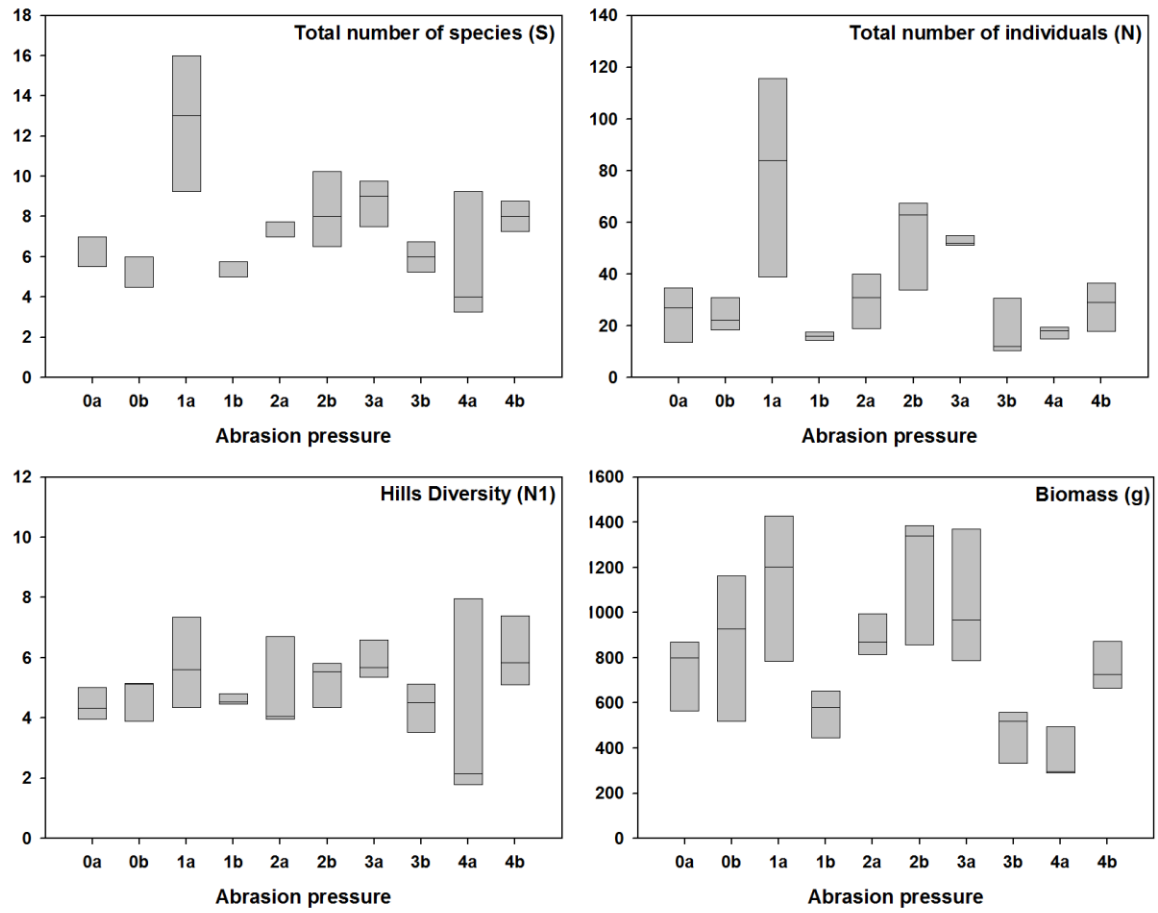



**Figure 37**. Boxplots of the univariate metrics; total number of individuals (N), total number of taxa (S) Hills diversity (N1) and biomass (g) for 2m beam trawls collected along the abrasion pressure gradient. Boxes represent the range of the data, horizontal line represents the median.

**Table 26.** Mann Kendall text statistic and p value calculated for number of species (S), abundance (N) and diversity (N1) of epifaunal communities sampled by 2m beam trawl across the pressure gradient.

| Univariate metric | P value | Mann Kendall statistic |
|---|---|---|
| S | 0.254 | 65 |
| N | 0.968 | 4 |
| N1 | 0.305 | 60 |
| Biomass (g) | 0.683 | 6 |

Multivariate patterns in epifaunal communities derived from beam trawl samples collected across the abrasion pressure gradient were also explored. Samples collected from within the pressure cells were highly variable. However, samples from pressure category 0, 1 and 2 showed tighter clustering than samples from pressure categories 3 and 4 which were distributed more evenly across the nMDS plot (Figure 38). Taxa contributing to the within category similarity are shown in Table 27.

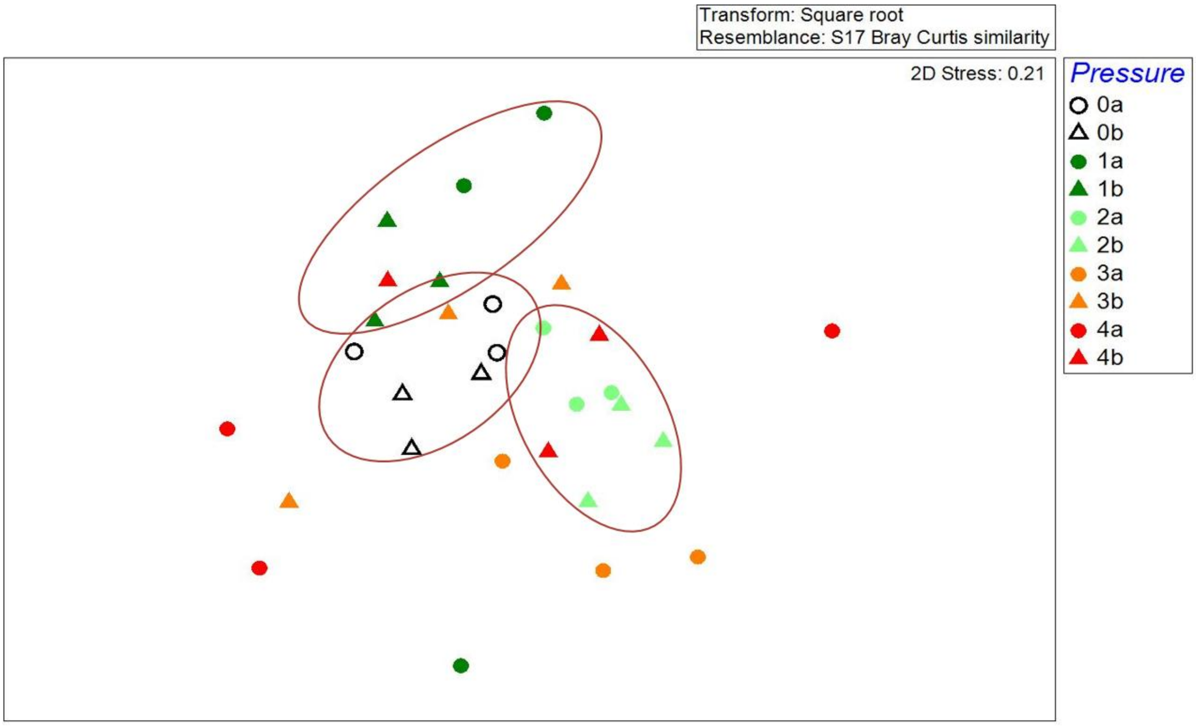



**Figure 38.** nMDS ordination of epifaunal communities sampled by 2m beam trawl within each of the pressure categories. Red circles highlighting observed clusters of samples in the same pressure category.

**Table 27.** Taxa contributing to 90% of the similarity (sampled by 2m beam trawl) within each pressure category (values are square-root transformed average abundances).

| Taxa | 0a | 0b | 1a | 1b | 2a | 2b | 3a | 3b | 4a | 4b |
|---|---|---|---|---|---|---|---|---|---|---|
| *Liocarcinus holsatus* | 2.06 | 1.96 | 2.54 | 1.33 | 2.55 | 3.16 | 1.78 | 1.63 | 0.67 | 2.28 |
| *Pagurus bernhardus* | 1.14 | 2.16 | 2.18 | | 1.52 | 2 | 3.47 | 2.47 | 2.87 | 1.47 |
| *Astropecten irregularis* | 1.88 | | 1.47 | 1.9 | 3.29 | 2.99 | 3.95 | 0.94 | | 1.24 |
| *Corystes cassivelaunus* | 1.15 | 2.74 | 1.52 | 1.05 | 1.79 | 4.28 | 2.05 | | | 2.82 |
| *Asterias rubens* | 3.08 | 2.22 | 3.89 | 2.2 | | | | 1.33 | | 1.05 |
| *Ophiothrix fragilis* | | | 3.38 | | | | | | | |
| *Crangon allmanni* | | | 2.11 | | | | | | | |
| *Liocarcinus* | | | | | | | 1.68 | | | |
| *Crangon crangon* | | | | 1.49 | | | | | | |
| *Pontophilus* | | | | | | | | | | 1.32 |
| *Aphrodita aculeata* | | | | | 1 | | | | | |
| *Ophiura ophiura* | | | | | | | | | | 0.67 |
| *Spisula subtruncata* | | | 0.67 | | | | | | | |

The abundances of epifaunal taxa collected in the beam trawl samples were combined according to major taxonomic group to explore the relative proportions of taxa within each pressure cell (Figure 39). Five major groups were present across all abrasion pressure categories and these included Annelida, Crustacea, Echinodermata, Mollusca and other (e.g. Cnidaria). Crustacea and Echinodermata represented the greatest proportions of epifaunal taxa present across all pressure categories.

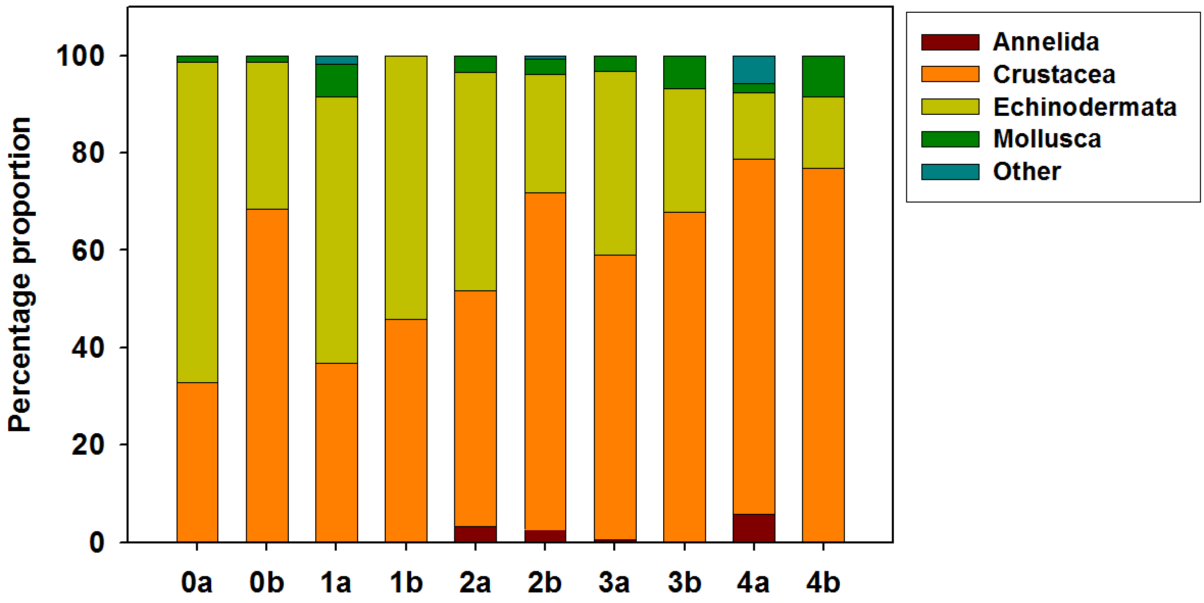



**Figure 39**. Relative abundance of epifaunal taxa collected in 2m beam trawls, according to major taxonomic group, within pressure cells located along the abrasion gradient.

Figure 40 shows the size class distribution for all pressure categories and each category separately. Similar distribution patterns were observed in all categories. Size classes 7 and 8 generally contained the highest abundances within all pressure categories, although abundances were reduced overall in samples from pressure category 4. Species with highest total abundances within these two size classes include *Liocarcinus holsatus*, *Astropecten irregularis* and *Corystes cassivelaunus*.

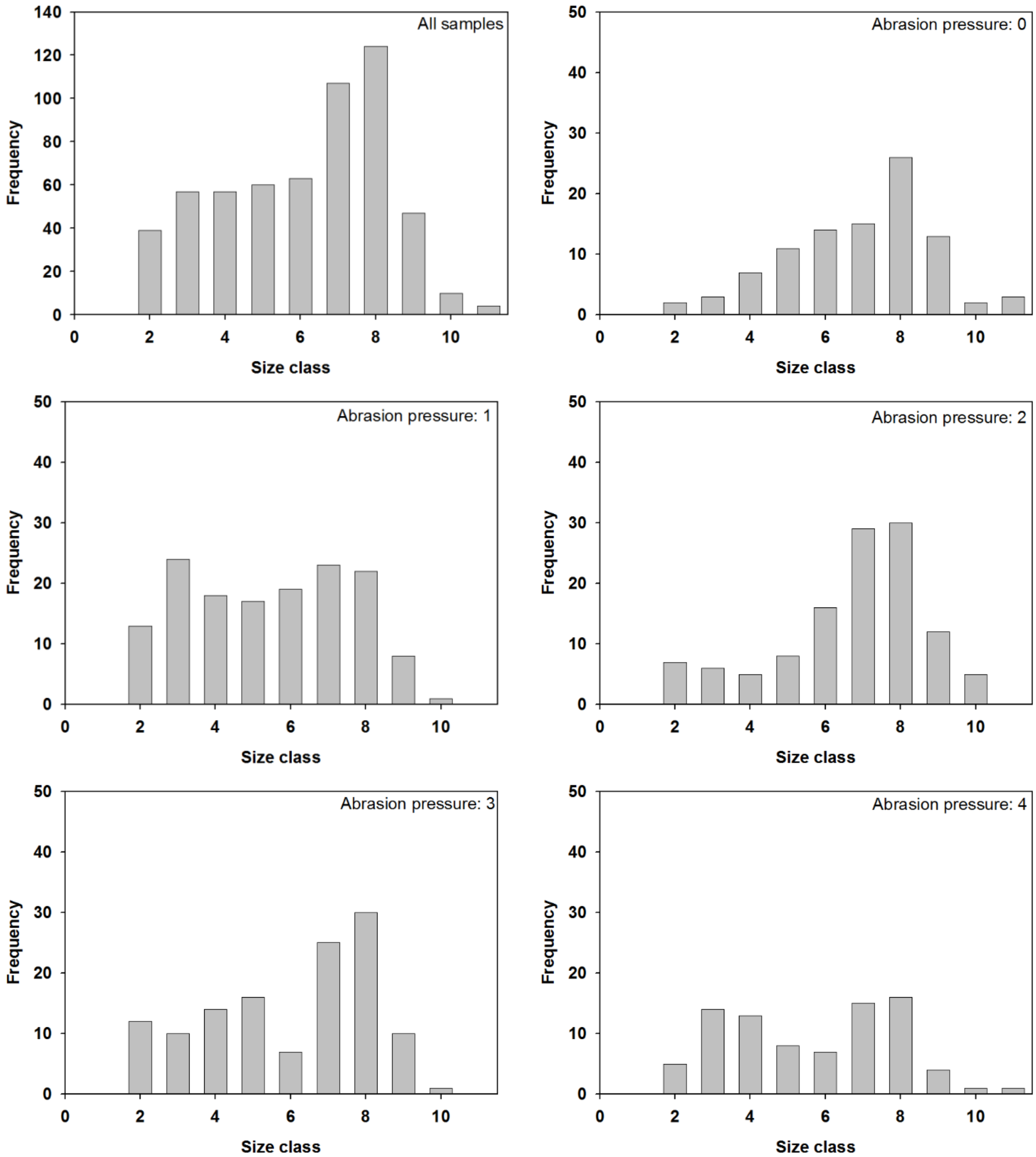



**Figure 40.** Size frequency of 2m beam trawl invertebrate catch across size categories (as detailed in section 3.2.3).

### 3.2.5 Biological traits analysis: Functional composition

Figure 41 – Figure 46, a) and b) illustrate faunal abundance and biomass, respectively, of the trait modalities for each of the five traits according to each station and pressure category. Fauna classed as fragile (3) are present within beam trawl samples acquired from within all pressure cells. Comparatively few epifaunal species were classified as robust (1) (Figure 41). The majority of fauna collected live in the top 5cm of the sediment with only a small proportion of subsurface dwellers (Figure 42) captured by the beam trawl, suggesting shallow penetration of the gear into the sediment. The majority of fauna were also classified as 'large' (>5cm) according to the maximum size category (Figure 43). Many species may, in reality, be significantly smaller than their maximum recorded size, however this trait gives insight into the potential proportion of species that may be removed by fishing gear. Predators or scavenging fauna were found to be prevalent across all pressure categories (Figure 44), however, category 1a also contained a higher proportion of other feeding types. Fauna with high or moderate mobility were also prevalent across the pressure categories indicating high potential for adult migration into an area recently trawled (Figure 45).

Community vulnerability, as derived using the traits size, position in sediment and fragility, was perceived to be highly variable within the different pressure categories (Figure 46). Cell 1a contained the only representatives of taxa classified as being the least vulnerable to fishing pressure. Highly vulnerable taxa were present in all pressure categories, although cell 1a contained highest abundances and cell 2a contained highest biomass of these taxa. Table 28 indicates the taxa associated with each vulnerability score. Five of the eleven most 'vulnerable to trawling' taxa (highlighted in bold) are also scavenging species.

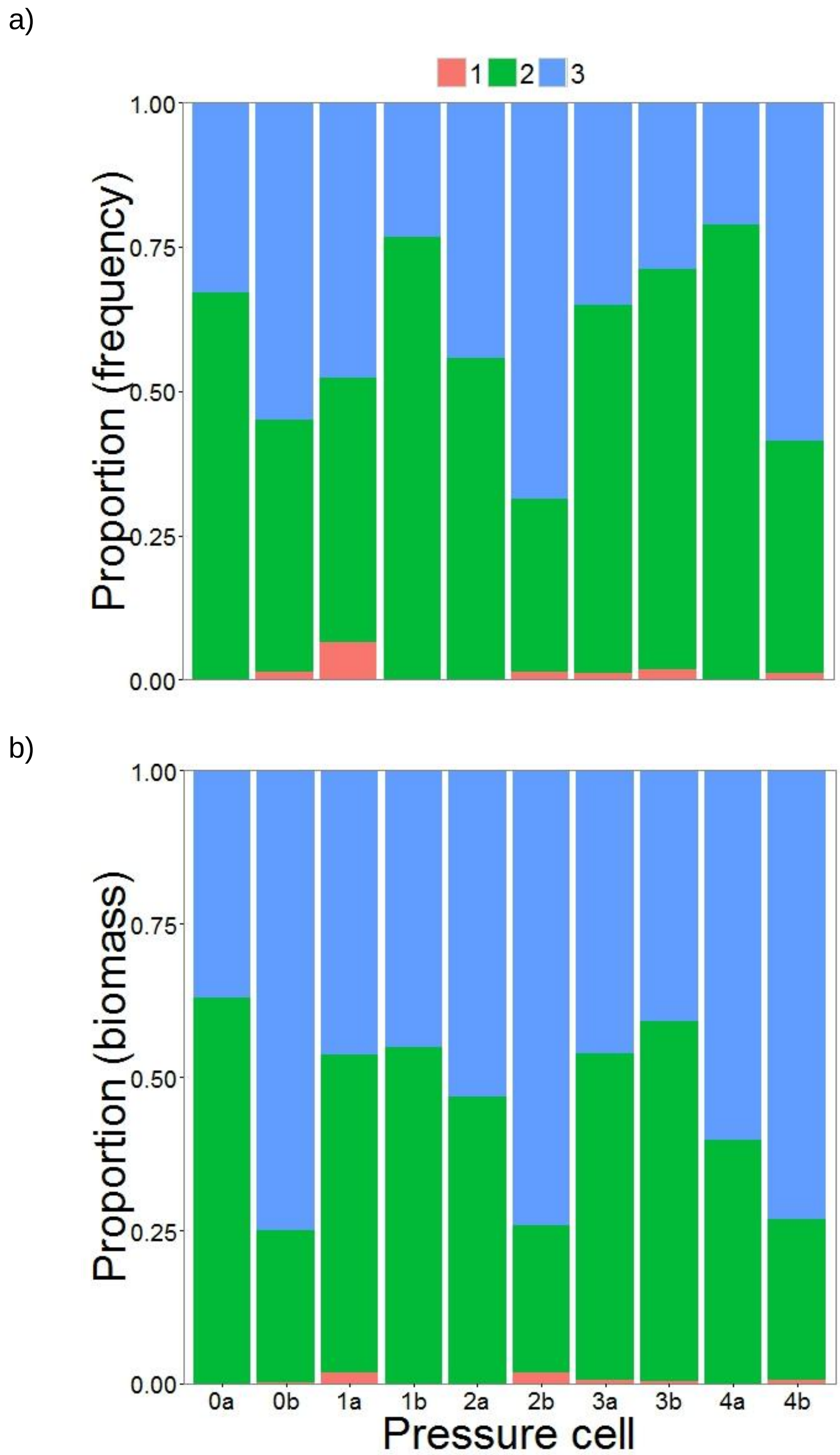



**Figure 41**. Fragility of epifaunal taxa sampled by 2m beam trawl at each station within the abrasion pressure cells according to a) abundance and b) biomass. Key: 1 = Robust, 2 = Intermediate, 3= Fragile.

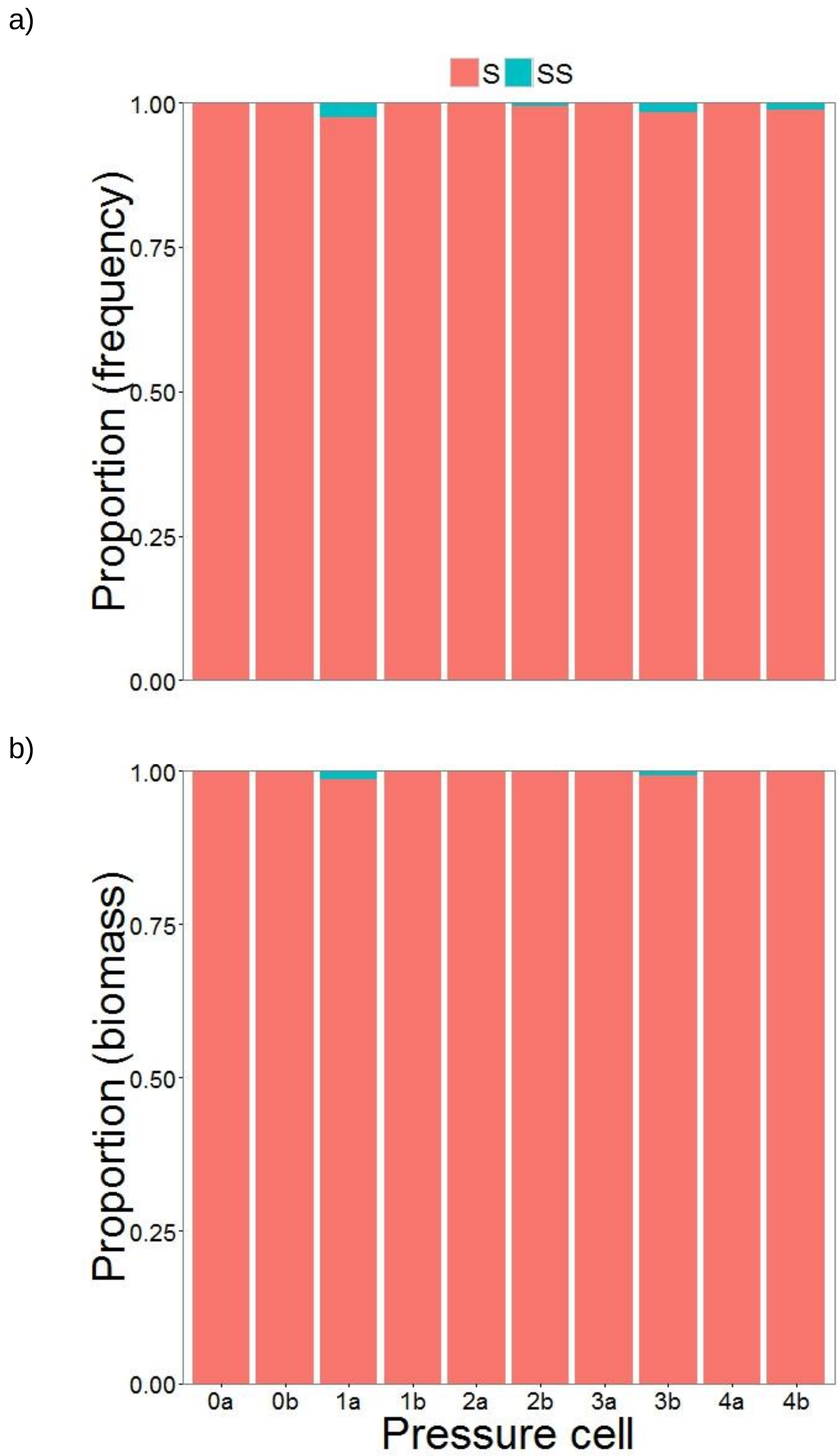



**Figure 42**.Position in the sediment of epifaunal taxa sampled by 2m beam trawl at each station within the abrasion pressure cells according to a) abundance and b) biomass. Key: S = Surface living (Surface-5cm), SS= Subsurface living (below 5cm).

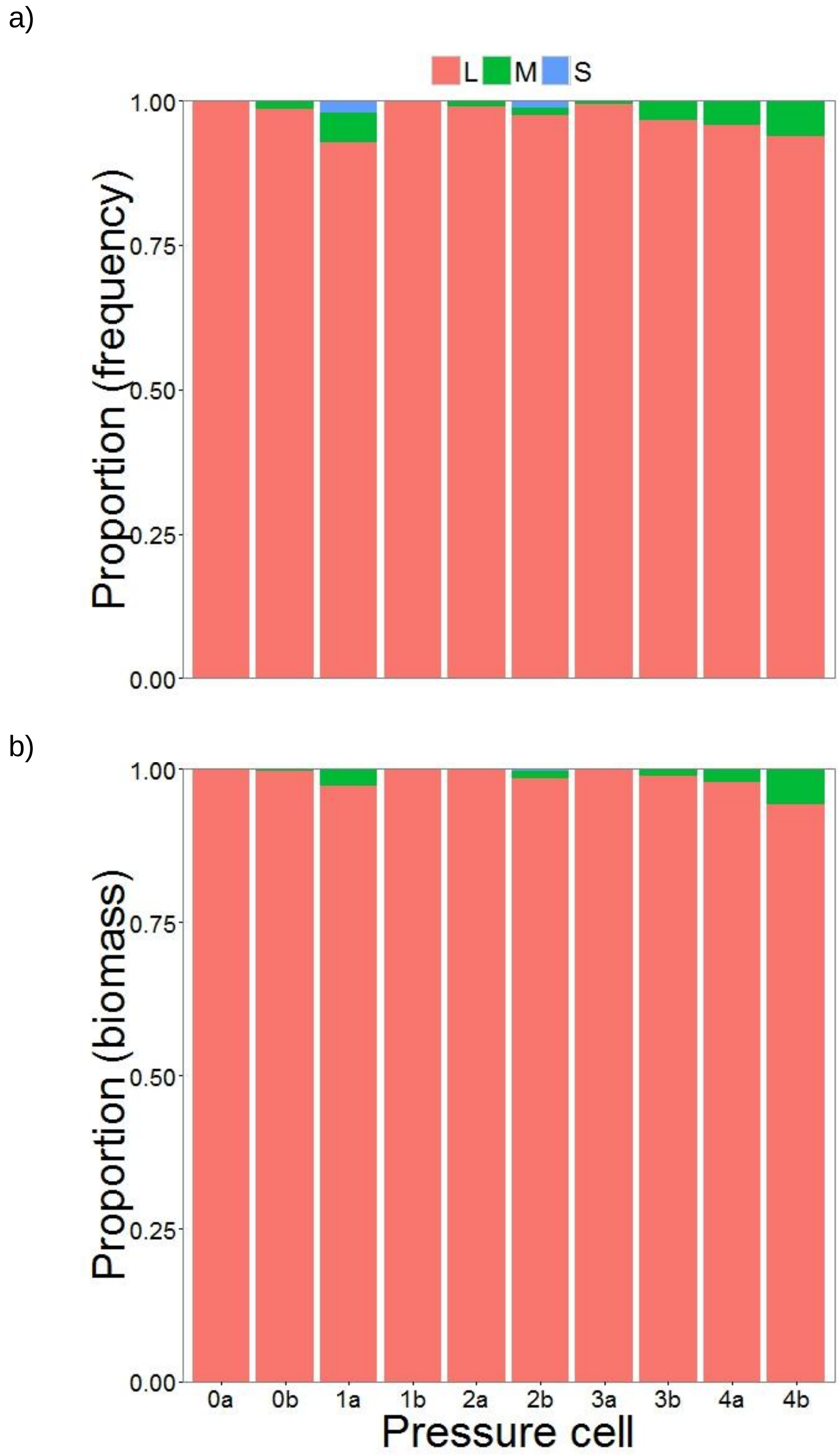
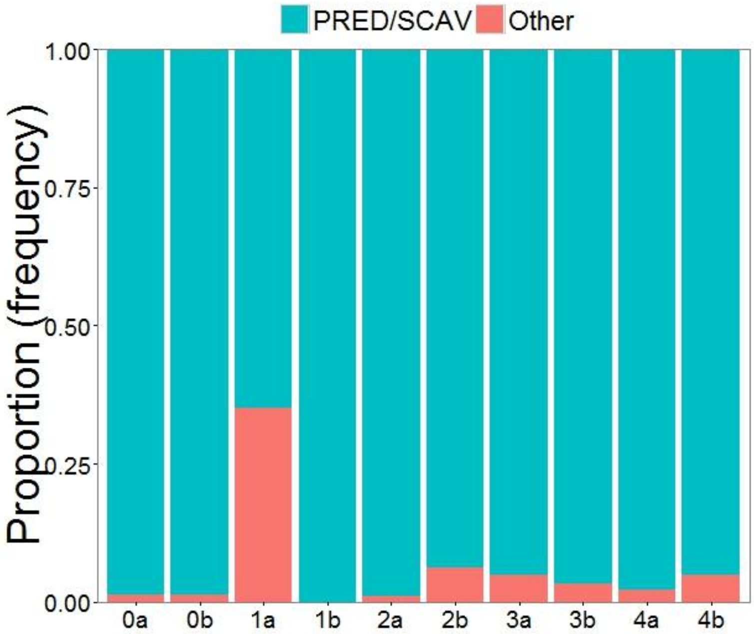



**Figure 43**. Maximum size of epifaunal taxa sampled by 2m beam trawl at each station within the abrasion pressure cells according to a) abundance and b) biomass. Key: S=Small, M= Medium, L=Large.

a)




b)

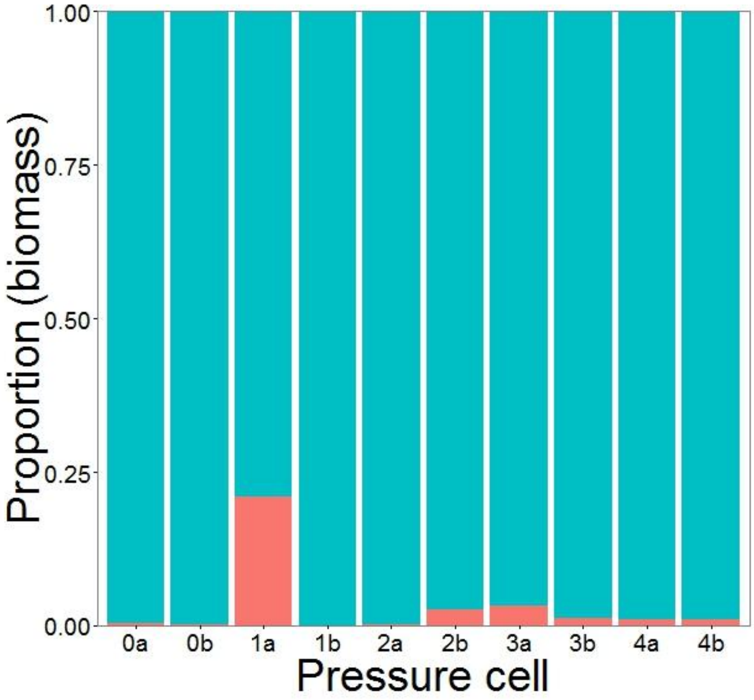



**Figure 44**. Feeding type of epifaunal taxa sampled by 2m beam trawl at each station within the abrasion pressure cells according to a) abundance and b) biomass. Key: PRED/SCAV = predators or scavengers, Other = suspension, surface and subsurface deposit feeders.

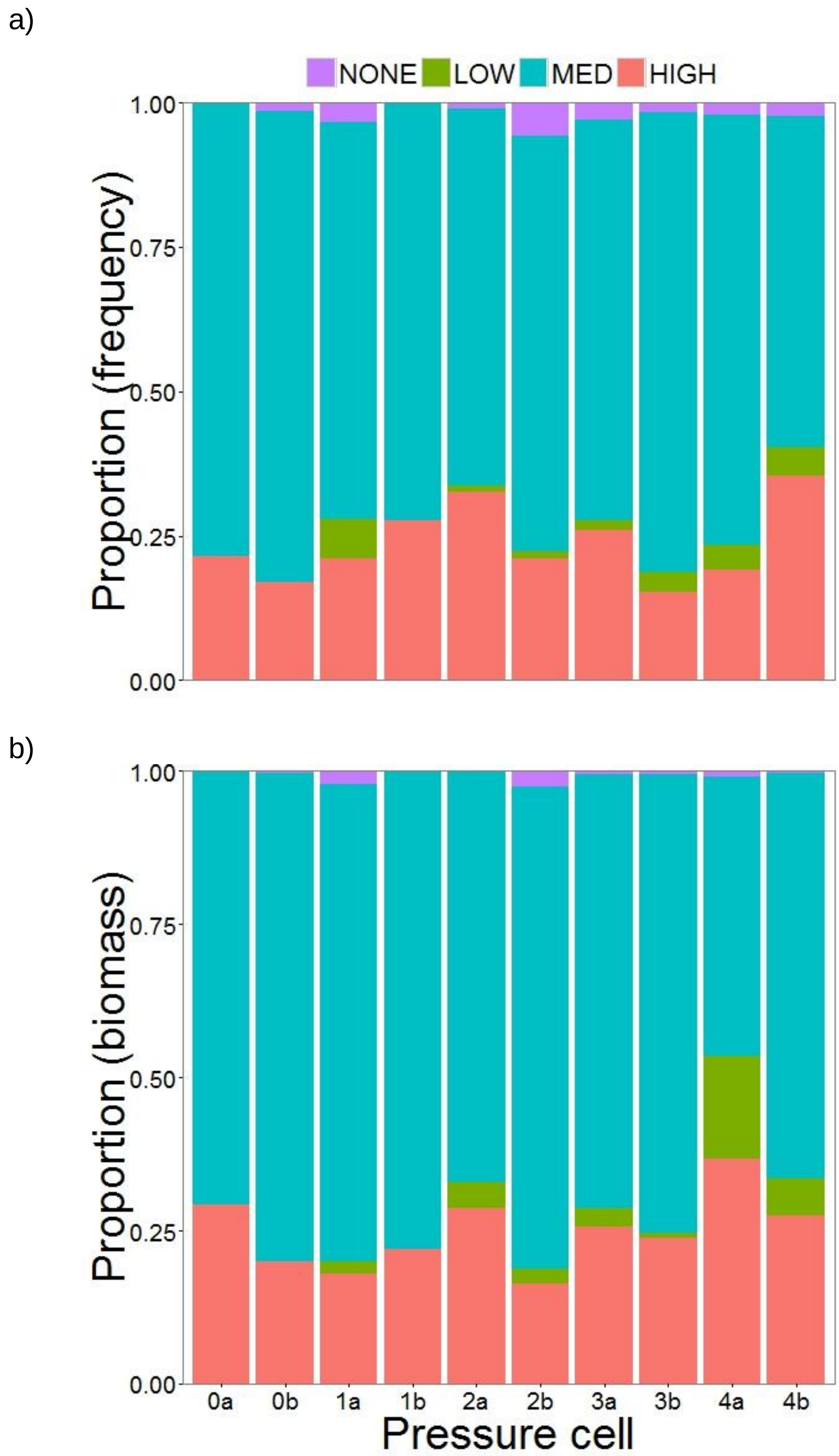



**Figure 45**. Mobility of epifaunal taxa sampled by 2m beam trawl at each station within the abrasion pressure cells according to a) abundance and b) biomass.

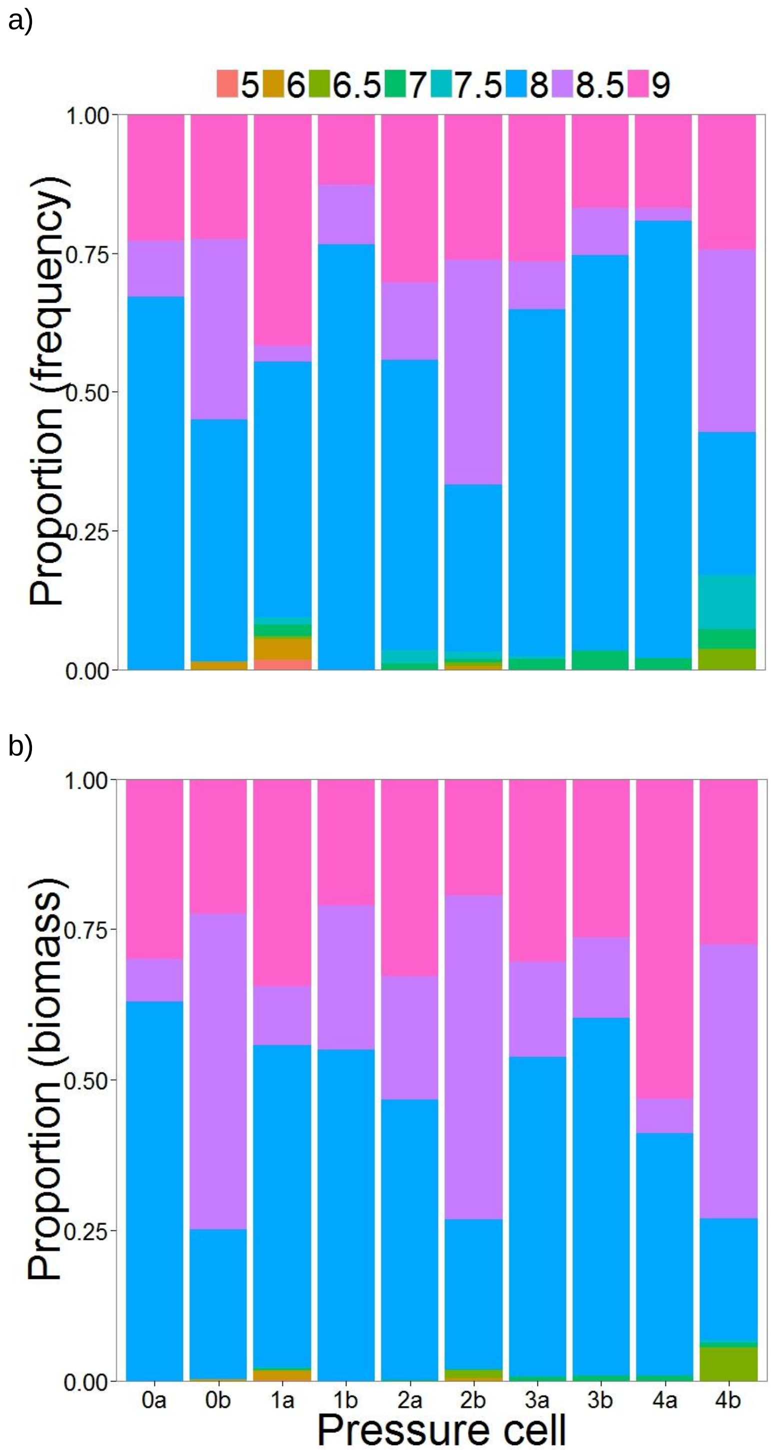



**Figure 47**. Community vulnerability, weighted by a) abundance and b) biomass, derived using combined trait scores from 'Size', 'Position in sediment' and 'Fragility' (5 = low vulnerability - 9 =high vulnerability).

**Table 28**. Taxa associated with each of the vulnerability scores (blue shading indicates taxa that are considered to have lowest vulnerability and red shading indicates taxa that are considered as having highest vulnerability to trawling based on three traits: Size, position in sediment and fragility). Taxa highlighted bold are also predator/scavengers.

| Vulnerability | Taxa | Vulnerability | Taxa |
|---|---|---|---|
| **5.0** | *Gibbula* | **8.0** | *Crangon* |
| **6.0** | *Chamelea* | **8.0** | *Ensis* |
| **6.0** | Glyceridae | **8.0** | *Mactra* |
| **6.0** | *Phascolion* | **8.0** | *Pagurus* |
| **6.5** | *Dosinia* | **8.0** | *Processa* |
| **6.5** | Mysidae | **8.0** | *Psammechinus* |
| **6.5** | *Scaphander* | **8.5** | *Corystes* |
| **7.0** | *Aporrhais* | **8.5** | *Sepiola* |
| **7.0** | *Buccinum* | **9.0** | ***Aphrodita*** |
| **7.0** | *Epizoanthus* | **9.0** | ***Galathea*** |
| **7.0** | *Pisidia* | **9.0** | ***Hyas*** |
| **7.0** | *Spisula* | **9.0** | ***Liocarcinus*** |
| **7.5** | Nudibranchia | **9.0** | *Mytilus* |
| **7.5** | *Pontophilus* | **9.0** | *Ophiothrix* |
| **8.0** | *Aequipecten* | **9.0** | ***Ophiura*** |
| **8.0** | *Asterias* | **9.0** | Ophiuroidea |
| **8.0** | *Astropecten* | | |

Figure 47 shows the composition of taxa according to their size, position in sediment, mobility and feeding type (as a proxy for immigration into a trawled area). Taxa which are hypothesised to quickly migrate into an area following a trawling event are large surface living scavengers with high mobility. This category is represented in all pressure categories, although highest abundances of these taxa are present at one station in category 1a. Highest abundances of mobile (med-high) scavenging taxa are present in samples collected from categories 2 and 3. Scavenging taxa associated with each of the 'immigration' groups are shown in Table 29. Taxa presumed to respond most quickly to an increase in dead or dying organisms as a result of trawling are swimming crabs (*Liocarcinus spp.*) and shrimps (e.g. *Crangon spp., Processa spp., Pontophilus spp.*).

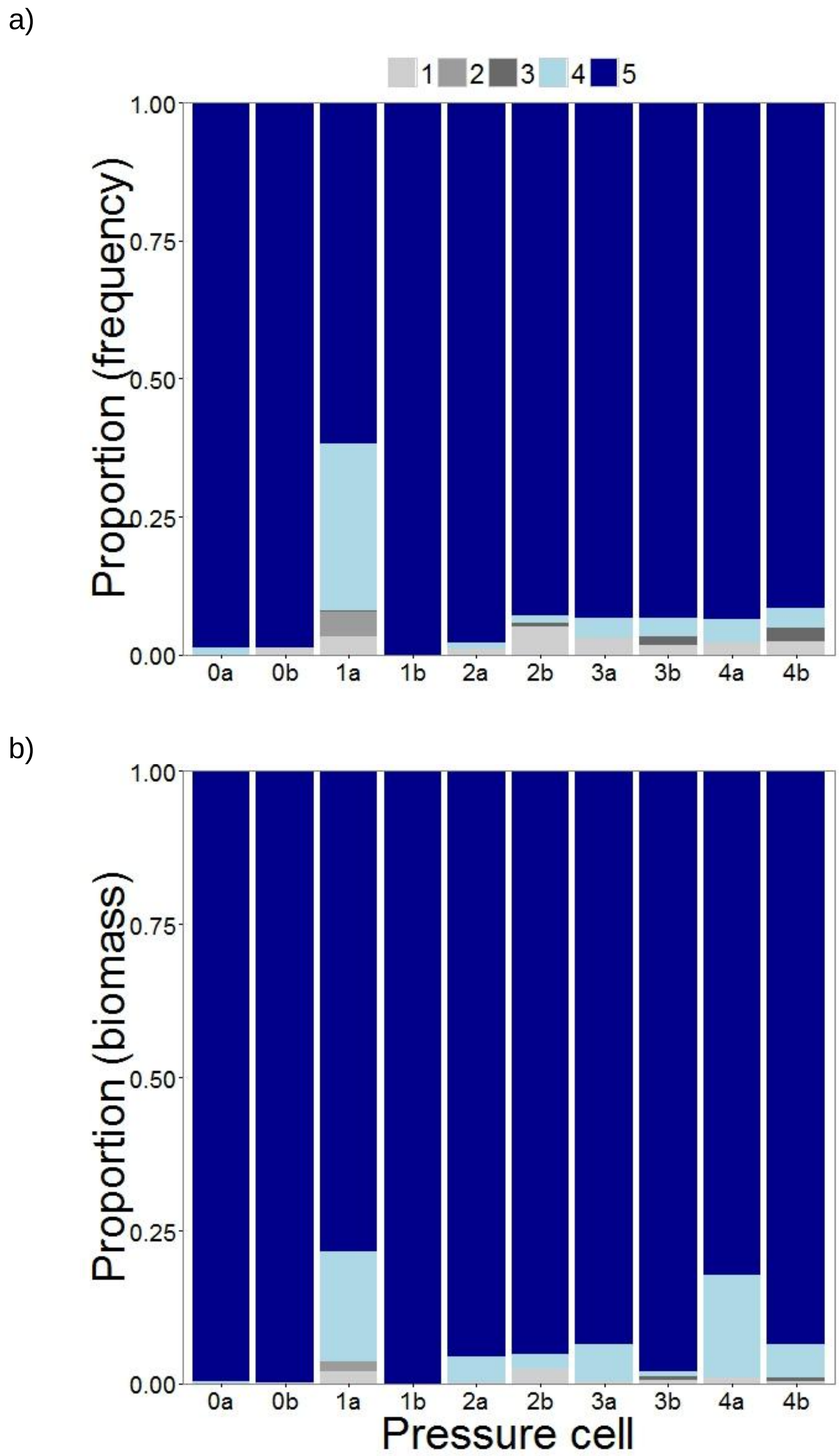



**Figure 47.** Composition of species according to size, position in sediment, mobility and feeding type (weighted by a) abundance and b) biomass) as a proxy for immigration into a trawled area with 1 being the lowest and 5 the highest.

**Table 29**. Scavenging taxa associated with each of the 'immigration' groups. Cells are coloured according mobility; high (red), medium (green), low (blue) mobility.

| Opportunistic traits | Genus | Opportunistic traits | Genus |
|---|---|---|---|
| **LSHIGHPRED/SCAV** | Caridea | | *Ophiura* |
| | *Crangon* | | Paguridae |
| | *Liocarcinus* | | *Pagurus* |
| | *Pasiphaea* | **SSMEDPRED/SCAV** | *Pisidia* |
| | *Pontophilus* | **LSLOWPRED/SCAV** | *Aphrodita* |
| | *Processa* | | *Buccinum* |
| | *Sepiola* | **MSLOWPRED/SCAV** | Nudibranchia |
| **LSMEDPRED/SCAV** | *Asterias* | | Polynoidae |
| | *Astropecten* | | *Psammechinus* |
| | *Corystes* | | *Scaphander* |
| | *Galathea* | **SSLOWPRED/SCAV** | *Polinices* |
| | *Hyas* | | |

## 3.3 Discussion

Changes in community composition along a perceived gradient of increasing abrasion pressure (resulting from demersal trawling) were not inferred from the univariate metrics (including candidate indicators under development in support of the UK MBMP) derived from infaunal or epifaunal abundance data. Previous research (e.g. Hiddink *et al* 2006) has highlighted that species richness or abundance may not be the best indicators of seabed disturbance attributable to fishing pressure as trawling often results in the replacement of species by those more resilient to this pressure, without affecting overall taxon richness or abundance. The Dogger Bank is also located in an area of high natural variability and the species that comprise the benthic communities present may have evolved to withstand frequent natural disturbance events.

Similarly, neither EQR nor AMBI responded negatively to an increase in abrasion pressure. In calculating these metrics, species are grouped according to their sensitivity to increases in organic matter to calculate an AMBI score which is, in turn, used in the calculation of the EQR. However, it is not ecologically intuitive that the sensitivity (or resilience) of a given taxon will be the same in terms of their response to a different pressure type (e.g. physical disturbance). As such, it is suggested that the re-grouping of taxa according to their perceived sensitivity to different pressure categories (e.g. physical disturbance) could potentially expand the effective application of this indicator for condition assessment of sedimentary habitat features subject to a wider range of pressure categories. Additionally, the EQR reference samples are known to underrepresent coarse sediments and were heavily dependent on inshore data available at the time of its development (e.g. the IQIv4 was developed for use in transistional and coastal waters at sites with muddy and sandy habitats (up to 3km offshore)). It is, therefore, acknowledged that the multimetric, in its current form, has not been shown to be effective for application in coarser sediment types and that a recalibration is necessary to reliably describe the ecological status of the benthos in both inshore and offshore habitats subject to different pressure types (Fitch *et al* 2014). Testing of the IQI metric for offshore environments is ongoing with the development of a new offshore calibrated workbook (pers comm Graham Phillips, EA).

Multivariate analyses showed infaunal communities present across the abrasion pressure gradient to be highly variable both within and between the pressure cells. The subtle differences observed between pressure cells along the abrasion gradient were largely due to variability in the relative proportion of a sub-set of species that were characteristic of the sediments present across the experimental survey block. Similar distribution patterns were observed in the size frequency composition (based on weight classes) of epifaunal taxa present in 2m beam trawl samples collected along the pressure gradient.

Vulnerability of epifaunal taxa to the direct effects of trawling (i.e. those most susceptible to removal or damage) was similar in all pressure cells, with the most highly vulnerable taxa also present in areas of highest pressure. However, a high proportion of the most highly vulnerable taxa were also highly mobile predator/scavengers. As such, it may be hypothesised that these species could have migrated into the area after a trawling event to feed on dead, injured or re-suspended fauna. However, we do not know when each of the cells was last trawled as fishing pressure was based on data taken five months prior to the survey. This is a limitation of the current method of creating the abrasion layers, as data from an entire year is aggregated and no weighting given to the time since the area was last impacted. Despite focusing on traits that have known responses to trawling (either positive or negative), no clear impact due to abrasion was detected using BTA.

Size-frequency analysis was only achievable for six of the 34 bivalve species collected by grab due to insufficient numbers of individuals present in the samples for the majority of species. Of the six species, *Phaxas pellucidus* (Average Length 23.32mm) collected from 1a and *Dosinia lupinus* (Average Length 33.98mm) collected from 3b, represented the largest specimens. However, the majority of individuals of both species were significantly smaller (<10mm). This was also the case for the other four most abundant bivalve species (*Thyasira flexuosa*, *Kurtiella bidentata*, *Abra prismatica* and *Tellina fibula*). These smaller species would be resuspended by fishing gear and although they may be preyed upon immediately after a trawl event, their life history traits suggest they would rapidly recover from the initial physical disturbance. Larger specimens of bivalves were insufficiently sampled using the grab sampling gear; a single adult *Arctica islandica* (measuring 107mm) was collected from the operational monitoring sampling area (cell 1b) and 19 *Ensis* sp. were collected (all cells combined), with the largest specimen measuring ~55mm (this species grows to a size of 120mm). Larger bivalves were also not effectively sampled using a scientific 2m beam trawl. This gear type is designed to skim over the sediment surface, therefore burrowing species such as *E. ensis,* which retracts rapidly when disturbed and *A. islandica,* which can periodically burrow up to 12cm (Strahl *et al* 2011), may be poorly sampled using this gear type. Dredges are more suitable for the comprehensive sampling of the larger burrowing fauna, although they are also more damaging to the seabed habitats surveyed. Commercial beam trawls are heavier and have been shown to penetrate up to 3cm in compacted sand, hence the increased impact on these species particularly since the introduction of tickler chains (Creutzberg *et al* 1987).

In conclusion, there are several reasons hypothesised to explain why faunal communities were not observed to noticeably differ along the perceived abrasion pressure gradient derived from both UK and non-UK fishing vessel VMS data:

1. Although the pressure cells (measuring 0.05dd x 0.05dd) have been categorised according to a perceived fishing derived abrasion gradient, we do not have access to the VMS data at sufficient temporal resolution to elucidate patterns in fishing distribution across the experimental study area during the period immediately prior to the survey being conducted. As such, an unknown period of recovery may have occurred prior to sample collection in relation to both infaunal and epifaunal communities previously disturbed by the demersal trawling activity.

2. Even if a high proportion of a given cell area was recently trawled, we do not know if the sampling station locations directly coincide with either the recent or historical spatial footprint of trawling on the seabed.

3. Natural disturbance in the form of wave and tides may be greater than any physical disturbance attributable to fishing activities. As a result, effects on the seabed and associated fauna resulting from trawling disturbance may be indiscernible from the effects attributed to the natural energy regime present.

4. The faunal community composition present in association with sediments across the Dogger Bank may currently be in an impoverished state as a result of long-term and sustained historical fishing activity.

In light of the conclusions drawn from this operational element of monitoring at the Dogger Bank SCI, it is suggested that our understanding of either the direct or wider chronic effects of fishing on the Dogger Bank communities may be further improved by either an experimental field approach or by creating ‘no fishing’ areas, thereby allowing insight into their potential for recovery in the absence of fishing disturbance. This latter approach will be the subject of the following section which details the investigative element of monitoring applied at this site which is intended to assess the efficacy of proposed management measures (e.g. fishery closures) following implementation.

# 4 Investigative monitoring to determine the efficacy of management measures

**Null Hypothesis:**
*At time zero (T0), benthic communities and sediment characteristics do not differ between control and impact stations located within/out with the proposed fishery management areas.*

## 4.1 Methods

### 4.1.1 Survey design

The survey design to deliver the objectives of the investigative monitoring element of the study was informed by *a priori* power analyses using existing data for the site. The analyses were carried out using sample data collected by the JNCC and Cefas in 2008 and data collected by Forewind (in support of their Environmental Impact Assessment (EIA) for the proposed Dogger Bank Round 3 windfarm development) in 2011 and 2012 using various functions within the *emon* library in R[6]. The metrics used for the power analyses were number of species (S) and abundance of individuals (N). In lieu of any suitable, fully developed indicators at the time of planning the survey, biodiversity metrics that were readily available from existing data were chosen for the power analyses. These metrics are not under consideration as potential future indicators, but displayed a high level of variability meaning that the resulting recommended number of samples required to detect a given amount of change (from the power analyses) would be sufficient to to detect a similar amount of change in any newly developed, more sensitive, indicator. The results of the analyses suggest that the achievable power for abundance of individuals is lower than for number of species because of the much higher variability exhibited by this metric. Therefore, the results of the power analyses performed using number of species were selected to inform the BACI sampling strategy (Appendix 6). Power analyses could not be carried out for Management Area A (UK 242) (hereafter referred to as area A) due to insufficient numbers of historical samples located within the zone.

Consideration of the available habitat maps suggested that reliably stratifying sampling by substratum would be difficult to achieve due to the high level of local heterogeneity in the substrata across the site. Therefore, the BACI survey was designed using a systematic grid to ensure comprehensive spatial coverage of the sediments within the treatments, whilst at the same time minimising any effects of spatial autocorrelation. The number of samples inside and outside of the management areas was selected based on the ability to detect a 20% level of change in species number (S) with a power of 0.8 (p=0.05) or higher, as presented in the results of the power analysis (Appendix 6). The general principles adopted for the purpose of the 2014 survey design are in accordance with the Healthy and Biologically Diverse Seas Evidence Group (HBDSEG) endorsed guidance outlined in Marubini (2014). It should also be noted that the metrics selected for the power analyses are intended as a proxy for other, potentially more responsive, metrics which will be explored using the dataset generated by the pilot monitoring R&D study (see section 3.2.2).

As no power analyses were performed to inform the sampling density within Management area A, an approximate number of samples required per treatment was inferred for this area based on the analyses conducted for the other management areas. The stations were placed within each proposed management area using the ETGeowizards 'Regular points in polygons' tool in ArcGIS (version 10.1), with a buffer of 0.01dd from the Fisheries Management Area boundary. This was done as a precaution to reduce the risk of stations

[6] https://r-forge.r-project.org/projects/emon/

falling within areas that still may be impacted by trawling activity being carried out on the boundary itself. Control areas (of approximately corresponding size) were delineated in those regions surrounding the proposed demersal fishery closures. This was intended (as far as possible) to ensure that environmental parameters influencing natural variability across the two treatments (e.g. inside and outside the proposed demersal fishery closures) were consistent. Figure 48 shows the four Management area boundaries overlain onto the subsurface abrasion pressure maps for the Dogger Bank SCI (2006 – 2013).

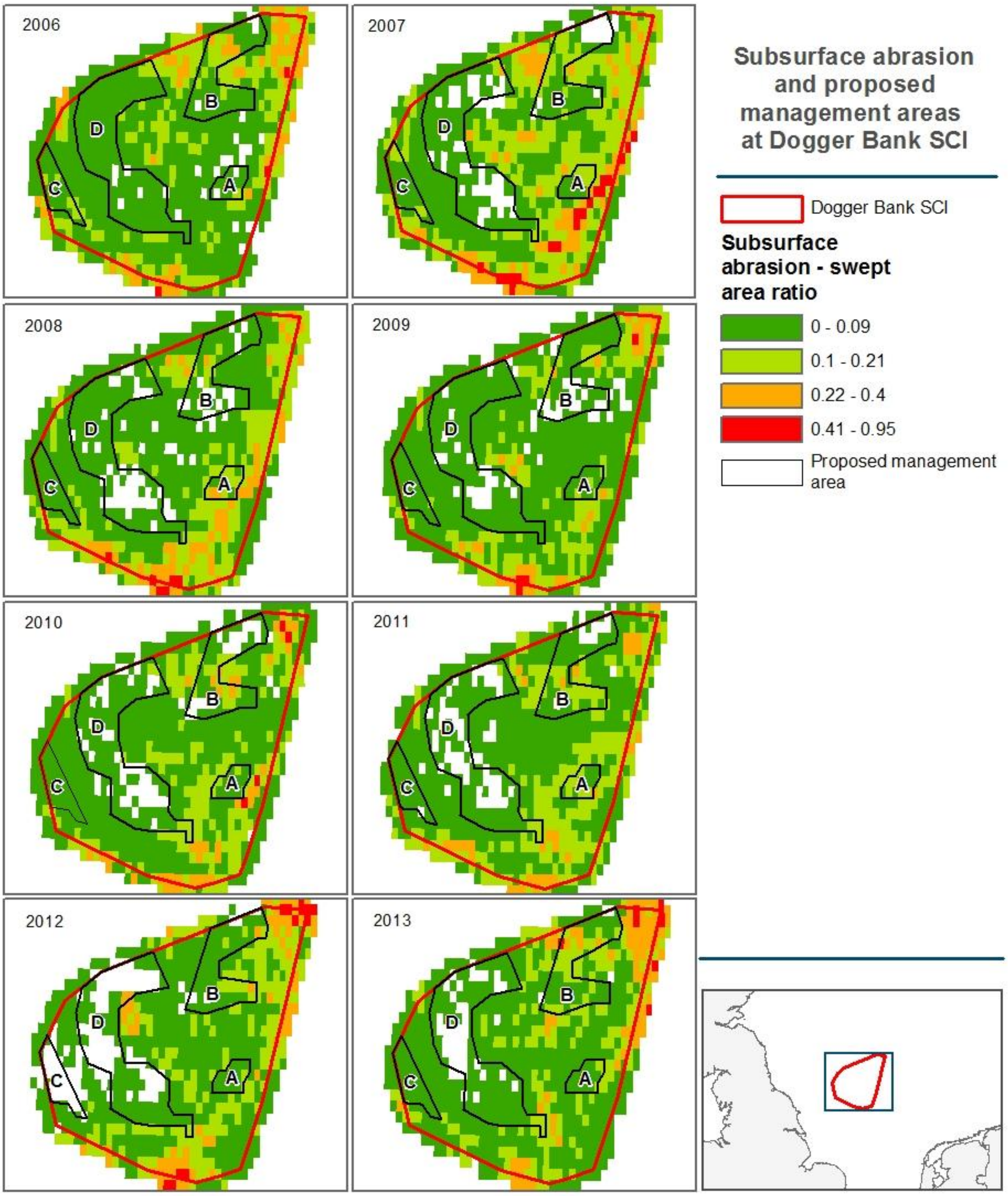



**Figure 48**. Subsurface abrasion pressure (swept area ratio) within the UK sector of the Dogger Bank SCI 2006-2013 with Mangement areas A – D overlain (full international codes for each Management area are shown in (Figure 49) and will hereafter be referred to as Management Areas A-D). Abrasion scores are from the UK-wide layer (Church *et al* 2016), however the categories were determined on the local scale of the Dogger Bank SCI.

### 4.1.2 Sample acquisition

Infaunal samples were collected using a 0.1m$^2$ Hamon grab. Epifaunal species data were acquired at a sub-set of the planned sampling stations (using underwater video and a 2m scientific beam trawl) (Figure 49). Appendix 1 and the Dogger Bank 2014 survey report (Ware & McIlwaine 2014) provide more detail on the specific methods that were used to support the investigative monitoring objectives and the precise locations of sampling points.

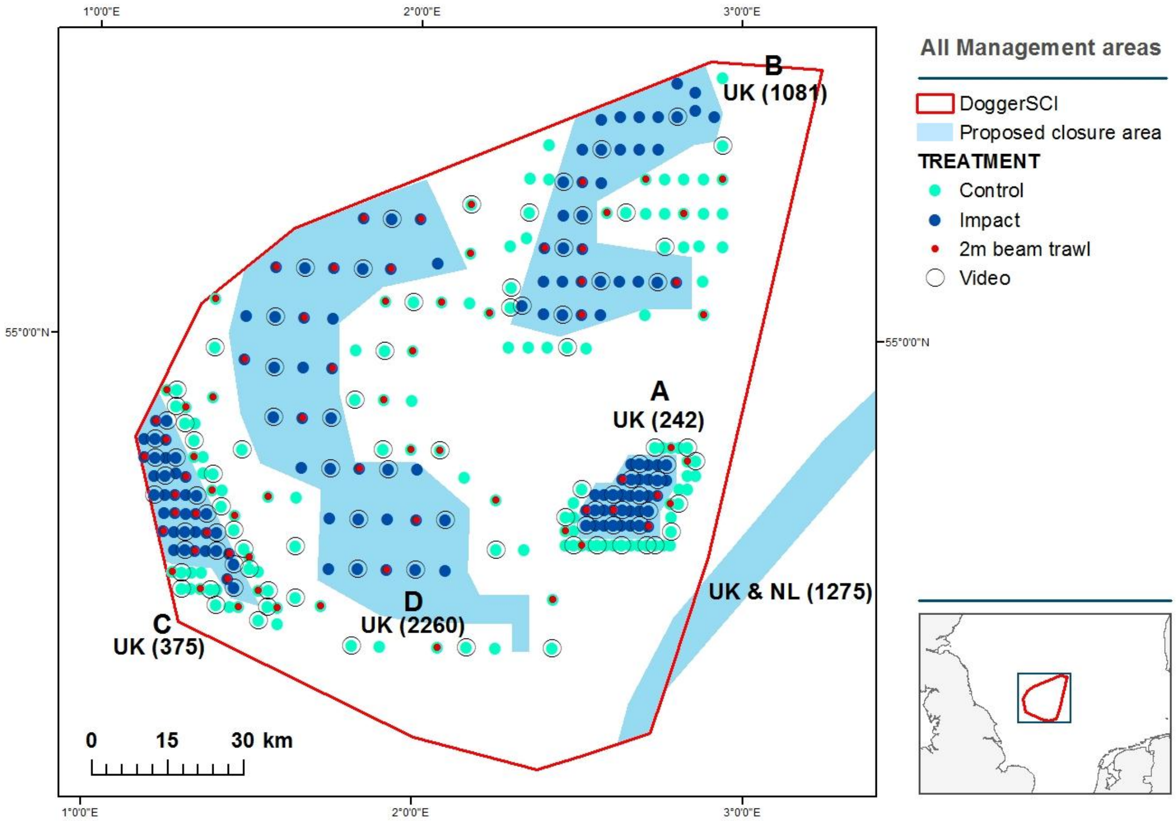



**Figure 49.** Location of the BACI stations in relation to the proposed demersal fishery closures/Management areas within the UK sector of the SCI.

### 4.1.3 Sample processing methods

Sample processing followed methods detailed in section 3.1.3.

### 4.1.4 Data analysis methods

Subsurface abrasion (swept-area ratio) statistics (standard deviation (population), standard deviation (sample), cumulative total (sum) and mean) were extracted from available VMS data (2009-2013) using R to gain an understanding of the variability of fishing pressure over time. Coefficient of Variation (CV) was calculated by dividing the standard deviation (population) by the mean. Boxplots were produced for each statistic in R, for each treatment (Control/Impact) and Management area.

Univariate metrics were calculated for each infaunal sample using Primer v6 and included: number of taxa (S); number of individuals (N); Hill's (1973) taxon diversity index (N1); and Biomass (g). Multimetric indices including Infaunal Quality Index (IQI), and one of its component metrics the AZTI Marine Biotic Index (AMBI), were calculated using both the infauna community and sediment partical size distribution data. Ecological quality ratios were calculated using the publically available MS Excel macro based 'IQI Workbook UKTAG v01 20150311.xlsm' accessed from the Water Framework Directive UK TG website (IQIv4, 2014). Forty-four taxa were initially rejected when calculating the IQI workbook due to their not being assigned an ecological group. Amendments to their taxonomic resolution and/or use of different synonyms resulted in the inclusion of all 44 previously rejected taxa as 43 distinct taxa. Particle size distribution information was reduced from 42 variables (percentage contribution at half-phi size classes) to 9 sediment size fractions (ranging from <63µm to ≥8000µm) for inclusion into the IQI metric.

A non-parametric Wilcoxon-Mann-Whitney test was performed on the infaunal univariate data to test for differences between Control and Impact areas at each Management area and boxplots produced (R Core Team 2015).

Multivariate analyses were performed using PRIMER v6. All infaunal data were square root transformed prior to calculation of a Bray-Curtis similarity matrix. A cluster analysis using the SIMPROF test was then carried out. The resultant cluster groups were displayed using nMDS ordinations. The Similarity Percentages (SIMPER) routine was used to identify the taxa characterising Control and Impact areas with cut off for low contributions set at 50%. SIMPROF clusters were calculated for each Management area.

Only twenty-five taxa in total were identified in the 141 videos collected across the Dogger Bank SCI in 2014. Many were only identified to higher taxonomic levels e.g. Hydroid/Bryozoan turf, Decapoda, Brachyura, Bivalvia, Asteroidea due to the poor image clarity. Better taxonomic resolution was possible for the following taxa: *Corystes cassivelaunus*, *Liocarcinus* spp., *Asterias rubens, Alcyonidium diaphanum and Flustra* spp. Univariate metrics calculated for each video sample were number of taxa and number of individuals. Multivariate data analysis was based on the presence/absence of fauna within the Impact versus Control areas. SIMPER was used to identify the species characterising Control and Impact areas. Statistical analysis was deemed inappropriate using this data due to the low number of species identified and variability in identification possible.

## 4.2 Results

### 4.2.1 Subsurface abrasion temporal variability

Coefficient of variation (CV) of the subsurface abrasion values (swept-area ratio) within each of the treatments for each area are shown in Figure 50. Management Area A displayed least amount of temporal variability in abrasion pressure, whilst Management Areas B-D were subject to high temporal variability both within and between treatments. Variability was largely comparable between treatments in all areas. Area D displayed a higher mean in the Impact compared to the Control treatment, however a large amount of variability was present.

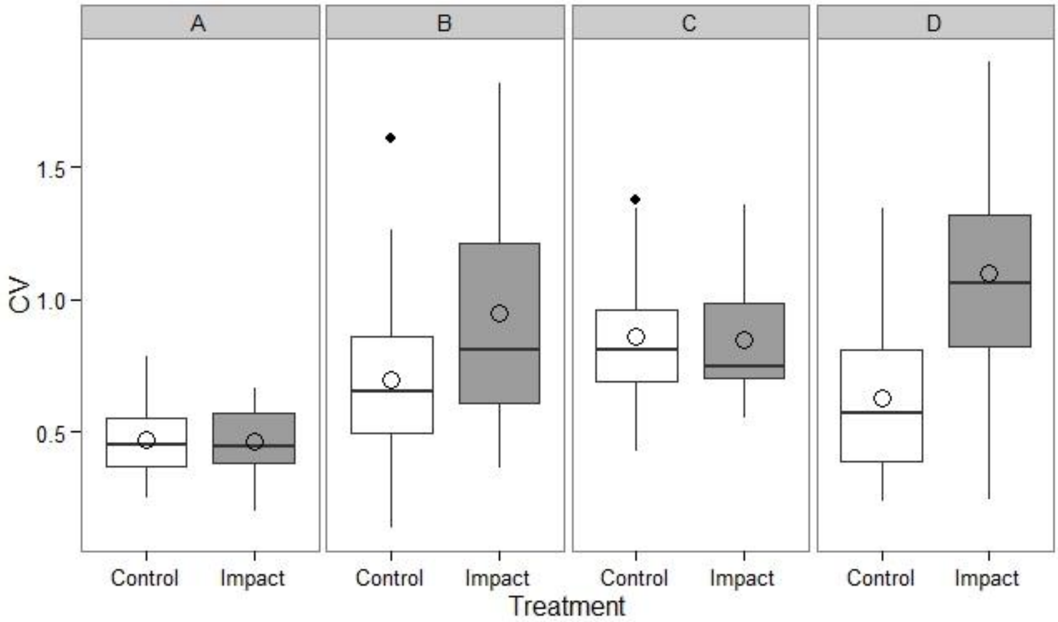



**Figure 50.** Coefficient of variation (CV) of the subsurface abrasion values (swept-area ratio) calculated at grab sampling locations within the Control and Impact areas of each Management area. Black line = median, open circle = mean, black dots=outliers, boxes represents the interquartile range of the data and whiskers represent the data range.

### 4.2.2 Particle size distribution

Management area A is mainly composed of sediments from Entropy group 1a (gravelly sand), (Figure 51). Sediment groups for the other three Management areas are more varied but broadly share similar range of sediment groups between Impact and Control treatments as shown in Table 30 – Table 32, Figure 52 and Figure 53.

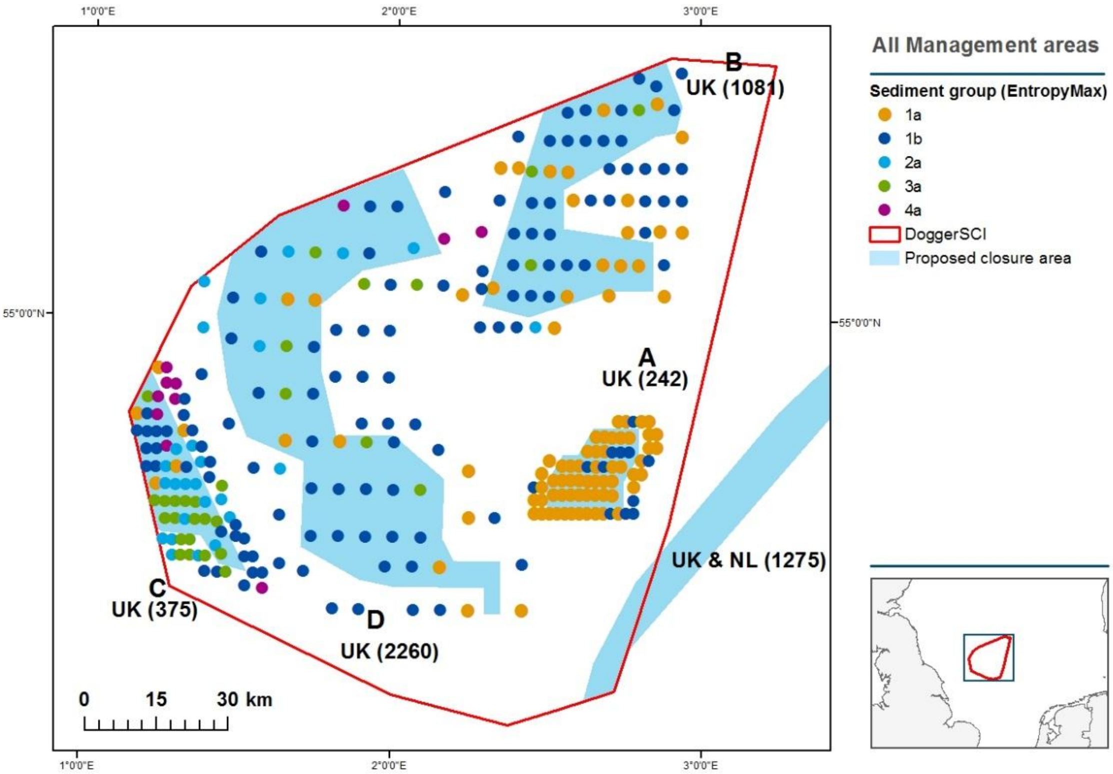



**Figure 51**. Sediment groups classified using EntropyMax for each Management area within the Dogger Bank SCI. Sediment groups are explained in Section 2.

**Table 30.** Sediment groups classified using EntropyMax for each Management area (delineated by Impact and Control treatment). Sediment groups are explained in Section 2. The number of samples in each sediment group is included in brackets.

| Management area | Sediment group | |
|---|---|---|
| | Impact | Control |
| A | 1a (30), 1b (5) | 1a (28), 1b (7) |
| B | 1b (23), 1a (9), 3a (3) | 1b (20), 1a (13), 2a (1), 4a (1) |
| C | 3a (12), 1b (11), 2a (9), 1a (3), 4a (3) | 1b (16), 2a (8), 3a (7), 4a (5), 1a (2) |
| D | 1b (22), 1a (5), 2a (5), 3a (5), 4a (1) | 1b (25), 1a (4), 2a (3), 3a (2), 4a (1) |

**Table 31.** Sediment groups classified according to Folk for each Management area (delineated by Impact and Control treatment). The number of samples in each Folk class is included in brackets.

| Management area | Folk classification | |
|---|---|---|
| | Impact | Control |
| A | gS (28), (g)S (7) | gS (26), (g)S (7), S (2) |
| B | (g)S (14), S (9), gS (7), sG (2), (g)mS (1), gmS (1), msG (1) | (g)S (14), S (7), gS (12), (g)mS (1), mS (1) |
| C | S (14), sG (10), (g)S (6), gS (3),mS (3), gmS (2) | S (17), (g)S (10), sG (6), gS (3), mS (2), msG (1) |
| D | S (19), (g)S (8), gS (5), sG (4), (g)M (1), (g)mS (1), msG (1) | S (18), (g)S (9), gS (4), (g)mS (2), msG (1), sG (1) |

**Table 31**. Sediment groups classified according to EUNIS Level 3 habitat classification for each Management area (delineated by Impact and Control treatment). C = coarse sediment; S = sand and muddy sand; Mi = mixed sediments; and Mu = mud and sandy mud. The number of samples in each EUNIS group is included in brackets.

| Management area | EUNIS groups | |
|---|---|---|
| | Impact | Control |
| A | C (28), S (9) | C (26), S (9) |
| B | S (24), C (9), Mi (2) | S (22), C (12), Mu (1) |
| C | S (23), C (13), Mi (2) | S (28), C (9), Mi (1) |
| D | S (27), C (9), Mu (2) | S (28), C (5), Mi (1), Mu (1) |

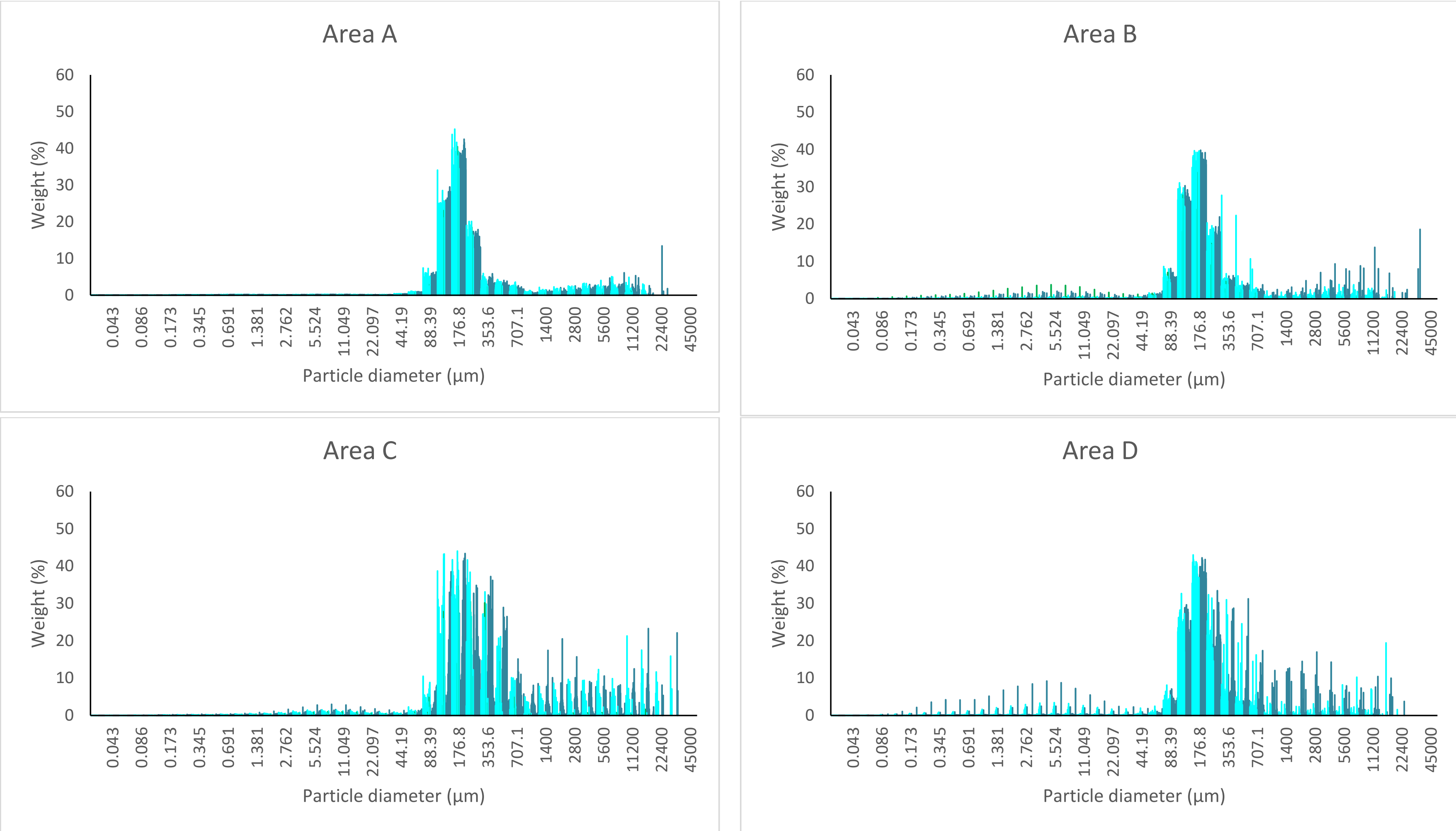



**Figure 52**. Comparison of Impact and Control particle size distribution (PSD) histograms at each Management area. Dark blue bars represent Impact stations; turquoise bars represent Control stations.

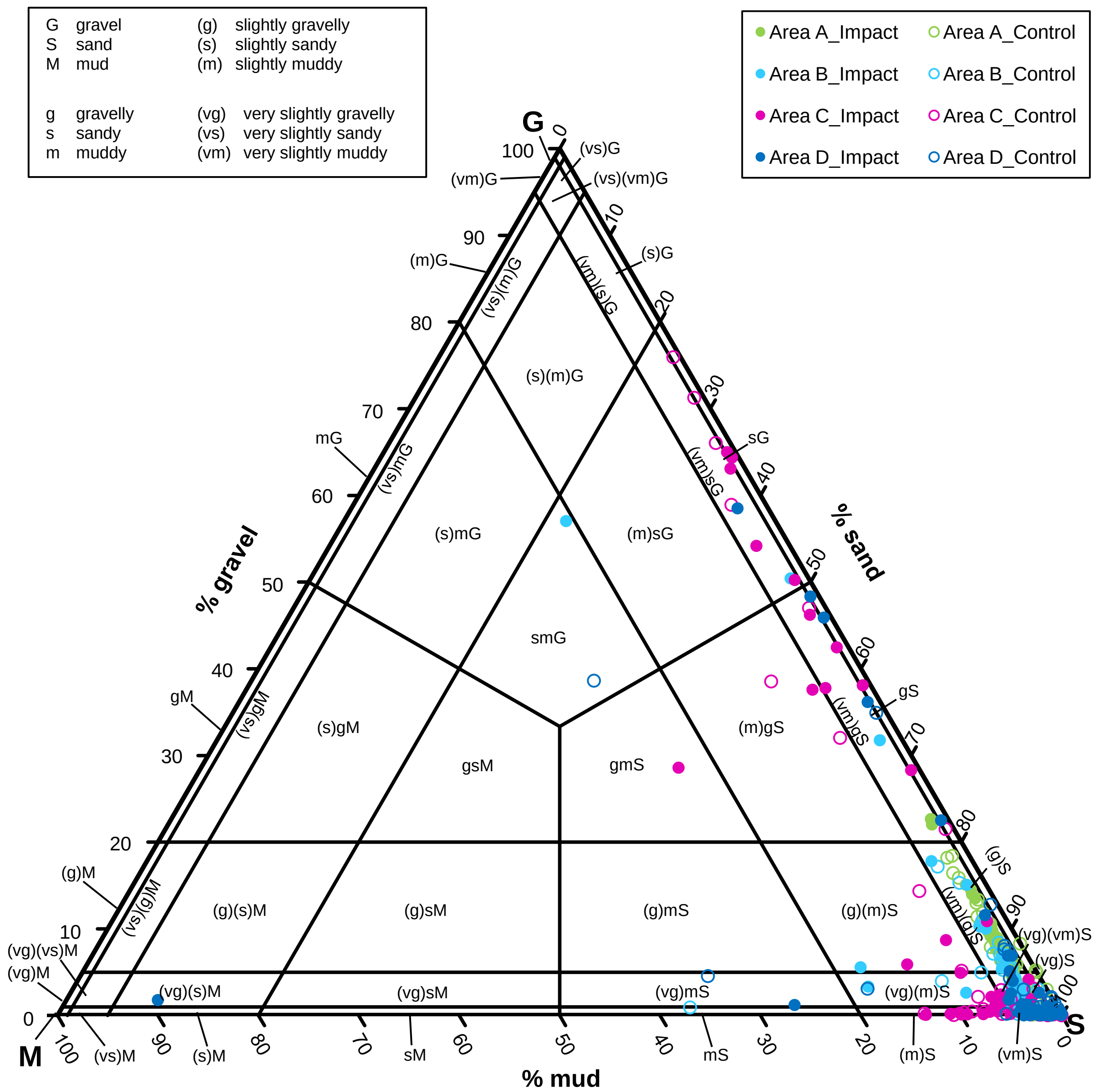



**Figure 53.** Gravel, sand and mud trigon (Blott & Pye 2012) comparing sediment compositions between Impact and Control samples at each Management area. Note this presentation is different to the classic Folk triangle as it represents each of the fractions (gravel, sand and mud) evenly rather than as a ratio of any two fractions from opposite vertices (e.g.sand:mud) and is therefore easier to interpret.

A non-metric multidimensional scaling (nMDS) ordination (Figure 54) comparing sediment distributions at 0.5phi resolutions for all Management areas supports previous comments that Impact and Control sediments are most similar for area A, and that while there is greater variability in sediment distributions in areas B, C and D, there is a similar contribution of each sediment type present in both the Impact and Control areas.

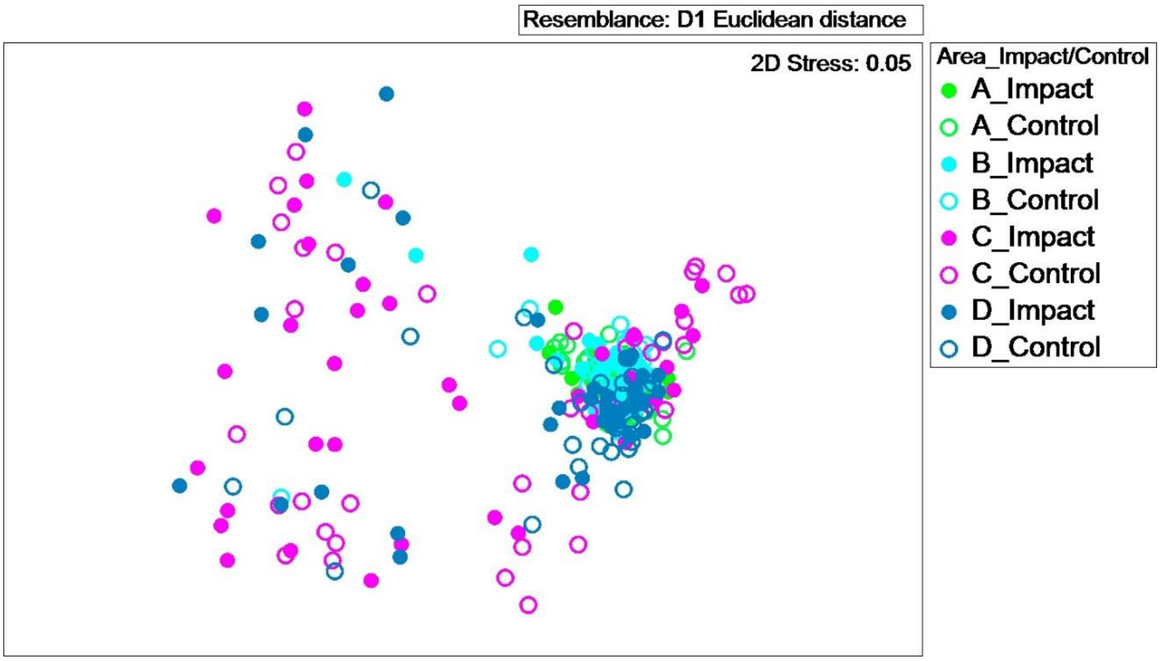



**Figure 54**. nMDS ordination of particle size distribution data (half-phi size classes) for all Mangement areas comparing sediment compositions of Impact and Control samples. Solid circles represent stations from within the Impact areas whereas open circles represent stations within the Control treatment. Management areas are distinguished by colour.

### 4.2.3 Comparison of bivalves collected within each Management area

| **Taxa** | **Area A** | | **Area B** | | **Area C** | | **Area D** | |
|---|---|---|---|---|---|---|---|---|
| | **C** | **I** | **C** | **I** | **C** | **I** | **C** | **I** |
| *Abra* | | | 11 | 53 | 10 | 23 | 4 | 22 |
| *Abra alba* | | | 2 | | 9 | 2 | 2 | 17 |
| *Abra nitida* | | | 2 | 1 | | | | |
| *Abra prismatica* | | | 3 | 11 | 6 | 7 | 3 | 3 |
| *Acropagia crassa* | | | | | | 5 | | |
| Anomidae | | | | | | | 1 | |
| *Arcopagia crassa* | | | | | 1 | | | 1 |
| *Arctica islandica* | | | | 1 | | | 1 | 1 |
| Bivalvia | 7 | 4 | 16 | 7 | 9 | 19 | 12 | 3 |
| Cardidae | | | 1 | 4 | | | 8 | 2 |
| *Chamalea striatula* | | 1 | 9 | 2 | | 10 | 10 | 27 |
| *Clausinella fasciata* | | | | | 4 | | | |
| *Cochlodesma praetenue* | | | | | | 2 | 5 | 7 |
| *Corbula gibba* | | 2 | 2 | 1 | 4 | 1 | 5 | 2 |
| *Donax vittatus* | 5 | 4 | 1 | | 4 | | 19 | 38 |
| *Dosinia* | | | 7 | 10 | 2 | 7 | 5 | 5 |
| *Dosinia exoleata* | | | | | 2 | 4 | 6 | 1 |
| *Dosinia lupinus* | 2 | 1 | 14 | 7 | 22 | 36 | 7 | 5 |
| *Ennucula tenuis* | | | | | 1 | | | |
| *Ensis* | 1 | 3 | | 1 | | 1 | 4 | 10 |
| *Ensis ensis* | 10 | 16 | 9 | 4 | 1 | | 6 | 8 |
| *Ensis siloqua* | | | | | | 2 | | |
| *Gari* | | | | | 2 | | | |

| Taxa | Area A | | Area B | | Area C | | Area D | |
|---|---|---|---|---|---|---|---|---|
| | C | I | C | I | C | I | C | I |
| *Gari fervensis* | 3 | | 1 | 5 | 1 | 3 | 3 | 3 |
| *Gari tellinella* | | | | | | | | 3 |
| *Goodallia triangularis* | | | | | 1 | | | |
| *Hemilepton nitidum* | | | | | 2 | | | |
| *Kurtiella bidentata* | | 3 | 82 | 68 | 23 | 30 | 42 | 4 |
| *Lucinoma borealis* | | | 1 | 2 | | 5 | | 1 |
| *Mactra stultorum* | 1 | 1 | 4 | | 1 | 1 | 10 | |
| Mactridae | | | | | 6 | | 4 | 4 |
| *Modiolula phaseolina* | | | | | 1 | 1 | 1 | |
| *Moerella pygmaea* | 1 | | | | | | | 1 |
| *Mya arenaria* | | | 2 | 1 | 1 | 2 | | 1 |
| *Nucula nitida* | | | 1 | | | | | |
| *Nucula nitidosa* | | | | | 25 | 20 | 1 | 1 |
| *Nucula nucleus* | | | | 1 | | | | |
| Nuculidae | | | | | | 1 | | |
| *Parvicardium scabra* | | | | | 2 | | | |
| Pharidae | 1 | 1 | 9 | 23 | 1 | 4 | 15 | 3 |
| *Phaxas pellucides* | | | | 4 | 7 | 17 | | 2 |
| *Polititapes rhomboides* | | | | | 11 | 10 | | |
| Semelidae | | | | | | | 6 | |
| *Spisula* | | | 1 | 2 | 5 | 4 | 24 | 8 |
| *Spisula elliptica* | | | 1 | | 2 | 3 | | 2 |
| *Spisula solida* | 1 | 1 | | | | | | |
| *Tapes* | | | | | | | 1 | |
| *Tellina fabula* | 66 | 87 | 78 | 55 | 67 | 60 | 29 | 37 |
| *Tellimya ferroginosa* | 4 | 2 | 12 | 11 | 9 | 11 | 20 | 5 |
| *Tellina ferruginosa* | | | 1 | | | | | |
| *Tellina pygmaea* | | | | | 1 | 1 | | 3 |
| *Tellina tenuis* | | | | | | | 3 | |
| Tellinidae | 1 | 1 | | | 5 | 3 | | |
| *Thracia* | | 4 | 7 | 6 | | 5 | 4 | 8 |
| *Thracia gracilis* | 14 | 12 | 13 | 10 | 15 | 16 | 6 | 6 |
| *Thracia papyracea* | | | | 1 | | | | |
| Thraciidae | | | | | 1 | | | |
| *Thyasira* | | | | 1 | | | | |
| *Thyasira equalis* | | | | 1 | | 2 | | |
| *Thyasira flexuosa* | | | 17 | 29 | | | 2 | |
| *Thyasira sarsi* | | | | | 4 | 4 | | |
| Thyasiridae | | | | | | | 1 | |
| *Timoclea ovata* | | | | 1 | 1 | 1 | | 1 |
| Veneridae | 1 | | | 2 | 1 | 3 | 2 | 8 |
| *Venus casina* | | | | 1 | | | | |
| **Number of species** | **15** | **16** | **27** | **31** | **38** | **36** | **34** | **35** |
| **Total** | **118** | **143** | **307** | **326** | **270** | **326** | **272** | **253** |

Table 33 shows the bivalve species and abundances according to Control and Impact stations of each Management area. Area C contained the highest number of different bivalve species (47), with 37 and 36 species found in Control and Impact areas, respectively. The highest abundances were observed in Area B, totalling 633 individuals. The most abundant bivalve species was *Tellina fabula* (1499 individuals), which was found within all Management areas.

**Table 33**. Bivalve species abundances collected in 2014 from the Control (C) and Impact (I) stations within each Management area of the Dogger Bank SCI.

| **Taxa** | **Area A** | | **Area B** | | **Area C** | | **Area D** | |
|---|---|---|---|---|---|---|---|---|
| | **C** | **I** | **C** | **I** | **C** | **I** | **C** | **I** |
| *Abra* | | | 11 | 53 | 10 | 23 | 4 | 22 |
| *Abra alba* | | | 2 | | 9 | 2 | 2 | 17 |
| *Abra nitida* | | | 2 | 1 | | | | |
| *Abra prismatica* | | | 3 | 11 | 6 | 7 | 3 | 3 |
| *Acropagia crassa* | | | | | | 5 | | |
| Anomidae | | | | | | | 1 | |
| *Arcopagia crassa* | | | | | 1 | | | 1 |
| *Arctica islandica* | | | | 1 | | | 1 | 1 |
| Bivalvia | 7 | 4 | 16 | 7 | 9 | 19 | 12 | 3 |
| Cardidae | | | 1 | 4 | | | 8 | 2 |
| *Chamalea striatula* | | 1 | 9 | 2 | | 10 | 10 | 27 |
| *Clausinella fasciata* | | | | | 4 | | | |
| *Cochlodesma praetenue* | | | | | | 2 | 5 | 7 |
| *Corbula gibba* | | 2 | 2 | 1 | 4 | 1 | 5 | 2 |
| *Donax vittatus* | 5 | 4 | 1 | | 4 | | 19 | 38 |
| *Dosinia* | | | 7 | 10 | 2 | 7 | 5 | 5 |
| *Dosinia exoleata* | | | | | 2 | 4 | 6 | 1 |
| *Dosinia lupinus* | 2 | 1 | 14 | 7 | 22 | 36 | 7 | 5 |
| *Ennucula tenuis* | | | | | 1 | | | |
| *Ensis* | 1 | 3 | | 1 | | 1 | 4 | 10 |
| *Ensis ensis* | 10 | 16 | 9 | 4 | 1 | | 6 | 8 |
| *Ensis siloqua* | | | | | | 2 | | |
| *Gari* | | | | | 2 | | | |
| *Gari fervensis* | 3 | | 1 | 5 | 1 | 3 | 3 | 3 |
| *Gari tellinella* | | | | | | | | 3 |
| *Goodallia triangularis* | | | | | 1 | | | |
| *Hemilepton nitidum* | | | | | 2 | | | |
| *Kurtiella bidentata* | | 3 | 82 | 68 | 23 | 30 | 42 | 4 |
| *Lucinoma borealis* | | | 1 | 2 | | 5 | | 1 |
| *Mactra stultorum* | 1 | 1 | 4 | | 1 | 1 | 10 | |
| Mactridae | | | | | 6 | | 4 | 4 |
| *Modiolula phaseolina* | | | | | 1 | 1 | 1 | |
| *Moerella pygmaea* | 1 | | | | | | | 1 |
| *Mya arenaria* | | | 2 | 1 | 1 | 2 | | 1 |
| *Nucula nitida* | | | 1 | | | | | |
| *Nucula nitidosa* | | | | | 25 | 20 | 1 | 1 |
| *Nucula nucleus* | | | | 1 | | | | |
| Nuculidae | | | | | | 1 | | |
| *Parvicardium scabra* | | | | | 2 | | | |

| Taxa | Area A | | Area B | | Area C | | Area D | |
|---|---|---|---|---|---|---|---|---|
| | C | I | C | I | C | I | C | I |
| Pharidae | 1 | 1 | 9 | 23 | 1 | 4 | 15 | 3 |
| *Phaxas pellucides* | | | | 4 | 7 | 17 | | 2 |
| *Polititapes rhomboides* | | | | | 11 | 10 | | |
| Semelidae | | | | | | | 6 | |
| *Spisula* | | | 1 | 2 | 5 | 4 | 24 | 8 |
| *Spisula elliptica* | | | 1 | | 2 | 3 | | 2 |
| *Spisula solida* | 1 | 1 | | | | | | |
| *Tapes* | | | | | | | 1 | |
| *Tellina fabula* | 66 | 87 | 78 | 55 | 67 | 60 | 29 | 37 |
| *Tellimya ferroginosa* | 4 | 2 | 12 | 11 | 9 | 11 | 20 | 5 |
| *Tellina ferruginosa* | | | 1 | | | | | |
| *Tellina pygmaea* | | | | | 1 | 1 | | 3 |
| *Tellina tenuis* | | | | | | | 3 | |
| Tellinidae | 1 | 1 | | | 5 | 3 | | |
| *Thracia* | | 4 | 7 | 6 | | 5 | 4 | 8 |
| *Thracia gracilis* | 14 | 12 | 13 | 10 | 15 | 16 | 6 | 6 |
| *Thracia papyracea* | | | | 1 | | | | |
| Thraciidae | | | | | 1 | | | |
| *Thyasira* | | | | 1 | | | | |
| *Thyasira equalis* | | | | 1 | | 2 | | |
| *Thyasira flexuosa* | | | 17 | 29 | | | 2 | |
| *Thyasira sarsi* | | | | | 4 | 4 | | |
| Thyasiridae | | | | | | | 1 | |
| *Timoclea ovata* | | | | 1 | 1 | 1 | | 1 |
| Veneridae | 1 | | | 2 | 1 | 3 | 2 | 8 |
| *Venus casina* | | | | 1 | | | | |
| **Number of species** | **15** | **16** | **27** | **31** | **38** | **36** | **34** | **35** |
| **Total** | **118** | **143** | **307** | **326** | **270** | **326** | **272** | **253** |

### 4.2.4 Infaunal assemblages

Significant differences were observed in the infaunal abundance, biomass and EQR values between treatments (Control/Impact) for Management area B and for the EQR values between treatments for Management area D (seeTable 34). Mean values for these metrics were significantly lower in the Impact compared to the Control treatments for both areas. However, EQR values within both areas were generally >0.64 suggesting good to high ecological status. Only two samples within the Impact treatment of mangement area B were classed as Moderate, whilst eight samples within the Impact treatment and two samples within the Control treatment of Management area D were classed as Moderate. Further interrogation of the IQI workbook shows that samples classified as Moderate were dominated by species, such as *S. bombyx*, classified within AMBI ecological group III (defined by Borja *et al* (2000) as species that are tolerant to excess organic enrichment, which occur under natural conditions but their populations are stimulated by organic enrichment e.g. surface deposit feeding species such as tubiculous spionids).

No other significant differences were found between the two treatments (Control and Impact) in the other Management areas (Table 34). See Appendix 7 for box-whisker plots and summary statistics of each metric (Control and Impact treatments) for each Management area.

**Table 34.** Results of the non-parametric Wilcoxon-Mann-Whitney test of differences between the univariate metrics calculated from samples located in each of the Management areas. W = test statistic, p-value=significance. Figures in bold are significant at the 5 % level. Figures in italics are significant at the 1 % level. The number of samples (n) in each treatment is indicated in subscript (I = Impact, C = Control)

| | **A $n_I$ = 35, $n_C$ = 35** | | **B $n_I$ = 35, $n_C$ = 35** | | **C $n_I$ = 38, $n_C$ = 38** | | **D $n_I$ = 35, $n_C$ = 35** | |
|---|---|---|---|---|---|---|---|---|
| **Univariate metric** | **W** | **p-value** | **W** | **p-value** | **W** | **p-value** | **W** | **p-value** |
| Number of taxa (S) | 538 | 0.38 | 457 | 0.07 | 832 | 0.25 | 654 | 0.64 |
| Number of individuals (N) | 536 | 0.37 | 447 | **0.05** | 886 | 0.10 | 708 | 0.27 |
| Hills diversity (N1) | 628 | 0.86 | 532 | 0.35 | 749 | 0.79 | 568 | 0.61 |
| Biomass (g) | 565 | 0.58 | 362 | ***0.01*** | 875 | 0.11 | 621 | 0.93 |
| Ecological Quality Ratio | 582 | 0.73 | 666 | **0.03** | 784 | 0.53 | 443 | **0.05** |
| AMBI | 699 | 0.51 | 666 | 0.54 | 644 | 0.42 | 559 | 0.54 |

An interrogation of the species matrix for each Management area and treatment revealed that only 50-60% of taxa were present in both Control and Impact treatments. A high percentage of singletons (one individual of a taxon) within both the Control and Impact treatments was also observed for all Management areas (Table 35). Although many of the dominant species are characteristic of both Control and Impact stations, their contribution to the within treatment similarity differs. This is particulary noticeable for Management area C (Table 36). The high incidence of singletons in addition to differences in the most abundant species may account for the high within treatment variability and low average community similarity within treatments observed in the SIMPER analysis (Table 36 and Appendix 5).

**Table 35**. Taxa within each Management area and treatment.

| **Mangement area** | **No of taxa** | **% of taxa in both Control and Impact stations** | **% of singletons in Control stations** | **% of singletons in Impact stations** |
|---|---|---|---|---|
| A | 144 | 60 | 41 | 38 |
| B | 169 | 54 | 37 | 39 |
| C | 279 | 52 | 43 | 43 |
| D | 202 | 50 | 44 | 39 |

**Table 36.** Ranked species contribution to within treatment (Control and Impact areas) similarity (~50% for samples taken within all Dogger Bank SCI Management Areas in 2014). Spatial distribution of species within each treatment is indicated by '% of samples present'.

| | **Impact** | | | **Control** | | |
|---|---|---|---|---|---|---|
| **Area** | **Species** | **% of samples present** | **% Contribution** | **Species** | **% of samples present** | **% Contribution** |
| *A* | *Bathyporeia elegans* | 94 | 22.85 | *Bathyporeia elegans* | 97 | 23.13 |
| | *Owenia borealis* | 94 | 13.19 | *Owenia borealis* | 94 | 12.08 |
| | *Sigalion mathildae* | 89 | 9.07 | *Sigalion mathildae* | 89 | 8.54 |
| | *Bathyporeia guilliamsoniana* | 83 | 7.97 | *Urothoe poseidonis* | 86 | 8.35 |

| | Impact | | | Control | | |
|---|---|---|---|---|---|---|
| **Area** | **Species** | **% of samples present** | **% Contribution** | **Species** | **% of samples present** | **% Contribution** |
| *B* | *Bathyporeia pelagica* | 74 | 13.63 | *Spiophanes bombyx* | 91 | 12.96 |
| | *Spiophanes bombyx* | 71 | 10.37 | *Bathyporeia pelagica* | 71 | 8.76 |
| | *Chaetozone christiei* | 69 | 10.32 | *Chaetozone christiei* | 77 | 8.68 |
| | *Goniada maculata* | 60 | 5.92 | *Tellina fabula* | 77 | 7.23 |
| | *Tellina fabula* | 57 | 5.14 | *Sigalion mathildae* | 80 | 6.76 |
| | *Owenia borealis* | 60 | 5.14 | *Echinocyamus pusillus* | 71 | 6.73 |
| *C* | *Spiophanes bombyx* | 79 | 14.42 | *Spiophanes bombyx* | 74 | 13.87 |
| | *Scoloplos armiger* | 66 | 9.91 | *Nephtys cirrosa* | 50 | 8.38 |
| | *Echinocyamus pusillus* | 58 | 8.07 | *Tellina fabula* | 53 | 8 |
| | *Goniada maculata* | 63 | 7.76 | NEMERTEA | 58 | 5.66 |
| | NEMERTEA | 68 | 6.8 | *Ophelia borealis* | 39 | 5.5 |
| | *Bathyporeia pelagica* | 50 | 4.9 | *Goniada maculata* | 53 | 5.45 |
| | | | | *Bathyporeia pelagica* | 45 | 5.04 |
| *D* | *Spiophanes bombyx* | 89 | 26.36 | *Bathyporeia elegans* | 91 | 26.62 |
| | *Bathyporeia elegans* | 83 | 20.69 | *Spiophanes bombyx* | 86 | 19.38 |
| | *Bathyporeia guilliamsoniana* | 54 | 5.67 | *Nephtys cirrosa* | 54 | 6.47 |

SIMPROF analysis revealed significantly different faunal groups (5% significance level) between Impact and Control areas Management area B-D (communities found in the Control and Impact stations of Area A were not significantly different and characterised by species shown in Table 36. The dominant SIMPROF groups (i and j) identified across Management area B were both characterised by low average abundances of *Bathyporeia pelagica*, *Chaetozone christei* and *Spiophanes bombyx*, although differences in the contribution of these species to the within group similarity along with differences in a number of other characteristic species accounted for significant separation of the groups. The main SIMPROF groups within Management area C (f and g) also shared characteristic species such as *S. bombyx* but differed due to the dominance by other species e.g group g was additionally characterised by *Ophelia borealis* and *Nephtys cirrosa*, whilst group f was characterised by *Tellina fabula* and *Scoloplos armiger*. Management area D major groups (k and l) were similarly characterised by *S. bombyx* and *Bathyporeia* (although the species was *elegans* rather than *pelagica*). All these species are typical of Infralittoral and Circalittoral fine sands. Figure 55**Figure** shows the location of the different SIMPROF groups identified within each Management area and Appendix 5 details the characteristic species of each SIMPROF group.

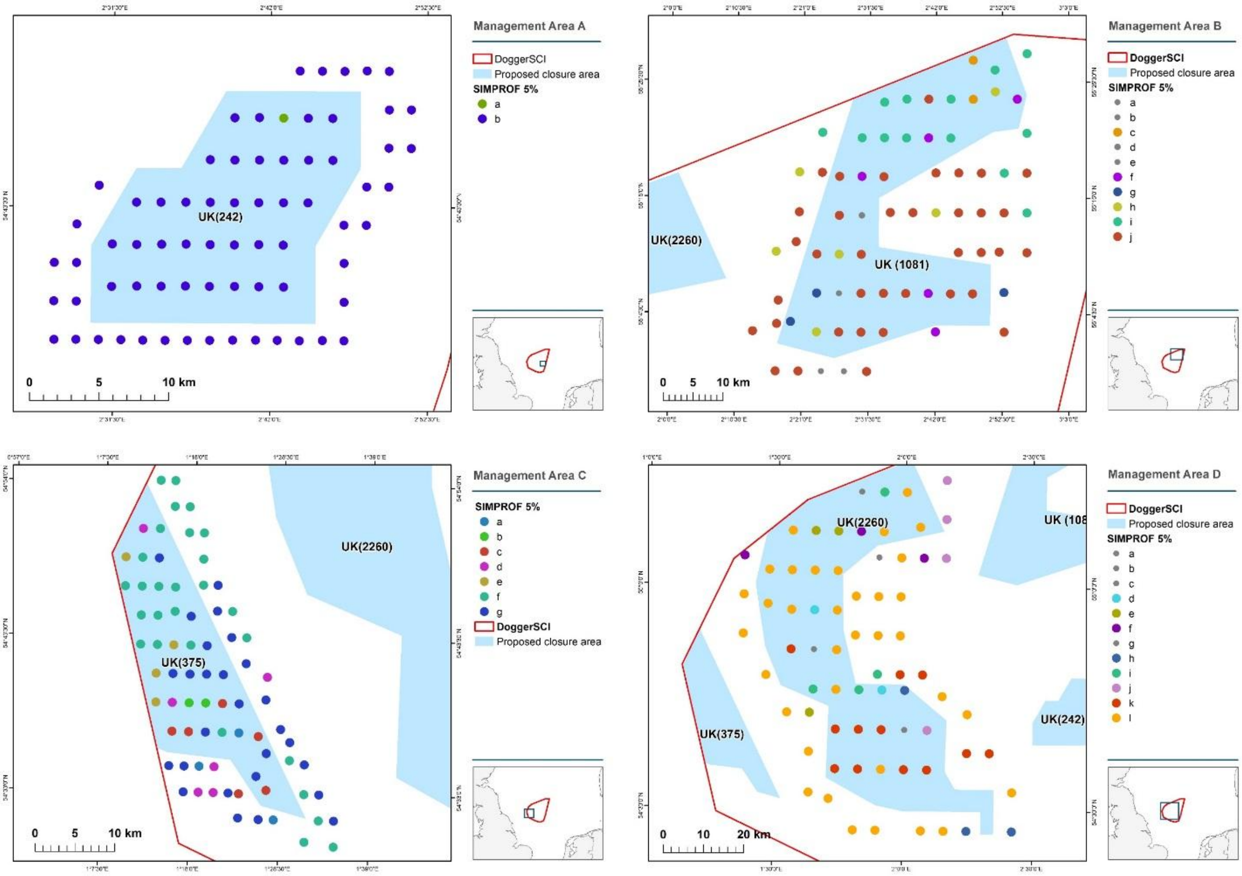



**Figure 55**. Location of SIMPROF groups across Management areas; A (topleft), B (top right), C (bottom left) and D (bottom right).

### 4.2.5 Epifauna assemblages: Video

The mean number of individuals present at stations from within the Impact treatment of Management area D (6 ± s.d. 8.4) was significantly lower than that found in the Control area (5 ± sd 6.2), (p =0.027). No other significant differences were found between the two treatments (Control and Impact) in the other Management areas (Table 37).
See Appendix 7 for box-whisker plots and summary statistics of each metric (Control and Impact treatments) for each Management area.

**Table 37.** Results of the non-parametric Wilcoxon-Mann-Whitney test (W) of differences between the univariate metrics calculated from video epifauna samples located in each of the Management areas. Tows were standardised by time (10 minutes). Figures in bold are significant (p-value) at the 5 % level. The number of samples (n) in each treatment is indicated in subscript (I = Impact, C = Control)

| | **A $n_I$ = 12, $n_C$ = 13** | | **B $n_I$ = 9, $n_C$ = 7** | | **C $n_I$ = 14, $n_C$ = 16** | | **D $n_I$ = 14, $n_C$ = 14** | |
|---|---|---|---|---|---|---|---|---|
| **Univariate metric** | **W** | **p-value** | **W** | **p-value** | **W** | **p-value** | **W** | **p-value** |
| Number of taxa (S) | 78 | 1 | 25 | 0.48 | 94 | 0.46 | 140 | 0.05 |
| Number of individuals (N) | 98 | 0.30 | 35 | 0.80 | 118 | 0.82 | 147 | **0.03** |
| Hills diversity (N1) | 79 | 1 | 29 | 0.84 | 66 | 0.06 | 130 | 0.15 |

SIMPER analysis of the taxa characterising the Impact and Control areas for each Management area are shown in Table 38. Average abundances are based on presence/absence transformed data and therefore are equivalent of occurrence across the site e.g. 0.83 equates to *Asterias rubens* observed in 83% of videos taken within the Impact area.

The main differences between Control and Impact areas in Management area A are the absence of the taxa *Liocarcinus* sp., Decapoda, Ophiurida, Buccinidae and the polychaete *Aphrodita aculeata* from the Impact treatment. N.B. although *Liocarcinus* sp., Decapoda and Ophiurida may be represented with the higher taxonomic groups of Eumalacostraca and Asteroidea which are present in the Control treatment.

Crustaceans and starfish were the most frequently observed taxa both in the Control and Impact areas of management area B. Notable absences from the impact stations are the bryozoan *Alcyonidium diaphanum* and the polychaete *Aphrodita aculeata*.

The most frequently observed taxonomic groups within the Control and Impact stations of Management area C were Asteroidea and Paguridae. Eighty-four percent of the species observed in all videos across the SCI were observed within this management area. Crustaceans and starfish were again the most frequently occurring taxa observed in videos from the Control and Impact areas of Management area D. Colonial taxa more characteristic of coarser substrata were observed at a few stations.

**Table 38**. Taxa contributing to the percentage dissimilarity between Impact and Control video stations in each Management area (taxa listed in order of contribution to dissimilarity).

| Management Area | Species | Impact<br>Average abundance | Control<br>Average abundance |
|---|---|---|---|
| **A** | *Asterias rubens* | 0.83 | 0.23 |
| | EUMALACOSTRACA | 0.75 | 0.54 |
| | ASTEROIDEA | 0.83 | 0.46 |
| | *Corystes cassivelaunus* | 0.58 | 0.62 |
| | Paguridae | 0.17 | 0.38 |
| | DECAPODA | 0 | 0.38 |
| | *Astropecten irregularis* | 0.25 | 0.08 |
| | OPHIURIDA | 0 | 0.23 |
| | *Liocarcinus* sp. | 0 | 0.15 |
| | *Aphrodita aculeata* | 0 | 0.15 |
| | BRACHYURA | 0.92 | 1 |
| | *Flustra* sp. | 1 | 0.92 |
| | Buccinidae | 0 | 0.08 |
| **B** | *Asterias rubens* | 0.67 | 0.43 |
| | *Liocarcinus* sp. | 0.44 | 0.57 |
| | BRACHYURA | 0.56 | 0.71 |
| | *Corystes cassivelaunus* | 0.67 | 0.86 |
| | *Alcyonidium diaphanum* | 0 | 0.29 |
| | Paguridae | 0.78 | 1 |
| | *Astropecten irregularis* | 0.22 | 0 |
| | ASTEROIDEA | 0.89 | 0.86 |
| | Serpulidae (tubes) | 0.11 | 0.14 |
| | DECAPODA | 0.11 | 0.14 |
| | *Aphrodita aculeata* | 0 | 0.14 |
| | EUMALACOSTRACA | 0 | 0.14 |
| | OPHIURIDA | 0.11 | 0 |
| | PORIFERA | 0.11 | 0 |
| | *Alcyonium digitatum* | 0.11 | 0 |
| | *Flustra* sp. | 0.11 | 0 |
| **C** | DECAPODA | 0.29 | 0.69 |
| | *Liocarcinus* sp. | 0.64 | 0.44 |
| | BRACHYURA | 0.5 | 0.38 |

| Management Area | Species | Impact Average abundance | Control Average abundance |
|---|---|---|---|
| | *Asterias rubens* | 0.5 | 0.44 |
| | *Alcyonium digitatum* | 0.5 | 0.25 |
| | Hydroid/Bryozoan Turf | 0.36 | 0.38 |
| | Paguridae | 0.71 | 0.88 |
| | *Corystes cassivelaunus* | 0.21 | 0.31 |
| | *Astropecten irregularis* | 0.21 | 0.19 |
| | ASTEROIDEA | 0.79 | 1 |
| | *Alcyonidium diaphanum* | 0.07 | 0.19 |
| | *Flustra* sp. | 0 | 0.13 |
| | *Cancer pagurus* | 0 | 0.13 |
| | Sabellidae (tubes) | 0.14 | 0 |
| | OPHIURIDA | 0 | 0.13 |
| | Serpulidae (tubes) | 0.07 | 0.06 |
| | *Luidia ciliaris* | 0.07 | 0 |
| | EUMALACOSTRACA | 0 | 0.06 |
| | PORIFERA | 0 | 0.06 |
| | *Aphrodita aculeata* | 0 | 0.06 |
| | BIVALVIA | 0.07 | 0 |
| **D** | BRACHYURA | 0.79 | 0.14 |
| | Paguridae | 0.5 | 0.71 |
| | DECAPODA | 0.64 | 0.57 |
| | *Corystes cassivelaunus* | 0.36 | 0.5 |
| | *Asterias rubens* | 0.79 | 0.57 |
| | *Liocarcinus* sp. | 0.64 | 0.71 |
| | *Astropecten irregularis* | 0.43 | 0.07 |
| | *Ophiura* sp. | 0.14 | 0.21 |
| | ASTEROIDEA | 0.86 | 0.86 |
| | *Flustra* sp. | 0.14 | 0.14 |
| | OPHIURIDA | 0.21 | 0 |
| | *Aphrodita aculeata* | 0.07 | 0.07 |
| | EUMALACOSTRACA | 0.14 | 0 |
| | Hydroid/Bryozoan Turf | 0.07 | 0.07 |
| | *Cancer pagurus* | 0.07 | 0 |
| | *Alcyonidium diaphanum* | 0 | 0.07 |

### 4.2.6 Epifauna assemblages: 2m beam trawl

In total, 23 taxa and 608 individuals were collected by 2m beam trawl within the Control and Impact stations of Management area A. Twenty-six taxa and 586 individuals were collected within the Control and Impact stations of Management area B. Sixty six taxa and 1,822 individuals were collected from the Control and Impact stations of Management area C and 64 taxa and 1,818 individuals were collected from the Control and Impact stations of Management area D.

The mean number of individuals present at stations from within the Impact treatment of Management area D (83 ± s.d. 40.8) was significantly higher than that found in the Control area (50 ± sd 37.9), ($p$ =0.034). No other significant differences were found between the two treatments (Control and Impact) in the other Management areas (Table 39). See Appendix 7 for box-whisker plots and summary statistics of each metric (Control and Impact treatments) for each Management area.

**Table 39.** Results of the non-parametric Wilcoxon-Mann-Whitney test (W) of differences between the univariate metrics calculated from 2m beam trawl epifauna samples located in each of the Management areas. Figures in bold are significant (p-value) at the 5 % level. The number of samples (n) in each treatment is indicated in subscript (I = Impact, C = Control).

| | **A $n_I = 5$, $n_C = 5$** | | **B $n_I = 6$, $n_C = 6$** | | **C $n_I = 12$, $n_C = 11$** | | **D $n_I = 13$, $n_C = 15$** | |
|---|---|---|---|---|---|---|---|---|
| **Univariate metric** | **W** | **p-value** | **W** | **p-value** | **W** | **p-value** | **W** | **p-value** |
| Number of taxa (S) | 8 | 0.40 | 16 | 0.75 | 83 | 0.32 | 134 | 0.10 |
| Number of individuals (N) | 14 | 0.83 | 11 | 0.31 | 87 | 0.21 | 144 | **0.03** |
| Hills diversity (N1) | 9 | 0.55 | 18 | 1 | 54 | 0.49 | 124 | 0.54 |

SIMPER analysis shows there is high similarity in the epifaunal communities sampled using the 2m beam trawl, both within and between treatments. Table 40 shows the taxa contributing to the dissimilarity between Control and Impact stations for each Management Area. 'Average abundance' values represent the proportion of samples in which a particular taxon was collected.

**Table 40**. Taxa contributing to the dissimilarity in epifaunal communities sampled by 2m beam trawl between the Control and Impact stations in each Management area (taxa listed in order of contribution to dissimilarity).

| **Management Area** | **Species** | **Impact Average abundance** | **Control Average abundance** |
|---|---|---|---|
| **A** | *Psammechinus miliaris* | 0.2 | 0.8 |
| | *Pontophilus* | 0.6 | 0.2 |
| | *Liocarcinus depurator* | 0.2 | 0.4 |
| | *Echinocardium cordatum* | 0.4 | 0.2 |
| | Hydrozoa | 1 | 0.6 |
| | *Mactra stultorum* | 0.2 | 0.4 |
| | *Macropodia rostrata* | 0.2 | 0.4 |
| | *Alcyonium digitatum* | 0 | 0.4 |
| | *Aphrodita aculeata* | 0.2 | 0.2 |
| | *Pisidia longicornis* | 0.2 | 0.2 |
| | *Astropecten irregularis* | 1 | 0.8 |
| | *Liocarcinus holsatus* | 1 | 0.8 |
| | *Ensis ensis* | 0 | 0.2 |
| | *Ophiura ophiura* | 0.8 | 1 |
| | Pasiphaea | 0 | 0.2 |
| | *Euspira* | 0.2 | 0 |
| | *Hyas* | 0 | 0.2 |
| | Algae | 0 | 0.2 |
| | *Spisula subtruncata* | 0 | 0.2 |
| **B** | *Flustra foliacea* | 0.83 | 0.5 |
| | *Ophiura ophiura* | 0.5 | 0.67 |
| | *Crangon crangon* | 0.33 | 0.5 |
| | *Processa canaliculata* | 0 | 0.5 |
| | *Pontophilus* | 0.5 | 0.5 |
| | *Alcyonidium diaphanum* | 0.33 | 0.33 |
| | *Crangon allmanni* | 0.33 | 0.33 |
| | *Astropecten irregularis* | 0.67 | 1 |
| | *Alcyonium digitatum* | 0.33 | 0 |
| | *Psammechinus miliaris* | 0 | 0.33 |
| | *Mactra stultorum* | 0.17 | 0.17 |
| | *Pagurus bernhardus* | 0.83 | 1 |
| | *Asterias rubens* | 1 | 0.83 |
| | *Liocarcinus depurator* | 0.17 | 0 |

| **Management Area** | **Species** | **Impact Average abundance** | **Control Average abundance** |
|---|---|---|---|
| | Cirripedia | 0 | 0.17 |
| | *Ebalia tumefacta* | 0 | 0.17 |
| | *Echinocardium cordatum* | 0 | 0.17 |
| | *Buccinum undatum* | 0.17 | 0 |
| | *Ensis ensis* | 0 | 0.17 |
| | *Euspira* | 0.17 | 0 |
| | Gastropoda | 0.17 | 0 |
| | *Epizoanthus incrustatus* | 0.17 | 0 |
| | Fucaceae | 0.17 | 0 |
| | *Pisidia longicornis* | 0 | 0.17 |
| **C** | *Ophiothrix fragilis* | 0.75 | 0.36 |
| | *Macropodia rostrata* | 0.67 | 0.27 |
| | *Alcyonidium diaphanum* | 0.5 | 0.55 |
| | Hydrozoa | 0.67 | 0.55 |
| | *Liocarcinus depurator* | 0.5 | 0.27 |
| | *Ophiura ophiura* | 0.25 | 0.45 |
| | *Corystes cassivelaunus* | 0.5 | 0.82 |
| | *Flustra foliacea* | 0.17 | 0.45 |
| | *Alcyonium digitatum* | 0.83 | 0.64 |
| | *Aphrodita aculeata* | 0.17 | 0.36 |
| | *Liocarcinus pusillus* | 0.42 | 0.18 |
| | *Alcyonidium parasiticum* | 0.42 | 0 |
| | *Pisidia longicornis* | 0.17 | 0.36 |
| | *Crangon allmanni* | 0.42 | 0.09 |
| | *Buccinum undatum* | 0.17 | 0.36 |
| | *Pontophilus* | 0.17 | 0.27 |
| | *Psammechinus miliaris* | 0.33 | 0.18 |
| | *Processa canaliculata* | 0.08 | 0.27 |
| | *Crangon crangon* | 0.25 | 0.18 |
| | *Clausinella fasciata* | 0.25 | 0.18 |
| | *Adamsia carciniopados* | 0.33 | 0.09 |
| | *Pagurus prideaux* | 0.33 | 0.09 |
| | *Atelecyclus rotundatus* | 0.33 | 0.09 |
| | *Liocarcinus holsatus* | 0.75 | 0.91 |
| | *Macropodia tenuirostris* | 0.33 | 0 |
| | *Paphia rhomboides* | 0.25 | 0.09 |
| | *Astropecten irregularis* | 0.75 | 0.91 |
| | *Aporrhais pespelecani* | 0.25 | 0.09 |
| | *Epizoanthus incrustatus* | 0.08 | 0.18 |
| | *Hyas* | 0.25 | 0.09 |
| | *Spisula solida* | 0.08 | 0.18 |
| | Cirripedia | 0.08 | 0.18 |
| | *Galathea* | 0.17 | 0.09 |
| | Anthozoa | 0.17 | 0 |
| | *Sepiola* | 0.17 | 0 |
| | *Inachus dorsettensis* | 0.17 | 0 |
| | *Liocarcinus marmoreus* | 0.08 | 0.09 |
| | *Pagurus bernhardus* | 0.83 | 1 |
| | *Luidia sarsi* | 0.17 | 0 |
| | *Spirobranchus* | 0.08 | 0.09 |
| | *Cancer pagurus* | 0.08 | 0.09 |
| | *Chiton* | 0.17 | 0 |
| | *Brissopsis lyrifera* | 0 | 0.09 |
| | *Spisula subtruncata* | 0 | 0.09 |
| | *Mactra stultorum* | 0 | 0.09 |
| | Bryozoa | 0 | 0.09 |

| Management Area | Species | Impact Average abundance | Control Average abundance |
|---|---|---|---|
| | Nudibranchia | 0 | 0.09 |
| | *Abra prismatica* | 0 | 0.09 |
| | *Dosinia lupinus* | 0 | 0.09 |
| | *Ensis ensis* | 0 | 0.09 |
| | *Phaxas pellucidus* | 0.08 | 0 |
| | *Anomia ephippium* | 0 | 0.09 |
| | *Gibbula* | 0 | 0.09 |
| | *Pagurus pubescens* | 0 | 0.09 |
| | *Gari fervensis* | 0.08 | 0 |
| | *Pagurus cuanensis* | 0 | 0.09 |
| | Gammarididae | 0 | 0.09 |
| | *Aequipecten opercularis* | 0.08 | 0 |
| | *Ophiura albida* | 0.08 | 0 |
| | *Chamelea striatula* | 0.08 | 0 |
| | Porifera | 0.08 | 0 |
| | *Simnia patula* | 0.08 | 0 |
| | *Colus gracilis* | 0.08 | 0 |
| | *Comarmondia gracillis* | 0.08 | 0 |
| | *Ebalia tumefacta* | 0.08 | 0 |
| **D** | *Crangon crangon* | 0.92 | 0.4 |
| | *Liocarcinus depurator* | 0.54 | 0.13 |
| | *Ophiura ophiura* | 0.46 | 0.47 |
| | *Flustra foliacea* | 0.69 | 0.6 |
| | *Alcyonium digitatum* | 0.46 | 0.33 |
| | *Astropecten irregularis* | 0.85 | 0.67 |
| | *Pagurus bernhardus* | 0.69 | 0.73 |
| | *Corystes cassivelaunus* | 0.92 | 0.67 |
| | *Pontophilus* | 0.31 | 0.27 |
| | *Alcyonidium diaphanum* | 0.23 | 0.33 |
| | *Asterias rubens* | 0.77 | 0.87 |
| | *Galathea* | 0.38 | 0.07 |
| | *Liocarcinus marmoreus* | 0.31 | 0.13 |
| | Hydrozoa | 0.31 | 0.13 |
| | *Ensis ensis* | 0.23 | 0.13 |
| | *Pisidia longicornis* | 0.15 | 0.27 |
| | *Processa canaliculata* | 0.23 | 0.13 |
| | *Donax vittatus* | 0.08 | 0.2 |
| | *Mactra stultorum* | 0.08 | 0.2 |
| | *Macropodia rostrata* | 0.23 | 0.13 |
| | *Spisula solida* | 0.23 | 0.13 |
| | *Ophiothrix fragilis* | 0.15 | 0.2 |
| | *Echinocardium cordatum* | 0.15 | 0.13 |
| | Glyceridae | 0.15 | 0.13 |
| | *Branchiostoma lanceolatum* | 0.23 | 0 |
| | *Clausinella fasciata* | 0.23 | 0.07 |
| | *Dosinia exoleta* | 0.23 | 0.07 |
| | *Gari tellinella* | 0.23 | 0.07 |
| | *Crangon allmanni* | 0.15 | 0.07 |
| | *Ebalia tumefacta* | 0.08 | 0.2 |
| | *Liocarcinus holsatus* | 0.92 | 0.93 |
| | *Atelecyclus rotundatus* | 0.15 | 0 |
| | *Liocarcinus pusillus* | 0.15 | 0.07 |
| | *Paphia rhomboides* | 0.15 | 0.07 |
| | Decapoda | 0.08 | 0.13 |
| | *Spisula subtruncata* | 0 | 0.13 |
| | *Epizoanthus incrustatus* | 0 | 0.13 |

| **Management Area** | **Species** | **Impact Average abundance** | **Control Average abundance** |
|---|---|---|---|
| | Gammarididae | 0.08 | 0.07 |
| | *Pandalus montagui* | 0.08 | 0.07 |
| | *Arcopagia crassa* | 0.08 | 0.07 |
| | *Gari fervensis* | 0 | 0.13 |
| | *Alcyonidium parasiticum* | 0.08 | 0 |
| | Fucaceae | 0.08 | 0 |
| | *Pinnotheres pisum* | 0.08 | 0 |
| | Ascidia | 0.08 | 0 |
| | Cirripedia | 0.08 | 0 |
| | Serpulidae | 0.08 | 0 |
| | *Ensis siliqua* | 0 | 0.07 |
| | *Brissopsis lyrifera* | 0 | 0.07 |
| | *Necora puber* | 0 | 0.07 |
| | *Sepiola* | 0 | 0.07 |
| | *Gari constulata* | 0.08 | 0 |
| | *Aequipecten opercularis* | 0.08 | 0 |
| | Aphroditidae | 0.08 | 0 |
| | *Botryllus schlosseri* | 0.08 | 0 |
| | *Calliostoma zizyphinum* | 0.08 | 0 |
| | *Hyas* | 0.08 | 0 |
| | Nudibranchia | 0.08 | 0 |
| | *Pandalina brevirostris* | 0.08 | 0 |
| | *Abra alba* | 0 | 0.07 |
| | *Aporrhais pespelecani* | 0 | 0.07 |
| | *Buccinum undatum* | 0 | 0.07 |
| | *Euspira* | 0 | 0.07 |
| | *Psammechinus miliaris* | 0 | 0.07 |

### 4.2.7 Post-hoc power analysis

A histogram of infaunal data pre-survey suggested the shape to be similar to many Poisson distributions, therefore simulated Poisson data were used to compute power values. Recent analysis revealed that the Poisson distribution did not fit as well to the data as negative binomial and Gaussian distributions (Figure 56). Density estimates and distribution of the Impact and Control data from Management area D (UK 2260) collected during the 2014 survey showed that Negative binomial distribution was the best fit to the data (Figure 57).

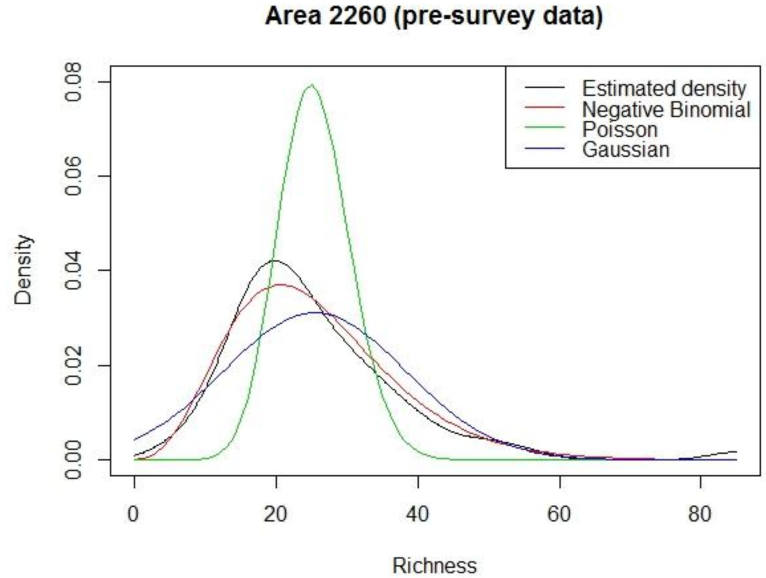



**Figure 56**. Distributions of pre-survey species richness data (estimated density) for Management area D, against simulated Poisson, Gaussian and Negative binomial distribution data.

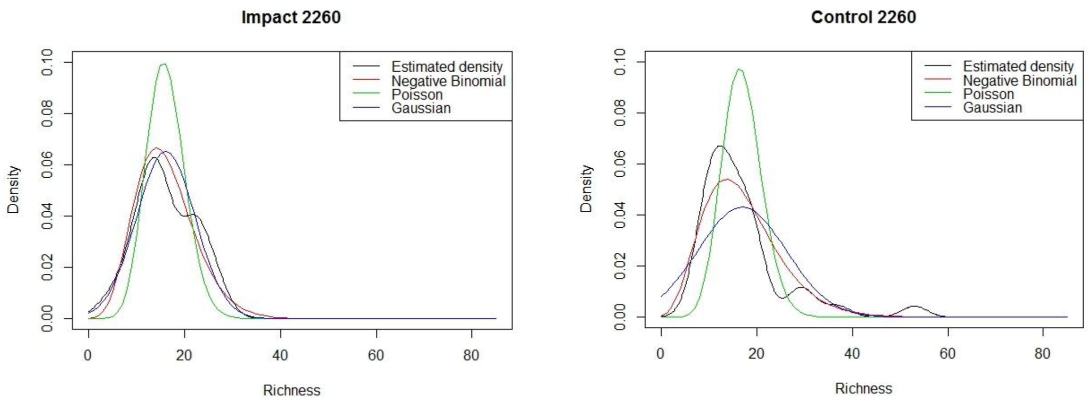



**Figure 57**. Distribution of 2014 species richness data for Left) Impact and Right) Control stations for Management area D against simulated Poisson, Gaussian and Negative binomial data.

A post hoc power analysis of the data, using Negative Binomial distribution powers for each of the proposed management areas, are shown in Table 41. The new power analysis revealed that the number of samples collected from each area were insufficient to detect 20% change with a power of 0.8 as targeted in the original objectives. However, the number of samples for Management areas A, B and C were sufficient to detect at least 30% change with a power of 0.8, according to the *post hoc* power analysis. For Management area D the number of samples taken in 2014 was too low to detect even a 40% change with a power of 0.8 (p=0.05).

**Table 41**. Results of post hoc power analyses using newly acquired survey data. Highlighted cells indicate the power of detecting a 20% change in species richness based on the number of samples collected from within each Management area in 2014.

| **Area A** | **Sample size** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| % change | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
| 10 | 0.075 | 0.099 | 0.111 | 0.125 | 0.148 | 0.140 | 0.139 | 0.138 | 0.152 | 0.161 |
| 20 | 0.210 | 0.349 | 0.449 | 0.528 | 0.576 | 0.641 | 0.7 | 0.725 | 0.764 | 0.786 |
| 30 | 0.39 | 0.635 | 0.797 | 0.9 | 0.932 | 0.966 | 0.975 | 0.985 | 0.996 | 0.994 |
| 40 | 0.635 | 0.87 | 0.958 | 0.985 | 0.997 | 0.999 | 0.998 | 1 | 1 | 1 |
| 50 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

| **Area B** | **Sample size** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| % change | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
| 10 | 0.088 | 0.092 | 0.095 | 0.114 | 0.121 | 0.111 | 0.113 | 0.127 | 0.123 | 0.121 |
| 20 | 0.198 | 0.287 | 0.398 | 0.450 | 0.541 | 0.559 | 0.623 | 0.658 | 0.695 | 0.710 |
| 30 | 0.365 | 0.576 | 0.722 | 0.825 | 0.871 | 0.929 | 0.941 | 0.972 | 0.982 | 0.990 |
| 40 | 0.536 | 0.830 | 0.921 | 0.972 | 0.986 | 0.994 | 0.999 | 1 | 1 | 1 |
| 50 | 0.725 | 0.939 | 0.986 | 0.996 | 0.999 | 1 | 1 | 1 | 1 | 1 |

| **Area C** | **Sample size** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| % change | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
| 10 | 0.069 | 0.062 | 0.062 | 0.053 | 0.054 | 0.052 | 0.071 | 0.063 | 0.056 | 0.044 |
| 20 | 0.128 | 0.147 | 0.189 | 0.216 | 0.233 | 0.255 | 0.268 | 0.293 | 0.304 | 0.297 |
| 30 | 0.184 | 0.296 | 0.385 | 0.431 | 0.508 | 0.530 | 0.580 | 0.634 | 0.682 | 0.750 |
| 40 | 0.255 | 0.465 | 0.605 | 0.710 | 0.766 | 0.833 | 0.868 | 0.915 | 0.923 | 0.954 |
| 50 | 0.390 | 0.625 | 0.742 | 0.852 | 0.924 | 0.96 | 0.97 | 0.981 | 0.991 | 0.993 |

| **Area D** | **Sample size** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| % change | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
| 10 | 0.056 | 0.041 | 0.048 | 0.048 | 0.048 | 0.053 | 0.035 | 0.026 | 0.027 | 0.035 |
| 20 | 0.094 | 0.095 | 0.115 | 0.158 | 0.149 | 0.147 | 0.173 | 0.165 | 0.174 | 0.198 |
| 30 | 0.146 | 0.222 | 0.268 | 0.355 | 0.389 | 0.395 | 0.414 | 0.445 | 0.461 | 0.509 |
| 40 | 0.205 | 0.315 | 0.444 | 0.531 | 0.613 | 0.660 | 0.700 | 0.758 | 0.793 | 0.843 |
| 50 | 0.291 | 0.482 | 0.627 | 0.744 | 0.787 | 0.843 | 0.907 | 0.926 | 0.953 | 0.960 |

## 4.3 Discussion

The results presented in this section provide the first stage of the Investigative Monitoring to determine the future efficacy of proposed management measures at the Dogger Bank SCI (i.e. the “Before” stage of the BACI experimental design) following implementation. As such, analyses to inform this element of the monitoring study are intended to determine the current status of benthic habitats within and outwith the proposed management areas, against which future assessments of status can be compared (in the context of maintenance or recovery of feature condition or favourable conservation status).

Differences in the historical patterns and intensity of fishing disturbance across the proposed management areas were also explored using the same abrasion metric (calculated annually for the period 2006-2013) as described in section 3. When the four Management area boundaries are overlaid onto subsurface abrasion, areas A and B are located within areas of historically higher abrasion pressure (Figure 48). Implementation of any management scenarios (e.g. a fishery management areas) with subsequent monitoring must take this into consideration as any areas of higher abrasion pressure are likely to be more responsive to change resulting from Fisheries management areas. Similarly, the differences identified between treatments may be due to a difference in levels of abrasion between the Control and Impact areas.

During survey planning, Control areas were positioned around the perimeter of the proposed management (or Impact) areas to minimise natural spatial variability between the two areas and ensure that both proposed management areas and control sites had been exposed to similar levels of abrasive pressure. However, without fully understanding the ecological responses of successful management, it is possible that there will be additional positive effects (e.g. ‘spill over’ of populations), from the Impact area into the surrounding Control area which could mask any changes in the condition of the Impact (Management) area. As future site monitoring progresses, it will be important to understand both the distribution and intensity of pressure in order to interpret the outcomes of monitoring and correlate pressure with ecological responses based on the suite of biological indicators outlined in this study. We further acknowledge that there is a need for provisions to facilitate management enforcement and compliance with the closed areas. As part of the management for other MPAs it has been proposed that there will be a 3nm reporting zone established around the closure within which higher frequency position reports to managers will be required. This information will be essential for understanding changes in the distribution of fishing actvites following enforcement of the proposed closures thereby allowing the associated responses (e.g. recovery) of benthic habitat features to be better understood in the context of wider, comparable unprotected habitat features.

The results from this stage of the Investigative Monitoring at the Dogger Bank SCI provide the baseline for future monitoring. It is suggested that the UK Oil and Gas, Offshore Windfarm and Telecommunication developments within the Dogger Bank SCI should be considered when conducting the next stages of Investigative Monitoring (see section 1.2.2). It is also important to note that the dataset and potential indicators reported in the present study may be revisited at any stage of the BACI design to calculate other metrics which may, in the future, prove to be more responsive to management scenarios than those used in the present study. An example of this would be using metrics derived from the same infaunal abundance and biomass matrices reported in section 3.2.2; such as the ratio of particular traits or functional groups; productivity estimates.

# 5 Conclusions

Previous research of the Dogger Bank macrofaunal assemblages suggests they are influenced by a combination of factors, including the influence of different water masses from the north and south, water depth, sediment type and food availability (Wieking & Kröncke 2003). The sentinel monitoring element of the current study supports the findings of benthic habitat studies undertaken in the Dogger Bank area over the past 50 years, whereby opportunistic species dominate the benthic community and bivalve species (e.g. *Mactra* spp, and *Spisula* spp.) and communities are less well represented. Whilst changes in faunal communities characteristics have been hypothesised to result from certain anthropogenic influences (e.g. increase in eutrophication and pollution of the Central North Sea). This study showed no empirical links between community composition and fishing pressure, however, even in the absence of a known causative factor for the decline of *Spisula* and *Mactra*, their perceived decrease implies the occurrence of potential changes in the ecosystem of the Dogger Bank.

The operational monitoring element of the current study did not indicate any discernible effects of subsurface abrasion pressure caused by fishing on the benthic habitats within the study area. This may be due to a number of reasons:

1. **Benthic communities are preconditioned to disturbance by natural hydrodynamics, such as waves and currents, which may influence their response to abrasion pressure.**
   Shallow, tide-swept and wave impacted sandy habitats such as those characteristic of the Dogger Bank are typified by fauna that are adapted to high rates of mortality and natural disturbance and hence exhibit greater resilience to seabed disturbance resulting from demersal fishing (Kaiser *et al* 1998). Abrasion pressure due to fishing activity has been shown to have a more discernible impact if it exceeds the background levels of natural disturbance (Diesing *et al* 2013). This same study indicated that modelled natural disturbance on the Dogger Bank exceeds that attributed to fishing disturbance. Benthic communities in naturally disturbed environments such as the Dogger Bank may therefore not be impacted by fishing.

2. **The abrasion pressure cell size of 0.05 may not be appropriate for detecting trawling impacts on the Dogger Bank.**
   A recent JNCC/Cefas project (Jenkins *et al* 2015) tested the effect of gridding Vessel Monitoring System (VMS) data at 0.05dd, 0.025dd and 0.0125dd. They found that regional maps of fishing pressure abrasion scores were visually different, depending on the size of the grid cell. Areas of ‘no fishing’ were only apparent when smaller grid sizes were used, indicating that larger grids overestimate the spatial footprint of fishing. This overestimation was more apparent when fishing activity was patchily distributed compared to areas of homogenous fishing activity. A reduction in the cell size resulted in an uneven reapportioning of fishing pressure, indicating that the assumption that fishing effort is homogeneously spread within each 0.05dd cell is not always valid. The current method developed by JNCC (Church *et al* 2016) to assign abrasion pressure to a cell involves dividing the swept area calculation by the grid cell area. This provides a swept area ratio that can be used to represent the mean number of times the seabed within a cell has been impacted by fishing gear. However, although a swept area ratio of one demonstrates that the swept area equals the grid cell area, it does not assume that 100% of the cell has been impacted by fishing as some areas may have been repeatedly trawled. Selecting the appropriate abrasion pressure grid size for different regions is therefore an important consideration in terms of the ability to explain the variability in benthic assemblages.

3. **Indicators tested may not be effective at detecting disturbance due to abrasion since:**
    - The IQI index incorporates AMBI, which was initially developed for assessing the ecological quality of coastal and estuarine benthic habitats in response to organic enrichment and contaminant effects (based on the model of Pearson and Rosenberg (1978) and (Van Hoey *et al* 2010). AMBI allocates benthic species to one of five ecological groups (EG) based on their sensitivity to increasing organic matter enrichment, ranging from EG I: disturbance-sensitive (specialist carnivores and some tubiculous polychaetes) to EG V:first order opportunistic (deposit feeders, which proliferate in reduced sediments) (Borja *et al* 2000). In terms of ecosystem quality (mainly in relation to organic enrichment) both AMBI and IQI generally assessed the Dogger Bank communities as good to high. However, the sensitivity or tolerance of benthic species can vary depending on the pressure, thus species assessed as sensitive to organic enrichment within AMBI may not be sensitive or respond in the same way to a physical disturbance pressure. For example, Borja *et al* (2000) classified the crabs *Corystes cassivelaunus* and *Liocarcinus* spp. as sensitive (to organic enrichment), however although these species may be physically impacted by a trawl pass, they also have been shown to opportunistically feed on dead and dying organisms recently impacted by fishing gear. High percentages of such organisms may therefore be indicative of poor ecosystem quality with respect to this pressure. The IQI in its current format does not allow for gears with greater than $0.1m^2$ surface area to be included. This prevents the use of the historical datasets derived from gears that sample a larger surface area. In recognition of the need for wider indicator development and calibration, to support assessments of the conservation status of benthic sedimentary habitats, a number of current studies seek to provide the necessary information required to further develop certain candidate indicators for wider application (Green & Phillips, in prep.; Murray *et al*, in prep.).

    - Bivalves with sufficient abundances sampled using grab and trawl were generally small and would therefore be unimpacted by fishing gear (resuspended by the bow wave) or possess biological traits which enable them recover rapidly from any impacts. Bivalve shell damage of long-lived species such as *Arctic islandica*, have been identified as a valuable identifier or trawl damage (Wittbaard & Klein 1993). However, as few examples of such species were collected in 2014, the testing of this indicator was not possible. The standard sampling gears used in this study were not effective at collecting appropriate abundances of large, long-lived bivalves required for testing both bivalve indicators. Deeper penetrating gears may collect sufficient abundances of these species, however these are often more invasive techniques. Therefore, these bivalve indicators are not recommended for future monitoring of this SCI.

    - Abrasion pressure data were not available for the five months prior to survey, therefore we cannot confirm whether the pressure cells selected are truly representative of the most recent fishing activity. When these data become available a reanalysis would be recommended based on the most recent pressure.

    - Trait composition was not observed to change with increasing pressure. This may confirm that the species present on the Dogger Bank possess traits that are resilient to abrasion pressure. Increases in the proportions of scavenging species were not apparent as pressure increased, however these species are widely represented across the Bank and are present in areas of ‘no fishing’ thus indicating their ubiquitous nature.

- Future studies should focus on collecting additional biotic and abiotic information such as organic carbon, chlorophyll a and contaminants to inform biodiversity ecosystem function (BEF) relationships in naturally disturbed habitats. Investigating links between food availability and feeding type composition using biological traits analysis, could provide a better indication of change in the benthic community across the Dogger Bank and over time.

- Reclassifying species sensitivity to abrasion, rather than organic enrichment, using biological traits within the IQI multi-metric would improve this tool for use as a candidate indicator under the MSFD.

The investigative monitoring element of the study involved the application of a BACI experimental design to allow future changes in benthic communities to be explored in response to the implementation of proposed management measures (e.g. a number of areas closed to mobile demersal fishing gears). Two of the proposed fishery management areas coincide with four recently granted offshore windfarm (OWF) developments. Assuming that the OWF sites will be inaccessible to large survey vessels, further analysis is required to ensure the Investigative monitoring BACI design is sufficiently robust to allow for a reduction in sample number (assuming the same sites will be revisited). For some of the proposed management areas, this will not pose a problem. However, for the largest closure area the results of post-hoc power analyses indicated that the number of samples acquired during the current study did not afford sufficient power to detect a change of 40%, even in the absence of the OWF developments. Such limitations will need to be considered in designing and prioritising the future monitoring strategy for this site.

All three monitoring strategies developed in delivery of the pilot R&D project for Dogger Bank SCI are complementary. Ideally, the results of the Sentinel and Operational monitoring surveys should identify whether further investigative monitoring is required. However, as this study was an R&D pilot, the outcomes reported here should be employed to inform both risk based prioritisation of assessment and monitoring across the MPA network along with the development of general survey design principles. In this context it is recommended that:

Prioritisation of assessment and monitoring across the MPA network should follow a consistent and unified, risk based approach which draws on site specific information such as:

a) Feature types present and their perceived sensitivity to spatially and temporally coincident pressures occurring within the MPA in the context of the prevailing natural regime (e.g. physical disturbance of benthic habitats attributable to mobile demersal fishing activity is more likely to exceed thresholds of natural physical disturbance in deep, relatively stable, low energy environments relative to those situated in shallow, highly naturally dynamic environments).

b) Historical distribution patterns and intensity of pressures occurring within the MPA. For example, does the evidence available support the conservation objectives proposed (e.g. maintenance of, or recovery to favourable conservation status) and how does this inform decisions around apportioning of assessment and monitoring effort across the network. As such, one outcome of the decision making process may be that where a maintain Conservation objective is implemented, no direct monitoring is required and instead pressure based monitoring is employed as a proxy for direct condition assessment. The alternative would be implementation of a direct monitoring campaign that, in order to afford the necessary power of detection of what is likely to be a subtle (and ultimately ecologically insignificant change), would be prohibitively expensive.

Adopting and developing strategic principles for prioritisation of site/feature monitoring across the MPA network would allow a consistant approach to monitoring to be achieved, which in turn may result in it being possible to comment on comparable sites and features at a network scale.

# 6 Summary Recommendations

- The further development and validation of indicator metrics, capable of detecting community changes in response to anthropogenic pressures, must continue to allow the effects of human induced pressures on marine systems to be effectively reported and managed.

- Methods of visualising and calculating pressure from activities data must be further developed and validated before being employed during survey design. This will ensure data are displayed at the necessary resolution and therefore appropriate for use during the monitoring and assessment of discrete marine habitats and communities.

- Pressure-Response studies must be planned and results interpreted in the context of natural levels of disturbance and community variability. It must be accepted that in naturally highly variable environments, it may not be possible to confidently link observed habitat and community changes to known anthropogenic effects.

- Clear guidance is required on what is deemed acceptable change in terms of the given conservation feature. This guidance has to be clearly linked to conservation objectives, policy drivers and national and international directives.

- It is necessary to have access to up to date, cleaned Vessel Monitoring System ping data to inform planning of pressure related studies. This will allow the visualisation of the distribution of fishing effort at the appropriate temporal and spatial resolution that can be linked to discrete marine habitats and communities and indicator metrics derived from survey data.

- A consistent and unified risk based approach using activities data and feature/site specific information should be adopted for the prioritisation of monitoring effort across the MPA network. This could improve our understanding of conservation status and efficacy of management at comparable sites and features that maximises scientific advances whilst at the same time achieving optimal efficiencies.

- Where possible, monitoring strategies currently being employed within the MPA network must ensure that results from feature/site specific operational and/or investigative monitoring can be put in context of sentinel monitoring of the wider marine environment. This requires a concerted effort to be made in the short-medium term to coordinate and integrate current and future monitoring activities to provide a more ecosystem based approach to monitoring going forward. This, in turn, will ensure that available survey and reporting budgets are spent in the most effective and efficient manner to allow common goals, across the full suite of relevant policy objectives, to be adequately met.

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# 8 Appendices

## Appendix 1 - Sample acquisition and processing

## Sediment grab sampling

### 0.1m$^2$ Hamon grab

The 0.1m$^2$ Hamon grab was the primary gear type used for sediment sample acquisition to inform all three elements (Type 1-3) of the R&D monitoring survey. The grab system comprised a 0.1m$^2$ mini Hamon grab fitted with a Bowtech video camera, the combined gear referred to as HamCam (Figure 58). Samples were collected from the planned ground truth stations anywhere within a 50m radius bullring centred on the target location.

**Figure 58.** 0.1m$^2$ mini Hamon grab with video camera (collectively referred to as HamCam).

On recovery, the grab was emptied into a large plastic bin and a representative integrated sub-sample of sediment (approx. 0.5-1 litre) taken for Particle Size Analysis (PSA). The PSA sample was stored in a labelled plastic container and frozen ready for transfer to a laboratory ashore. The remaining sample was photographed and the volume of sediment measured and recorded. Benthic fauna were collected by washing the sample with sea-water over a 1mm sieve. The retained >1mm fraction was transferred to a labelled container and preserved in buffered 4% formaldehyde for later analysis ashore. A visual assessment was made of the sediment type sampled by the grab and noted on the field records, assigning the sample to a preliminary Folk class and its equivalent EUNIS Level 3 and Broadscale Habitat (BSH) sediment class.

## 0.2m$^2$ Van Veen Grab

The grab system comprised a 0.2m$^2$ Van Veen grab (Figure 39). Samples were collected from the planned ground truth stations anywhere within a 50m radius bullring centred on the target location.

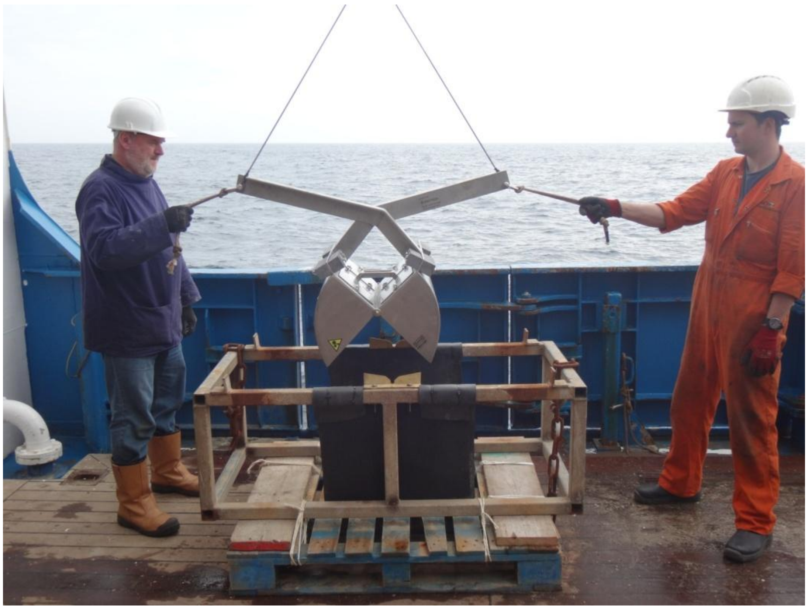


**Figure 59.** 0.2m$^2$ Van Veen grab.

On recovery, the grab sample surface was photographed and sample depth recorded after which a sub-sample of sediment was taken from the full depth of the sample using a 10cm diameter core. The grab contents were then decanted into a large plastic bin where the sample was photographed again and the volume of remaining sediment measured and recorded. Benthic fauna were collected by washing the sample with sea-water over a 1mm sieve. The retained >1mm fraction was transferred to a labelled container and preserved in 4% buffered formaldehyde for later analysis ashore. A visual assessment was made of the sediment type sampled by the grab and noted on the field records, assigning the sample to a Folk class and its equivalent EUNIS Level 3 and Broadscale Habitat (BSH) sediment class.

# Underwater imagery

## Camera Sledge

Observations of the seabed (and associated epifaunal species) were made using an underwater camera system mounted on a towed sledge (Figure 60), using a 5 megapixel Kongsberg video camera with capability to also capture still images.

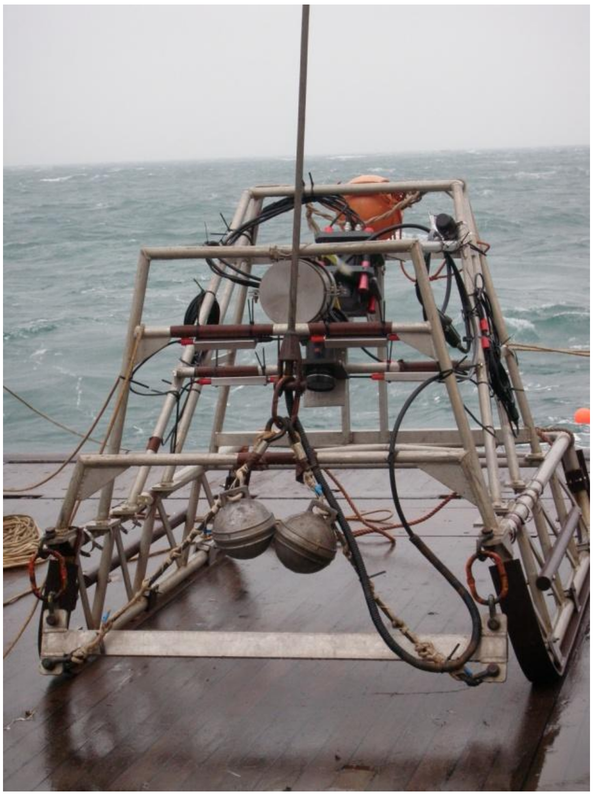


**Figure 60.** Towed camera sledge comprising Kongsberg video and still image capture systems along with HD video acquisition system.

A High Definition (HD) video camera was also mounted in parallel with the Konsgberg video and stills system in order to acquire continuous video (uninterrupted by still image acquisition).  An initial pre-survey trial of the dual camera systems indicated that the quality of the images generated was inadequate due to a combination of the camera height above the seabed and turbidity levels in the water column. Therefore, the two systems were repositioned on the camera sledge to bring them closer to the seabed. Due to the different zoom capabilities of the two systems, this resulted in the video footage provided by the HD camera comprising a smaller (but overlapping) field of view than the SD camera (Figure 61). The field of view of the HD camera was $0.30m^2$ and the field of view of the SD camera was $0.75m^2$.

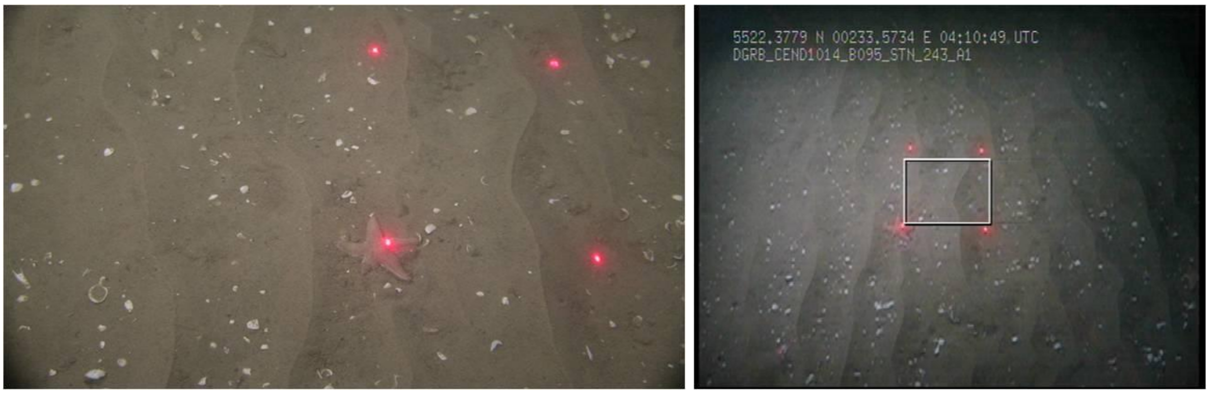



**Figure 61.** Field of view provided by the HD camera (left) and the SD camera (right).

Illumination was provided by six LED lights and a dedicated flash unit. The camera was oriented to provide a forward oblique view of the seabed and was fitted with a four-spot laser-scaling device which projects the corners of a 170mm x 170mm square along the axis of the lens onto the seabed.

Set-up and operation followed the MESH ‘Recommended Operating Guidelines (ROG) for underwater video and photographic imaging techniques’ (http://www.searchmesh.net/pdf/GMHM3_Video_ROG.pdf). Video was recorded simultaneously to a Sony GV-HD700 DV tape recorder and a computer hard drive. A video overlay was used to provide station metadata, time and position (of the GPS antenna) in the recorded video image.

## Epifaunal sampling

### 2m Scientific Beam Trawl

Epibenthic fauna were sampled with a 2m scientific Jenning’s beam trawl (Figure 62). The beam trawl was fitted with a chain mat and a 4mm mesh liner and was deployed from the stern gantry of the vessel, using a warp length of 3 times water depth. Two 5 minute tows, at a speed of 1 knot (1.85km h-1) were completed at each station. Tows were generally oriented parallel to each other across the bull ring but on some, infrequent, occasions they were carried out sequentially. The 5 minute period was timed from the moment that the net contacted the seabed until the moment of hauling from the seabed. This equates to a ‘swept area’ per station of approximately 600m$^2$.

On recovery of the beam trawl catch, fauna were identified and weighed individually (on heave compensated balances) and assigned to a log$^2$ size class. Hermit crabs were weighed after removal from their shells but animals that secreted their own shells were weighed with shells intact. All bivalve specimens were retained and preserved (in buffered 4% Formaldehyde) for subsequent transport back to the laboratory to allow further morphometric analyses to be carried out.

**Figure 62.** 2m scientific beam trawl utilised for epibenthic faunal sampling.

## Data QA/QC

### GPS positions and corrections

GPS fixes were recorded using the Tower Navigation system on RV *Cefas Endeavour*. This records the positional coordinates of the steer point from which the sampling equipment is being deployed, automatically compensating for the offset between these gantries and the GPS antenna.

Fixes for grab samples were taken at the instant the grab contacted the seabed. The grab systems were always deployed from the side gantry and the position recorded is taken to be their true position on/above the seabed.

Fixes for the camera sledge were taken continuously during the planned transect, e.g. positional fixes began once the camera system had settled on the seabed and the vessel was moving across the station target and positional fixes ceased on completion of the 10 minute transect prior to recovery of the camera sledge back on board. GPS positional fixes were taken during camera sledge transects, for both the stern gantry steer point and the position derived from HiPAP (High Precision Acoustic Positioning), continuously at 10 second intervals throughout the tow. The HiPAP system consists of a transceiver, which is mounted on a pole under the vessel, and a transponder/responder on the towed camera system. A "topside unit", is used to calculate a position from the ranges and bearings measured by the transceiver. It should be noted, however, that due to technical limitations the use/accuracy of HiPAP positioning in shallow waters is limited. This allowed the position of the camera system on the seabed to be cross referenced with the time at which the still image was captured to accurately determine the position of each still image acquired.

All GPS positions (derived from both the HiPAP and stern gantry steer point) were checked prior to translation into the video transect and still image survey metadata. Where positions derived from HiPAP were observed to be erroneous (due multipath reflections), layback corrections were applied (using a combination of the stern gantry steer point position, the ships heading and 'cable out') to derive the location of the camera system on the seabed at the time each still image was acquired.

**Particle Size Analysis (PSA) of sediments**

PSA was carried out by Cefas sedimentologists following standard laboratory practice; results were checked internally following the recommendations of the National Marine Biological Analytical Quality Control (NMBAQC) scheme (Mason 2011).

**Infaunal samples from grabs**

Infaunal samples were processed by Thomson Ecology. Following standard laboratory practices, results were checked following the recommendations of the National Marine Biological Analytical Quality Control (NMBAQC) scheme (Worsfold et al., 2010). The length, width and height (mm) of all bivalve specimens present were measured and results provided alongside the species abundance and biomass matrices.

**Video and still images and analysis**

Video and photographic stills were processed by Ocean Ecology Ltd. in accordance with the guidance documents developed by Cefas and the JNCC for the acquisition and processing of video and stills data (Coggan & Howell 2005; JNCC, in prep.).

**Epifaunal samples from the 2m Beam Trawl**

All beam trawl samples were processed in the field under the guidance of experienced benthic ecologists with a specialism in benthic faunal identification. Reference specimens were retained for all taxon observed to be present in the epifaunal samples and these were applied, back in the laboratory, to validate the species identification assigned in the field. Additionally, all bivalve specimens present in the epifaunal samples were retained to allow their length, width and height measurements to be recorded on return to the laboratory.

# Appendix 2 – Historical subsurface abrasion pressure (swept-area ratio) (2006-2013)

N:B. Cells are classified according to 2013 categories

| | 0a | 0b | 1a | 1b | 2a | 2b | 3a | 3b | 4a | 4b |
|---|---|---|---|---|---|---|---|---|---|---|
| 2006 | 0 - 0.09 | 0.1 - 0.21 | 0 - 0.09 | 0 | 0.1 - 0.21 | 0 - 0.09 | 0.1 - 0.21 | 0 - 0.09 | 0 - 0.09 | 0.22 - 0.4 |
| 2007 | 0 - 0.09 | 0 - 0.09 | 0 - 0.09 | 0 | 0.22 - 0.4 | 0 - 0.09 | 0.1 - 0.21 | 0 | 0 - 0.09 | 0 - 0.09 |
| 2008 | 0 | 0 - 0.09 | 0 | 0 - 0.09 | 0.22 - 0.4 | 0 - 0.09 | 0 - 0.09 | 0 - 0.09 | 0 - 0.09 | 0 - 0.09 |
| 2009 | 0 | 0 - 0.09 | 0 - 0.09 | 0 - 0.09 | 0.1 - 0.21 | 0 - 0.09 | 0 - 0.09 | 0 - 0.09 | 0 - 0.09 | 0.22 - 0.4 |
| 2010 | 0 - 0.09 | 0 - 0.09 | 0 - 0.09 | 0 | 0.1 - 0.21 | 0 - 0.09 | 0 | 0 - 0.09 | 0 - 0.09 | 0 - 0.09 |
| 2011 | 0.1 - 0.21 | 0 - 0.09 | 0.1 - 0.21 | 0 | 0.1 - 0.21 | 0 - 0.09 | 0 - 0.09 | 0 - 0.09 | 0 - 0.09 | 0.1 - 0.21 |
| 2012 | 0 | 0.1 - 0.21 | 0 - 0.09 | 0 - 0.09 | 0 - 0.09 | 0 - 0.09 | 0 - 0.09 | 0.22 - 0.4 | 0 - 0.09 | 0.22 - 0.4 |
| 2013 | 0 | 0 | 0 - 0.09 | 0 - 0.09 | 0.1 - 0.21 | 0.1 - 0.21 | 0.22 - 0.4 | 0.22 - 0.4 | 0.41 - 0.95 | 0.41 - 0.95 |

# Appendix 3 – Analysis to investigate the relationship between species richness and abundance metrics and physical abrasion pressure

Relationships between species richness and abundance in sandy and coarse sediments with surface and subsurface abrasion pressure were explored using historical data. No links with abrasion were confirmed.

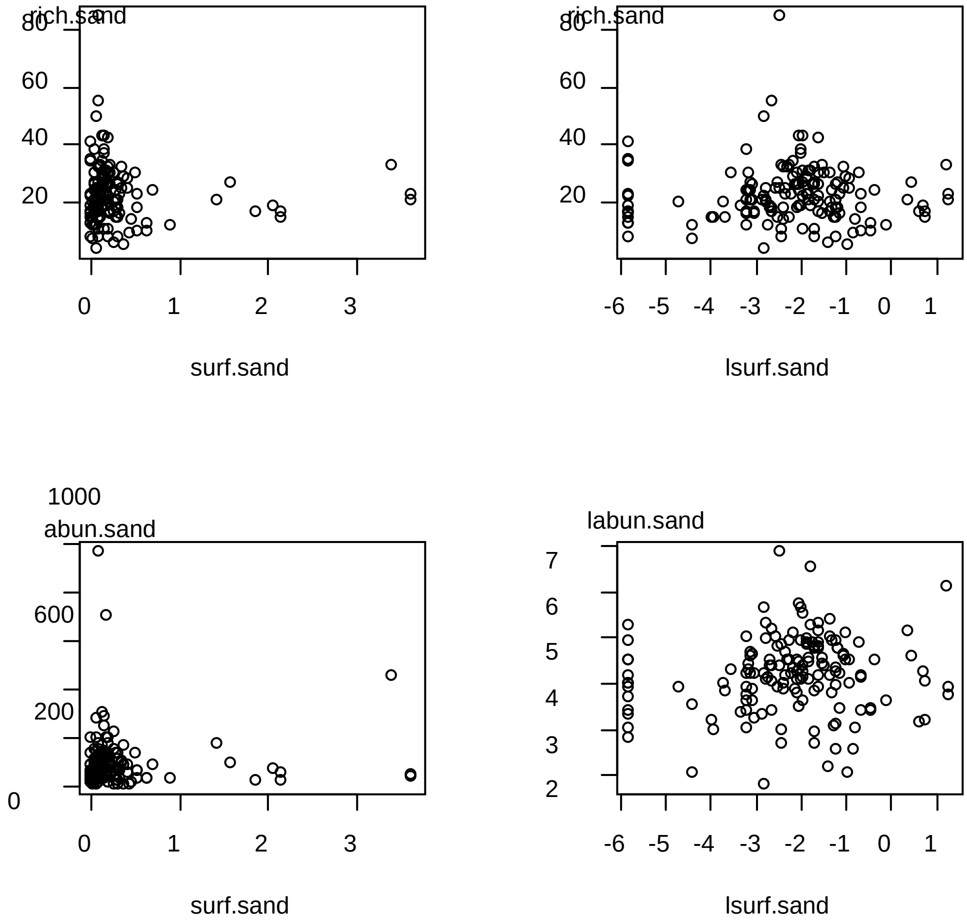



**Figure 63.** SURFACE Abrasion and SAND relationship.

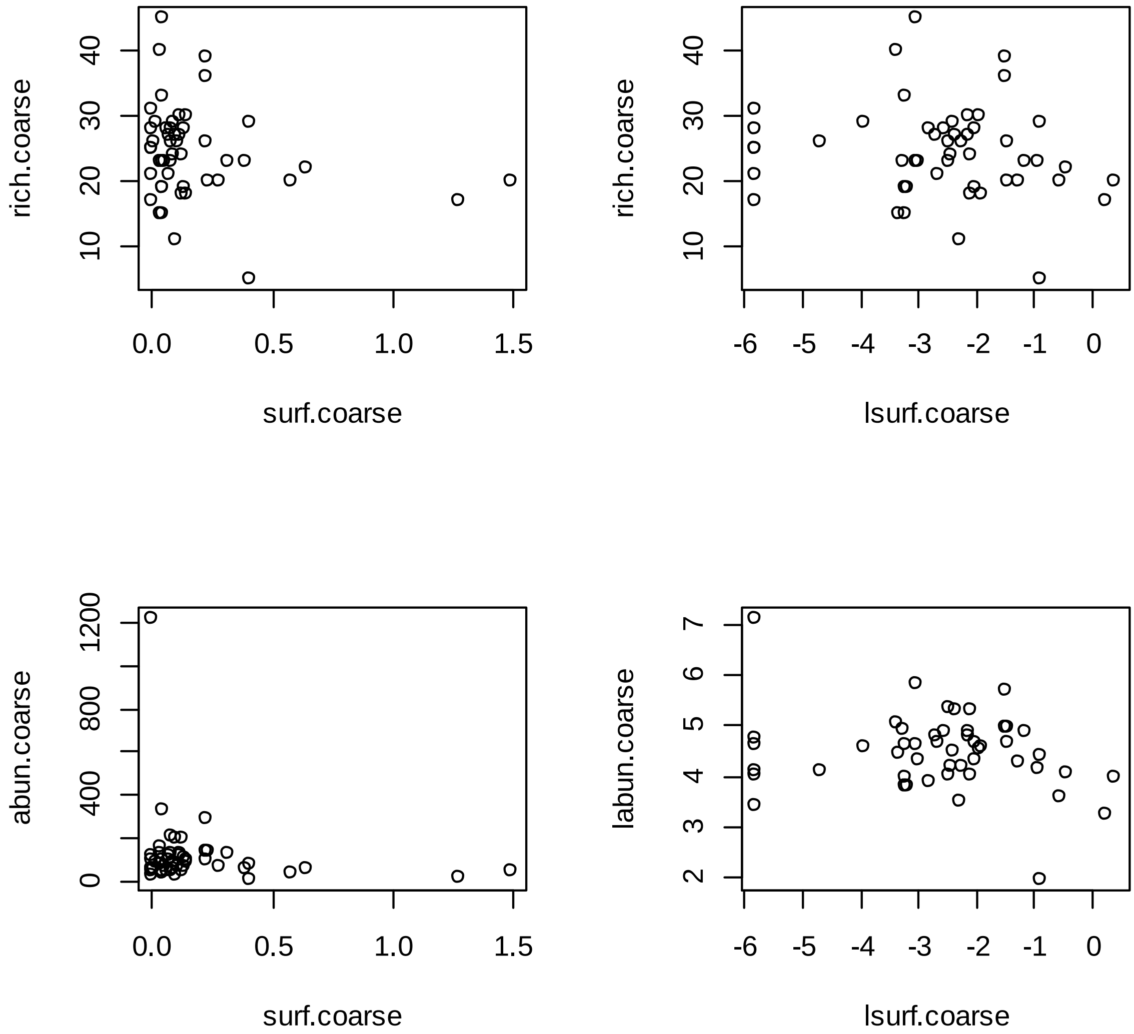



**Figure 64.** SURFACE abrasion and COARSE sediments relationship.

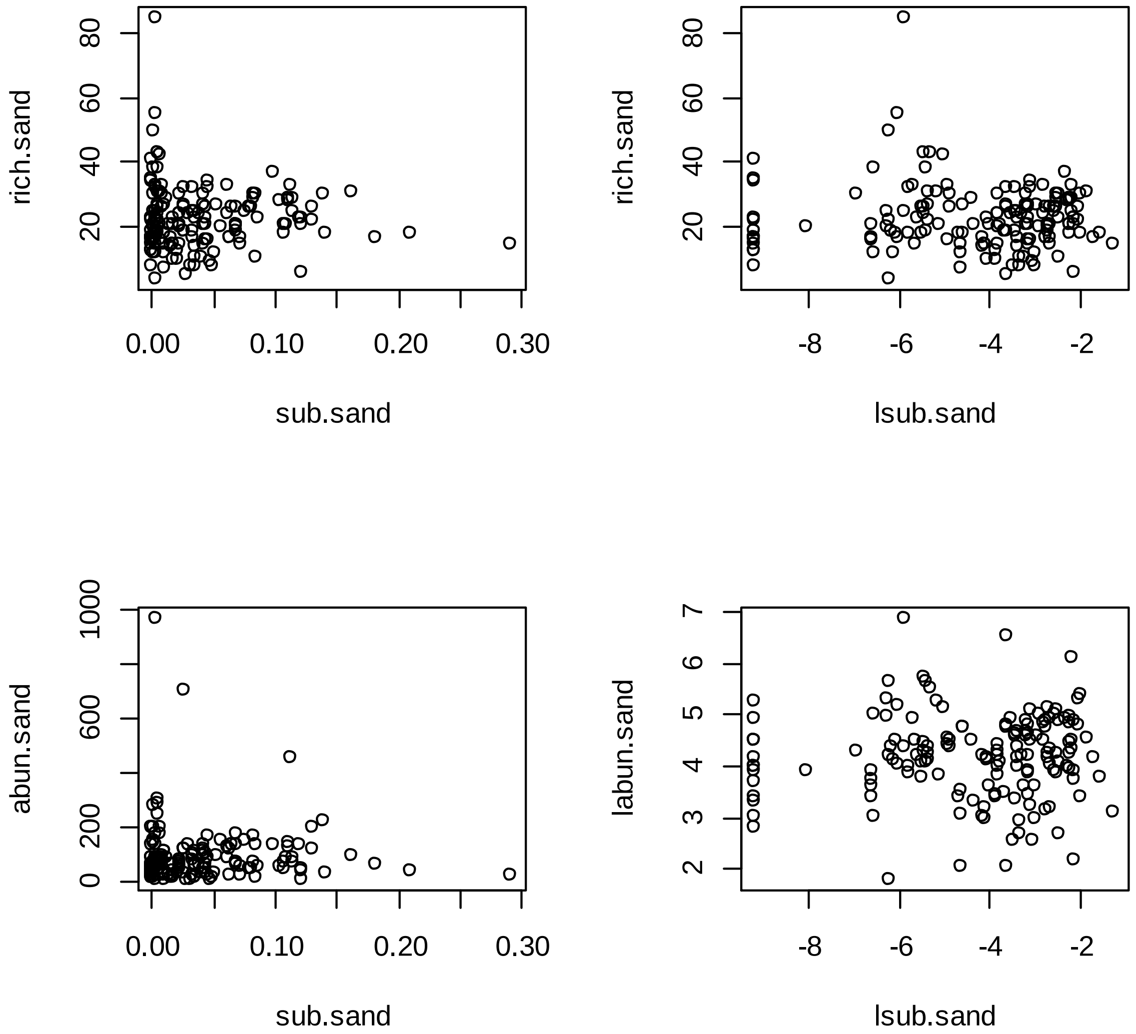



**Figure 65.** SUBSURFACE abrasion and SAND relationship.

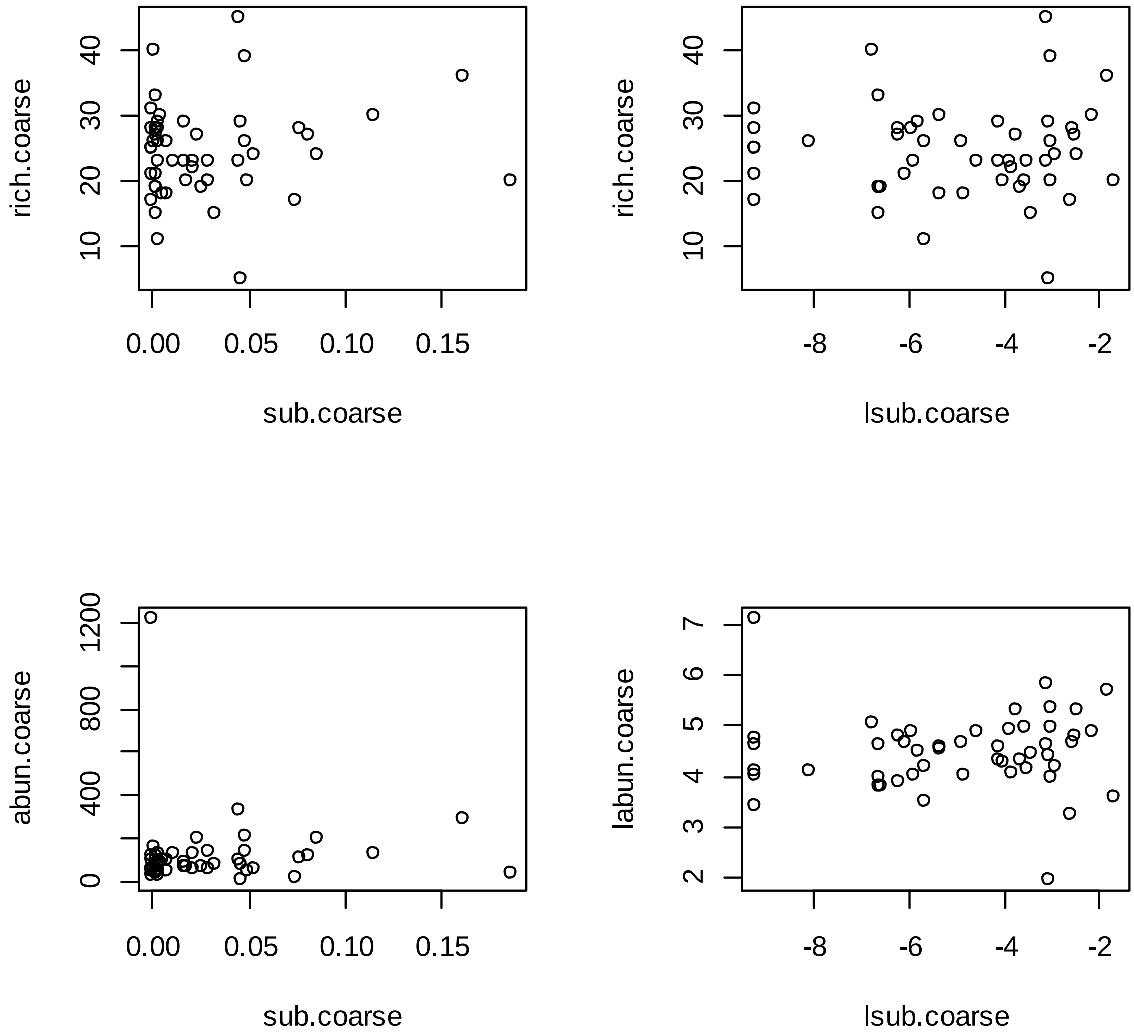
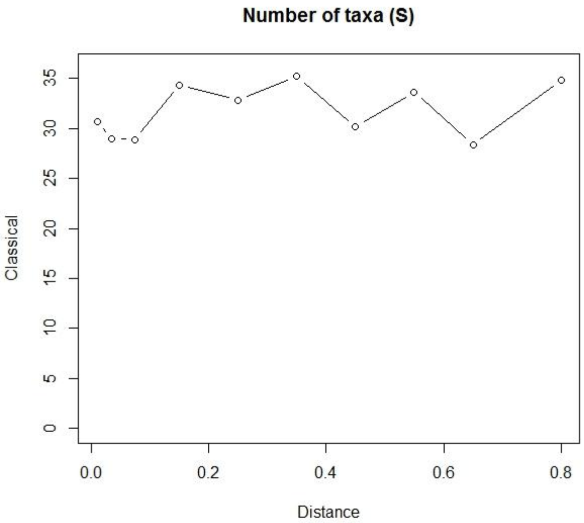
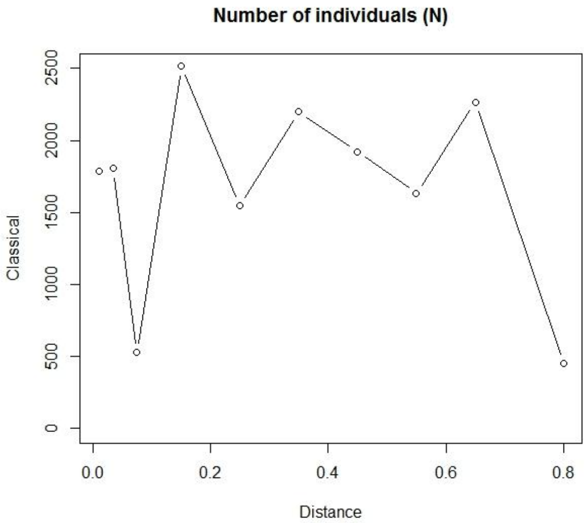


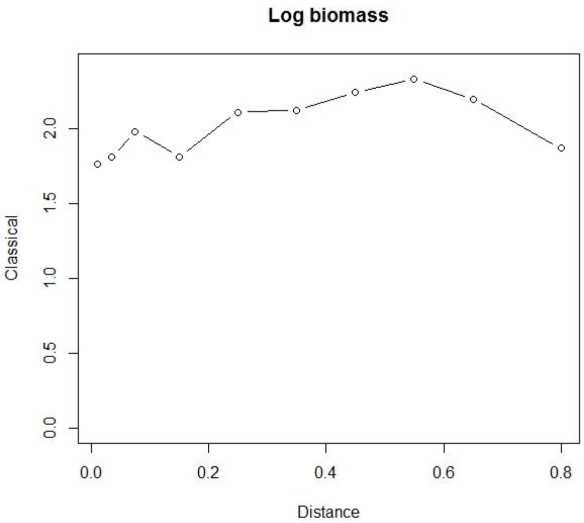

**Figure 66.** SUBSURFACE abrasion and COARSE sediments relationship.

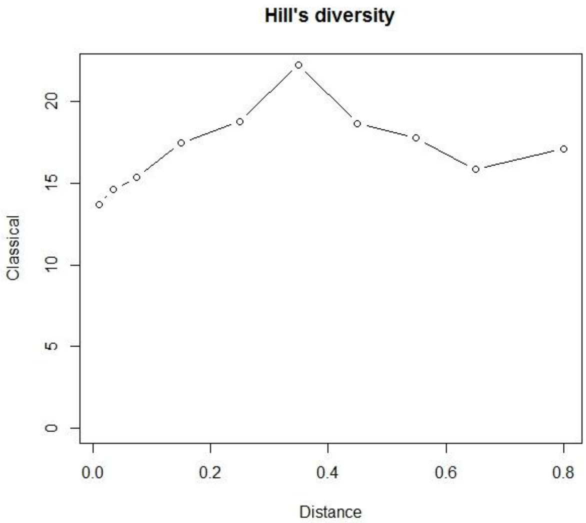
# Appendix 4 - Semivariogram plots

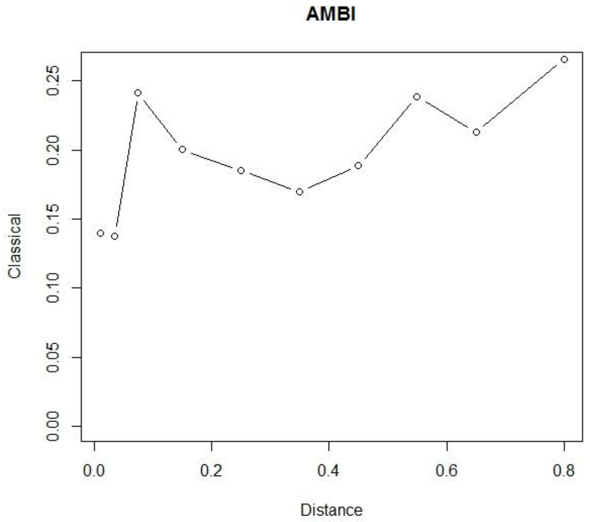
Semi-variogram plots showing the distances between each of the sampling points on the x axis and the classical semi-variogram estimator on the y axis. The cloud of all paired observations is smoothed by averaging the distances within each bin.

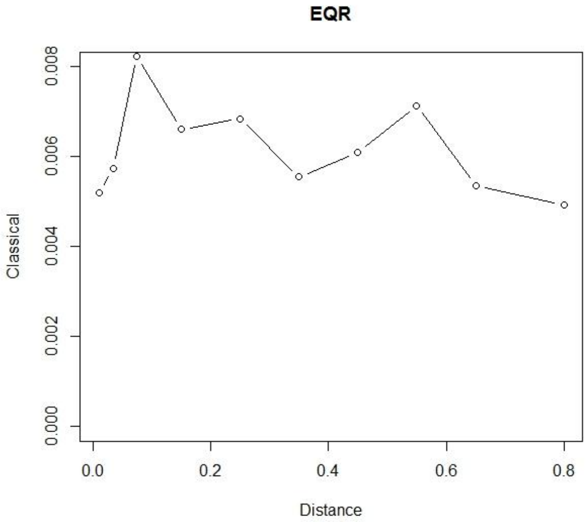



AMBI
Classical
0.00
0.05
0.10
0.15
0.20
0.25
0.0
0.2
0.4
0.6
0.8
Distance


EQR
Classical
0.000
0.002
0.004
0.006
0.008
0.0
0.2
0.4
0.6
0.8
Distance

# Appendix 5 - SIMPER outputs

Sentinal Monitoring: Spatial analysis. Taxa contributing to 50% of the within group similarity for 1st and 2nd SIMPROF analyses (values represent square-root transformed average abundances). Top characterising species are indicated for each group.

| **1st SIMPROF** | **p** | **aa** | **r** | **s** | **y** | **ab** | **ac** | **ae** | **af** | **z** | **ag** | **ah** | **am** | **l** | **aj** | **ak** | **al** | **d** | **f** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **2nd SIMPROF** | **k** | **aa** | | | | **v** | | | | **y** | **l** | **t** | | | **p** | | **o** | **e** | |
| | **Bathyporeia** | **Spiophanes / Echinocyamus** | | | | **Bathyporeia / Spiophanes** | | | | **Spiophanes / Bathyporeia** | **Fabulina / Sigalion / Chaetozone** | **Fabulina / Spiophanes** | | | **Fabulina / Magelona** | | **Fabulina / Magelona / Bathyporeia** | **Pisione / Branchiostoma** | |
| **Taxa** | | | | | | | | | | | | | | | | | | | |
| *Spiophanes bombyx* | | 1.65 | 2.45 | 2.52 | 3.52 | 1.65 | | | 3.12 | 2.36 | | | 1.22 | 1.68 | | | | | |
| *Bathyporeia elegans* | 3.2 | 1.74 | | | 1.95 | 1.47 | 3.35 | 2.53 | 3.1 | 1.82 | | | | | | | 1.54 | | |
| *Fabulina fabula* | | | 1.18 | 1.11 | | 1.47 | | | | | 3.05 | 2.17 | 2.15 | | 2.75 | 3.75 | 2.9 | | |
| *Echinocyamus pusillus* | | 1.69 | 1.28 | 1.56 | 2.59 | | | | | | | | | | | | | | |
| *Chaetozone christiei* | | | 1.7 | 1.56 | 1.32 | | | | | 2.03 | 1.21 | | 1.37 | | | | | | |
| *Kurtiella bidentata* | | 1.87 | | | | | | | | | | | | | | | | | |
| *Sigalion mathildae* | | 1.3 | | | | 1.17 | 1.28 | | | | 1.5 | | 1.12 | | | 1.86 | | | |
| *Acrocnida brachiata* | | 1.56 | | | | | | | | | | 1.84 | | | | | | | |
| *Magelona filiformis* | | | | | | | | | | | | 1.68 | 1.77 | | 2.47 | 1.68 | | | |
| *Polygordius* | | | | | | | | | | | | | | | | | | | 7.96 |
| *Pisione remota* | | | | | | | | | | | | | | | | | | 2.33 | 5.19 |
| *Notomastus* | | | | | | | | | | | | | | | | | | | |
| *Glycera lapidum* | | | | | | | | | | | | | | | | | | | 3.81 |
| *Ophelia borealis* | | | | | 2.04 | | | | | | | | | | | | | 2.07 | |
| *Magelona johnstoni* | | | | | | 1.49 | | | | | | | | | 2.75 | | 1.64 | | |
| *Nephtys cirrosa* | | | | | | | | 1.24 | | | | | | | | | | 1.58 | |
| *Bathyporeia pelagica* | | | 2.19 | | | | | | | | | | | | | | | | |
| *Protodorvillea kefersteini* | | | | | | | | | | | | | | | | | | | 5.09 |
| *Urothoe poseidonis* | | 2.12 | | | | | 1.38 | | | | | | | | | | | | |
| NEMERTEA | | | | | | | | | | | | | | 1.14 | | | | | |
| *Goniada maculata* | | | | 1.11 | | | | | | | | | | 1.29 | | | | | |
| *Owenia borealis* | | | | | | | 1.96 | | | | | | | | | | | | |
| *Spirobranchus lamarcki* | | | | | | | | | | | | | | | | | | | |
| *Bathyporeia guilliamsoniana* | 1.89 | | | | | | | | | 1.28 | | | | | | | | | |
| *Branchiostoma lanceolatum* | | | | | | | | | | | | | | | | | | 3.03 | |
| *Aonides paucibranchiata* | | | | | | | | | | | | | | | | | | | |
| *Polycirrus* | | | | | | | | | | | | | | | | | | | |
| *Pholoe baltica* (sensu Petersen) | | | | | | | | | | | | | | | | | | | |
| *Donax vittatus* | | | | | | | | 2.47 | | | | | | | | | | | |
| Edwardsiidae | | | | | | | | | | | | | | | | | | | |
| *Scoloplos armiger* | | | | | | | | | | | | | | 1.83 | | | | | |
| *Lanice conchilega* | | | | | | | | | | | | | | | | 1.78 | | | |
| *Spio filicornis* | | | | | | | | | | | | | | | | | | 1.41 | |
| *Scalibregma inflatum* | | | | | | | | | | | | | | | | | | | |
| *Thyasira flexuosa* | | | | | | | | | | | | 1.31 | | | | | | | |
| *Amphiura filiformis* | | | | | | | | | | | | | | 1.28 | | | | | |
| NUDIBRANCHIA | | | | | | | | | | | | | | | | | | | |
| *Phoronis* | | | | | | | | | | | | | | | | | | | |
| *Galathowenia oculata* | | | | | | | | | | | | | | | | | | | |
| LEPTOTHECATA | | | | | | | | | | 1 | | | | | | | | | |

Sentinal Monitoring: Spatial analysis cont. Taxa contributing to 50% of the within group similarity for 1st and 2nd SIMPROF analyses (values represent square-root transformed average abundances). Top characterising species are indicated for each group.

| 1st SIMPROF | g | h | j | k | m | q | t | v | c | u | x | n |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2nd SIMPROF | g | | d | u | q | m | r | w | c | z | x | s |
| | Notomastus / Aonides / Glycera | | Nephtys / Ophelia / Spiophanes | Ophelia / Spiophanes / /Nephtys | Bathyporeia / Spiophanes | Spiophanes / Goniada / Bathyporeia | Spiophanes / Echinocyamus | Spiophanes / Chaetozone | Kurtiella / Polycirrus / Spirobranchus | Acrocnida / Spiophanes / Kurtiella | Kurtiella / Bathyporeia / Acrocnida | Acrocnida / Sigalion / Kurtiella |
| **Taxa** | | | | | | | | | | | | |
| *Spiophanes bombyx* | | | 0.97 | 1.71 | 1.57 | 2.5 | 2.5 | 2.64 | | 2.01 | | |
| *Bathyporeia elegans* | | | | | | 1.83 | | | | | 2.32 | |
| *Fabulina fabula* | | | | | | | | | | 1.23 | | |
| *Echinocyamus pusillus* | 2.16 | | | | | | 2 | | | | 1.55 | |
| *Chaetozone christiei* | | | | | | | | 1.21 | | | | 1.17 |
| *Kurtiella bidentata* | | | | | | | | | 3.26 | 2.23 | 1.88 | 1.61 |
| *Sigalion mathildae* | | | | | 1.03 | | | | | | | 1.31 |
| *Acrocnida brachiata* | | | | | | | | | | 2.43 | 1.38 | 2.01 |
| *Magelona filiformis* | | | | | | | | 1 | | | | |
| *Polygordius* | | | | | | | | | | | | |
| *Pisione remota* | | | | | | | | | | | | |
| *Notomastus* | 3.08 | 2.3 | | | | | 1.57 | | | | | |
| *Glycera lapidum* | 1.81 | 1.21 | | | | | | | | | | |
| *Ophelia borealis* | | | 1.14 | 1.51 | | | | | | | | |
| *Magelona johnstoni* | | | | | | | | | | | | |
| *Nephtys cirrosa* | | | 1.38 | 1.16 | | | | | | | | |
| *Bathyporeia pelagica* | | | | 1.5 | 1.61 | | | | | | | |
| *Protodorvillea kefersteini* | | | | | | | | | | | | |
| *Urothoe poseidonis* | | | | | | | | | | 1.31 | | |
| NEMERTEA | 1.15 | 1 | | | | | | | | | 1.24 | |
| *Goniada maculata* | | | | | | 1.57 | | | | | | |
| *Owenia borealis* | | | | | | | | | 1.75 | | | |
| *Spirobranchus lamarcki* | | | | | | | | | 3.21 | | | |
| *Bathyporeia guilliamsoniana* | | | | | | | | | | | | |
| *Branchiostoma lanceolatum* | | | | | | | | | | | | |
| *Aonides paucibranchiata* | 1.21 | 1.58 | | | | | | | | | | |
| *Polycirrus* | | | | | | | | | 2.75 | | | |
| *Pholoe baltica* (sensu Petersen) | | 1.42 | | | | | | | | 1.25 | | |
| *Donax vittatus* | | | | | | | | | | | | |
| Edwardsiidae | | | | | | | 1.37 | 1 | | | | |
| *Scoloplos armiger* | | | | | | | | | | | | |
| *Lanice conchilega* | | | | | | | | | | | | |
| *Spio filicornis* | | | | | | | | | | | | |
| *Scalibregma inflatum* | | | | | | | | | 1.38 | | | |
| *Thyasira flexuosa* | | | | | | | | | | | | |
| *Amphiura filiformis* | | | | | | | | | | | | |
| NUDIBRANCHIA | | 1.16 | | | | | | | | | | |
| *Phoronis* | | | | | | | | | | 1.08 | | |
| *Galathowenia oculata* | | | | | | | | 1 | | | | |
| LEPTOTHECATA | | | | | | | | | | | | |

Sentinal Monitoring: Temporal analysis – Taxa contributing to 90% of the within year similarity (values represent fourth-root transformed average abundances).

| Taxa | 1985 | 1986 | 1987 | 1997 | 1998 | 2006 | 2007 | 2014 |
|---|---|---|---|---|---|---|---|---|
| Bathyporeia | 4.64 | 3.8 | 4.03 | 4.39 | 3.55 | 3.44 | 3.95 | 3.24 |
| Spiophanes bombyx | 3.1 | 3.75 | 1.3 | 4.09 | 3.86 | 3.79 | 3.15 | 2.72 |
| Magelona | 2.97 | 2.47 | | 2.41 | 2.35 | 3.04 | 2.47 | 2 |
| Tellina fabula | 2.25 | 2.86 | | 1.97 | 1.38 | 2.34 | 2.46 | 2.48 |
| Nephtys cirrosa | 2.73 | 2.12 | 1.88 | 1.83 | 1.98 | 1.2 | 1.26 | 1.06 |
| Euspira nitida | 1.93 | 1.97 | | 2.06 | 1.57 | 1.15 | 1.36 | 1.51 |
| NEMERTEA | | 1.5 | 2.02 | 1.11 | 1.15 | 2.05 | 0.93 | 1.07 |
| Owenia | 1.52 | 1.43 | | 1.32 | 1.18 | 1.02 | 1.48 | 1.58 |
| Sigalion mathildae | 2.11 | 1.82 | | 1.6 | 1.03 | 0.88 | | 1.77 |
| Urothoe poseidonis | 1.35 | 1.9 | | 1.09 | | 1.59 | 1.62 | 1.59 |
| Goniada maculata | 1.38 | 1.14 | | 1.03 | 0.64 | 1.54 | 1.28 | 1.81 |
| Pontocrates | 2.24 | | | 1.49 | 1.45 | 1.63 | | 0.95 |
| Acrocnida brachiata | | 1.81 | | 1.68 | 1.11 | 2.22 | | 0.8 |
| Nephtys assimilis | 2.33 | 1.44 | | 0.88 | 1.18 | 1.01 | | 0.5 |
| Perioculodes longimanus | | 1.1 | | 2.22 | 1.44 | 0.85 | 1.61 | |
| Lanice conchilega | | | | 1.78 | | 0.96 | 3.56 | |
| Chaetozone | | 0.86 | 1.42 | | | 1.44 | | 1.81 |
| Edwardsiidae | 1.57 | 1.85 | | | 0.79 | | | 0.98 |
| Phoronis | 1.16 | 1.74 | | 1.24 | 1.04 | | | |
| Echinocardium cordatum | 1.24 | 1.74 | | | 0.78 | | | 0.9 |
| Spio decorata | 1.61 | 1.1 | | 0.93 | 0.68 | | | |
| Donax vittatus | | 1.12 | 1.39 | 0.94 | | | | 0.86 |
| Megaluropus agilis | | | | 1.65 | | 0.89 | 1.3 | |
| Echinocyamus pusillus | | | | | 0.77 | | 1.65 | 1.39 |
| Syllidae | | | 3.51 | | | | | |
| Thracia phaseolina | 1.12 | | | | | 1.19 | 1.05 | |
| Nephtys caeca | 1.6 | 1.72 | | | | | | |
| Dosinia lupinus | 1.27 | 0.76 | | | | | 1.05 | |
| Cheirocratus assimilis | | | 3.05 | | | | | |
| Kurtiella bidentata | | 1.14 | 0.89 | | | | | 0.91 |
| Scoloplos armiger | | 1.17 | | | | | 0.95 | 0.71 |
| Chamelea | 1.22 | | | | 0.94 | | | 0.56 |
| Diastylis bradyi | 1.22 | | 1.5 | | | | | |
| Minuspio cirrifera | | | 2.35 | | | | | |
| Glycinde nordmanni | | 1.05 | | | | | | 1.29 |
| Abra prismatica | 0.99 | 1.34 | | | | | | |
| Nucula nitidosa | | | 2.3 | | | | | |
| Leucothoe incisa | 1.38 | | | | | | | 0.71 |
| Ophelia | | | 0.84 | | | | | 1.16 |
| Siphonoecetes kroyeranus | | 1.05 | | | | | 0.93 | |
| Phyllodoce rosea | | | 1.92 | | | | | |
| Retusa | | | 1.89 | | | | | |
| Phaxas pellucidus | | | | | | 0.87 | 0.95 | |
| Orbinia sertulata | | | 1.81 | | | | | |
| Anthozoa | | | 1.79 | | | | | |
| Iphinoe trispinosa | | | | 0.86 | 0.92 | | | |
| Synchelidium maculatum | | | | 0.95 | | | 0.79 | |
| Eudorellopsis deformis | | | 1.69 | | | | | |
| Schistomysis kervillei | | | 1.69 | | | | | |
| Sthenelais limicola | | | 1.66 | | | | | |
| Pholoe baltica (sensu Petersen) | | | | | | 0.89 | | 0.76 |
| Byblis gairmardi | | | 1.62 | | | | | |
| Tryphosites longipes | | | 1.55 | | | | | |
| Synchelidium haplocheles | | | 1.4 | | | | | |
| Brissopsis lyrifera | | | 1.39 | | | | | |
| Spio filicornis | | | | | | 0.73 | | 0.65 |
| Lagis koreni | | | 1.37 | | | | | |
| Scopelocheirus hopei | | | 1.37 | | | | | |
| Ophiura albida | | | 1.28 | | | | | |
| Phyllodocidae | | 1.28 | | | | | | |
| Leptopentacta elongata | | | 1.23 | | | | | |
| Nephtys hombergii | | | 1.22 | | | | | |

Sentinal Monitoring: Temporal analysis – Taxa contributing to 50% of the community similarity within each of the macrofaunal communities identified by Wieking and Kröncke (2003).

| | Bank community | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Taxa** | **1985** | **1986** | **1987** | **1997** | **1998** | **2006** | **2007** | **2014** |
| *Bathyporeia* | 4.64 | 3.82 | 4 | 4.35 | 3.73 | 3.29 | 4.1 | 2.87 |
| *Spiophanes bombyx* | 3.1 | 3.54 | | 4.68 | 4.42 | 3.77 | 3.86 | 2.49 |
| *Magelona* | 2.97 | 2.61 | | 3.04 | 2.85 | 3.51 | 2.68 | 2.54 |
| *Tellina fabula* | 2.25 | 3.02 | | 2.95 | | 2.84 | 2.71 | 2.77 |
| *Sigalion mathildae* | | 2.18 | | 2.4 | 1.8 | | | 2.28 |
| *Euspira nitida* | 1.93 | 1.98 | | | 1.94 | | | 1.85 |
| *Lanice conchilega* | | | | 2.67 | | | 4.49 | |
| *Nephtys cirrosa* | 2.73 | 2.25 | 1.93 | | | | | |
| NEMERTEA | | | 1.99 | | 1.64 | 2.37 | | |
| *Acrocnida brachiata* | | | | 2.53 | | 2.76 | | |
| *Pontocrates* | 2.24 | | | | | 1.9 | | |
| Syllidae | | | 3.17 | | | | | |
| *Cheirocratus assimilis* | | | 3.15 | | | | | |
| *Nucula nitidosa* | | | 2.63 | | | | | |
| *Minuspio cirrifera* | | | 2.4 | | | | | |
| *Nephtys assimilis* | 2.33 | | | | | | | |
| *Schistomysis kervillei* | | | 2.31 | | | | | |
| *Urothoe poseidonis* | | | | | | | | 2.2 |
| *Byblis gairmardi* | | | 2.15 | | | | | |
| *Echinocardium cordatum* | | 2.08 | | | | | | |
| *Goniada maculata* | | | | | | | | 2.03 |
| *Megaluropus agilis* | | | | | | | 1.96 | |
| *Retusa* | | | 1.94 | | | | | |
| *Phyllodoce rosea* | | | 1.92 | | | | | |
| *Lagis koreni* | | | 1.83 | | | | | |
| *Ensis* | | | | | 1.61 | | | |

| | SW Patch community | | | | | |
|---|---|---|---|---|---|---|
| **Taxa** | **1987** | **1997** | **1998** | **2006** | **2007** | **2014** |
| *Bathyporeia* | 4.82 | 4.46 | 3.63 | 3.67 | 3.57 | 4.82 |
| *Nephtys cirrosa* | | 2.64 | 3.27 | 2.5 | 2.47 | 2.89 |
| *Spiophanes bombyx* | | | 3.77 | 4.03 | 2.59 | 2.88 |
| *Cheirocratus assimilis* | 2.85 | | | | | |
| Syllidae | 2.83 | | | | | |
| *Orbinia sertulata* | 2.74 | | | | | |
| *Donax vittatus* | | 2.18 | | | | |
| *Minuspio cirrifera* | 2.04 | | | | | |
| *Montacuta substriata* | 1.9 | | | | | |
| *Retusa* | 1.84 | | | | | |
| Anthozoa | 1.64 | | | | | |

Sentinel Monitoring: Gear comparison.

| | **Group VV** | **Group** | | | | |
|---|---|---|---|---|---|---|
| **Species** | **Av.Abund** | **Av.Abund** | **Av.Diss** | **Diss/SD** | **Contrib%** | **Cum.%** |
| Thyasiridae | 0 | 0.14 | 0.18 | 0.29 | 0.25 | 88.34 |
| ENTEROPNEUSTA | 0 | 0.14 | 0.15 | 0.37 | 0.22 | 89.75 |
| *Magelona alleni* | 0 | 0.11 | 0.12 | 0.29 | 0.17 | 92.1 |
| Pholoidae | 0 | 0.08 | 0.09 | 0.3 | 0.14 | 93.7 |
| *Protodorvillea kefersteini* | 0 | 0.08 | 0.09 | 0.3 | 0.14 | 93.83 |
| *Acidostoma neglectum* | 0 | 0.06 | 0.07 | 0.21 | 0.1 | 95.88 |
| *Euspira catena* | 0 | 0.04 | 0.05 | 0.2 | 0.08 | 96.84 |
| ANTHOATHECATA | 0 | 0.04 | 0.05 | 0.2 | 0.07 | 97.3 |
| *Iphinoe trispinosa* | 0 | 0.04 | 0.05 | 0.2 | 0.07 | 97.44 |
| GASTROPODA | 0 | 0.04 | 0.05 | 0.21 | 0.07 | 97.51 |
| Cardiidae | 0 | 0.04 | 0.05 | 0.21 | 0.07 | 97.58 |
| *Euspira* | 0 | 0.04 | 0.05 | 0.21 | 0.07 | 97.72 |
| *Malmgrenia ljungmani* | 0 | 0.04 | 0.05 | 0.21 | 0.07 | 97.79 |
| *Nototropis guttatus* | 0 | 0.04 | 0.05 | 0.21 | 0.07 | 97.85 |
| *Gammaropsis* | 0 | 0.04 | 0.04 | 0.21 | 0.06 | 98.56 |
| *Orchomenella nana* | 0 | 0.04 | 0.04 | 0.21 | 0.06 | 98.62 |
| *Podarkeopsis* | 0 | 0.04 | 0.04 | 0.21 | 0.06 | 98.87 |
| *Pisione remota* | 0 | 0.04 | 0.04 | 0.21 | 0.06 | 98.99 |
| *Chaetozone gibber* | 0 | 0.04 | 0.04 | 0.21 | 0.06 | 99.05 |
| *Siphonoecetes kroyeranus* | 0.46 | 0 | 0.47 | 0.64 | 0.68 | 72.63 |
| *Spio filicornis* | 0.27 | 0 | 0.29 | 0.54 | 0.42 | 80.26 |
| *Ensis* | 0.25 | 0 | 0.29 | 0.56 | 0.42 | 80.67 |
| *Hippomedon denticulatus* | 0.24 | 0 | 0.26 | 0.4 | 0.38 | 83.04 |
| *Pariambus typicus* | 0.21 | 0 | 0.24 | 0.5 | 0.35 | 84.46 |
| *Diastylis rugosa* | 0.21 | 0 | 0.22 | 0.5 | 0.32 | 85.74 |
| Maldanidae | 0.17 | 0 | 0.2 | 0.44 | 0.29 | 87.26 |
| Orbiniidae | 0.17 | 0 | 0.2 | 0.44 | 0.29 | 87.54 |
| *Ampelisca brevicornis* | 0.16 | 0 | 0.17 | 0.37 | 0.24 | 89.07 |
| *Sthenelais limicola* | 0.14 | 0 | 0.16 | 0.35 | 0.22 | 89.53 |
| *Kellia suborbicularis* | 0.12 | 0 | 0.15 | 0.3 | 0.21 | 89.97 |
| DECAPODA | 0.13 | 0 | 0.14 | 0.37 | 0.2 | 90.98 |
| *Nototropis vedlomensis* | 0.13 | 0 | 0.14 | 0.37 | 0.2 | 91.17 |
| Amphiuridae | 0.13 | 0 | 0.13 | 0.37 | 0.19 | 91.55 |
| *Nucula nucleus* | 0.12 | 0 | 0.13 | 0.3 | 0.19 | 91.93 |
| *Scolelepis korsuni* | 0.08 | 0 | 0.11 | 0.3 | 0.16 | 92.57 |
| *Campanulariidae* | 0.08 | 0 | 0.1 | 0.3 | 0.14 | 93.15 |
| *Lepidepecreum longicorne* | 0.08 | 0 | 0.1 | 0.3 | 0.14 | 93.29 |
| *Abludomelita obtusata* | 0.1 | 0 | 0.09 | 0.3 | 0.14 | 93.56 |
| *Aora gracilis* | 0.08 | 0 | 0.09 | 0.3 | 0.13 | 94.1 |
| *Nephtys caeca* | 0.08 | 0 | 0.09 | 0.29 | 0.13 | 94.23 |
| *Astropecten irregularis* | 0.08 | 0 | 0.09 | 0.29 | 0.13 | 94.36 |
| *Aoridae (female)* | 0.08 | 0 | 0.09 | 0.3 | 0.12 | 94.75 |
| *Lagotia viridis* | 0.08 | 0 | 0.09 | 0.29 | 0.12 | 94.87 |
| *Mangelia nebula* | 0.08 | 0 | 0.08 | 0.3 | 0.12 | 95.11 |
| *Electra pilosa* | 0.08 | 0 | 0.08 | 0.3 | 0.12 | 95.22 |
| *Retusa umbilicata* | 0.08 | 0 | 0.08 | 0.3 | 0.12 | 95.34 |

| | Group VV | Group | | | | |
|---|---|---|---|---|---|---|
| **Species** | **Av.Abund** | **Av.Abund** | **Av.Diss** | **Diss/SD** | **Contrib%** | **Cum.%** |
| *Scolelepis bonnieri* | 0.08 | 0 | 0.08 | 0.3 | 0.11 | 95.45 |
| *Aonides paucibranchiata* | 0.08 | 0 | 0.08 | 0.3 | 0.11 | 95.57 |
| *Mediomastus fragilis* | 0.08 | 0 | 0.07 | 0.3 | 0.11 | 95.78 |
| *Spio armata* | 0.04 | 0 | 0.07 | 0.21 | 0.1 | 95.98 |
| *Ebalia granulosa* | 0.06 | 0 | 0.06 | 0.21 | 0.09 | 96.07 |
| *Myriochele danielsseni* | 0.04 | 0 | 0.06 | 0.21 | 0.09 | 96.16 |
| *Anaitides lineata* | 0.04 | 0 | 0.06 | 0.21 | 0.09 | 96.25 |
| AMPHIPODA | 0.04 | 0 | 0.06 | 0.21 | 0.09 | 96.34 |
| *Diastyloides serratus* | 0.04 | 0 | 0.06 | 0.21 | 0.09 | 96.43 |
| *Tellina* | 0.04 | 0 | 0.06 | 0.21 | 0.09 | 96.52 |
| *Sigalionidae* | 0.04 | 0 | 0.06 | 0.21 | 0.08 | 96.6 |
| *Iphinoe serrata* | 0.04 | 0 | 0.06 | 0.21 | 0.08 | 96.68 |
| *Processa modica* | 0.04 | 0 | 0.06 | 0.21 | 0.08 | 96.76 |
| *Spio* | 0.04 | 0 | 0.05 | 0.21 | 0.08 | 96.92 |
| CRUSTACEA | 0.04 | 0 | 0.05 | 0.21 | 0.08 | 96.99 |
| *Pseudocuma simile* | 0.04 | 0 | 0.05 | 0.21 | 0.08 | 97.07 |
| *Moerella pygmaea* | 0.04 | 0 | 0.05 | 0.21 | 0.08 | 97.15 |
| *Malmgrenia darbouxi* | 0.04 | 0 | 0.05 | 0.21 | 0.07 | 97.22 |
| *Ophelina acuminata* | 0.04 | 0 | 0.05 | 0.21 | 0.07 | 97.37 |
| *Synchelidium maculatum* | 0.04 | 0 | 0.05 | 0.21 | 0.07 | 97.65 |
| *Pinnotheres pisum* | 0.04 | 0 | 0.05 | 0.21 | 0.07 | 97.92 |
| TURBELLARIA | 0.04 | 0 | 0.05 | 0.21 | 0.07 | 97.98 |
| *Nephtys longosetosa* | 0.04 | 0 | 0.04 | 0.21 | 0.06 | 98.05 |
| *Ampharete lindstroemi* | 0.04 | 0 | 0.04 | 0.21 | 0.06 | 98.11 |
| *Thyasira equalis* | 0.04 | 0 | 0.04 | 0.21 | 0.06 | 98.18 |
| *Diplodonta rotundata* | 0.04 | 0 | 0.04 | 0.21 | 0.06 | 98.24 |
| *Argissa hamatipes* | 0.04 | 0 | 0.04 | 0.21 | 0.06 | 98.31 |
| *Atylus falcatus* | 0.04 | 0 | 0.04 | 0.21 | 0.06 | 98.37 |
| *Spisula subtruncata* | 0.04 | 0 | 0.04 | 0.21 | 0.06 | 98.43 |
| *Myrianida* | 0.04 | 0 | 0.04 | 0.21 | 0.06 | 98.5 |
| *Lovenella clausa* | 0.04 | 0 | 0.04 | 0.21 | 0.06 | 98.68 |
| Cirratulidae | 0.04 | 0 | 0.04 | 0.21 | 0.06 | 98.74 |
| *Tryphosella* | 0.04 | 0 | 0.04 | 0.21 | 0.06 | 98.81 |
| *Ebalia tumefacta* | 0.04 | 0 | 0.04 | 0.21 | 0.06 | 98.93 |
| *Pisidia longicornis* | 0.04 | 0 | 0.04 | 0.21 | 0.06 | 99.11 |
| *Bela* | 0.04 | 0 | 0.04 | 0.21 | 0.06 | 99.17 |
| *Philine* | 0.04 | 0 | 0.04 | 0.21 | 0.06 | 99.23 |
| *Spisula solida* | 0.04 | 0 | 0.04 | 0.21 | 0.06 | 99.29 |
| Tubulariidae | 0.04 | 0 | 0.04 | 0.21 | 0.06 | 99.35 |
| *Autonoe* | 0.04 | 0 | 0.04 | 0.21 | 0.06 | 99.41 |
| *Leucothoe lilljeborgi* | 0.04 | 0 | 0.04 | 0.21 | 0.06 | 99.47 |
| *Aphrodita* | 0.04 | 0 | 0.04 | 0.21 | 0.06 | 99.52 |
| Glyceridae | 0.04 | 0 | 0.04 | 0.21 | 0.06 | 99.58 |
| *Ophiodromus flexuosus* | 0.04 | 0 | 0.04 | 0.21 | 0.06 | 99.63 |
| *Siphonoecetes* | 0.04 | 0 | 0.04 | 0.21 | 0.06 | 99.69 |
| Nereididae | 0.04 | 0 | 0.04 | 0.21 | 0.05 | 99.74 |
| *Pontocrates arcticus* | 0.04 | 0 | 0.04 | 0.21 | 0.05 | 99.8 |

| | Group VV | Group | | | | |
|---|---|---|---|---|---|---|
| **Species** | **Av.Abund** | **Av.Abund** | **Av.Diss** | **Diss/SD** | **Contrib%** | **Cum.%** |
| *Urothoe* | 0.04 | 0 | 0.04 | 0.21 | 0.05 | 99.85 |
| *Epizoanthus couchii* | 0.04 | 0 | 0.03 | 0.21 | 0.05 | 99.9 |
| *Aporrhais* | 0.04 | 0 | 0.03 | 0.21 | 0.05 | 99.95 |
| *Branchiostoma* | 0.04 | 0 | 0.03 | 0.21 | 0.05 | 100 |

Investigative Monitoring: Management Area A: Impact vs Control
Average dissimilarity = 54.98

| | Group Impact | Group Control | | | | |
|---|---|---|---|---|---|---|
| Species | Av.Abund | Av.Abund | Av.Diss | Diss/SD | Contrib% | Cum.% |
| *Bathyporeia elegans* | 3.27 | 3.44 | 3.34 | 1.33 | 6.07 | 6.07 |
| *Owenia borealis* | 1.92 | 1.94 | 2.18 | 1.26 | 3.96 | 10.03 |
| *Urothoe poseidonis* | 1.22 | 1.46 | 2.01 | 1.2 | 3.66 | 13.69 |
| *Tellina fabula* | 1.33 | 1.13 | 1.95 | 1.33 | 3.54 | 17.23 |
| *Bathyporeia guilliamsoniana* | 1.3 | 1.2 | 1.84 | 1.21 | 3.34 | 20.57 |
| *Spiophanes bombyx* | 0.69 | 0.81 | 1.64 | 1.21 | 2.97 | 23.54 |
| *Magelona filiformis* | 1.18 | 1.21 | 1.59 | 1.22 | 2.89 | 26.43 |
| *Goniada maculata* | 0.84 | 1.01 | 1.51 | 1.19 | 2.75 | 29.18 |
| *Magelona johnstoni* | 0.49 | 0.6 | 1.41 | 1.04 | 2.56 | 31.74 |
| *Sigalion mathildae* | 1.28 | 1.32 | 1.38 | 1.17 | 2.5 | 34.24 |
| *Echinocyamus pusillus* | 0.61 | 0.28 | 1.31 | 1.02 | 2.38 | 36.62 |
| *Clymenura* | 0.54 | 0.44 | 1.23 | 1.02 | 2.24 | 38.87 |
| *Nephtys cirrosa* | 0.43 | 0.25 | 1.07 | 0.8 | 1.94 | 40.8 |
| LEPTOTHECATA | 0.49 | 0.71 | 1.06 | 0.99 | 1.93 | 42.73 |
| NEMERTEA | 0.33 | 0.39 | 1.03 | 0.9 | 1.86 | 44.6 |
| *Phoronis* | 0.3 | 0.42 | 1.01 | 0.91 | 1.83 | 46.43 |
| *Thracia gracilis ?* | 0.34 | 0.31 | 0.95 | 0.85 | 1.74 | 48.16 |
| BIVALVIA | 0.11 | 0.43 | 0.91 | 0.88 | 1.66 | 49.82 |
| *Ensis ensis* | 0.3 | 0.27 | 0.89 | 0.79 | 1.61 | 51.43 |

Management Area B: Impact v’s Control
Average dissimilarity = 67.59

| | Group Impact | Group Control | | | | |
|---|---|---|---|---|---|---|
| Species | Av.Abund | Av.Abund | Av.Diss | Diss/SD | Contrib% | Cum.% |
| *Spiophanes bombyx* | 1.57 | 1.94 | 2.82 | 1.38 | 4.18 | 4.18 |
| *Bathyporeia pelagica* | 1.67 | 1.54 | 2.71 | 1.3 | 4.01 | 8.18 |
| *Kurtiella bidentata* | 0.74 | 1 | 2.25 | 1.04 | 3.33 | 11.51 |
| *Acrocnida brachiata* | 0.78 | 1.08 | 2.13 | 1.22 | 3.15 | 14.66 |
| *Echinocyamus pusillus* | 0.94 | 1.19 | 2.11 | 1.34 | 3.12 | 17.78 |
| *Urothoe poseidonis* | 0.83 | 1.19 | 2.08 | 1.16 | 3.08 | 20.86 |
| *Chaetozone christiei* | 1.24 | 1.38 | 2.02 | 1.19 | 2.99 | 23.85 |
| *Tellina fabula* | 0.88 | 1.23 | 1.97 | 1.22 | 2.92 | 26.77 |
| *Sigalion mathildae* | 0.66 | 1.1 | 1.76 | 1.26 | 2.6 | 29.37 |
| *Owenia borealis* | 0.84 | 0.97 | 1.73 | 1.2 | 2.56 | 31.93 |
| *Bathyporeia guilliamsoniana* | 0.6 | 0.88 | 1.72 | 1.16 | 2.55 | 34.48 |
| *Magelona filiformis* | 0.62 | 0.91 | 1.69 | 1.2 | 2.5 | 36.98 |
| *Ophelia borealis* | 0.78 | 0.29 | 1.6 | 0.89 | 2.36 | 39.34 |
| *Goniada maculata* | 0.78 | 0.78 | 1.54 | 1.11 | 2.28 | 41.62 |
| NEMERTEA | 0.51 | 0.59 | 1.23 | 1.03 | 1.82 | 43.44 |
| Edwardsiidae | 0.38 | 0.45 | 1.21 | 0.84 | 1.79 | 45.23 |

| | Group Impact | Group Control | | | | |
|---|---|---|---|---|---|---|
| Species | Av.Abund | Av.Abund | Av.Diss | Diss/SD | Contrib% | Cum.% |
| *Thyasira flexuosa* | 0.52 | 0.3 | 1.21 | 0.84 | 1.79 | 47.02 |
| *Glycinde nordmanni* | 0.26 | 0.5 | 1.07 | 0.88 | 1.58 | 48.6 |
| *Bathyporeia elegans* | 0.17 | 0.39 | 1.04 | 0.49 | 1.54 | 50.14 |

Management Area B: SIMPROF groups

| Taxa | Group c | Group f | Group g | Group h | Group i | Group j |
|---|---|---|---|---|---|---|
| *Bathyporeia pelagica* | 1.71 | | 3.3 | | 1.85 | 1.68 |
| *Chaetozone christiei* | | 1.17 | | 1.62 | 1.51 | 1.39 |
| *Spiophanes bombyx* | | | | | 1.7 | 2.25 |
| *Magelona filiformis* | | | 1.49 | | | 1.12 |
| *Goniada maculata* | 1.21 | | | | 1.33 | |
| *Sigalion mathildae* | | 1.31 | | | | 1.21 |
| *Bathyporeia elegans* | | | | 2.33 | | |
| *Acrocnida brachiata* | | 2.01 | | | | |
| *Echinocyamus pusillus* | | | | 1.72 | | |
| *Kurtiella bidentata* | | 1.61 | | | | |
| *Tellina fabula* | | | | | | 1.44 |
| *Urothoe poseidonis* | | | | | | 1.36 |
| *Paramphinome jeffreysii* | 1 | | | | | |
| *Scoloplos armiger* | 1 | | | | | |

Management Area C – Imact V's Control
Average dissimilarity = 79.03

| | Group Impact | Group Control | | | | |
|---|---|---|---|---|---|---|
| Species | Av.Abund | Av.Abund | Av.Diss | Diss/SD | Contrib % | Cum. % |
| *Scoloplos armiger* | 1.34 | 0.73 | 2.44 | 1.13 | 3.08 | 3.08 |
| *Echinocyamus pusillus* | 1.26 | 0.64 | 2.43 | 1.07 | 3.07 | 6.15 |
| *Spiophanes bombyx* | 1.51 | 1.22 | 2.22 | 1.15 | 2.81 | 8.96 |
| *Tellina fabula* | 0.77 | 0.93 | 2.1 | 1.06 | 2.66 | 11.62 |
| *Notomastus* | 0.83 | 0.86 | 2.08 | 0.97 | 2.64 | 14.26 |
| *Ophelia borealis* | 0.73 | 0.65 | 1.89 | 0.94 | 2.4 | 16.66 |
| *Bathyporeia pelagica* | 0.73 | 0.68 | 1.81 | 1 | 2.28 | 18.94 |
| *Goniada maculata* | 0.97 | 0.62 | 1.67 | 1.14 | 2.11 | 21.05 |
| *Nephtys cirrosa* | 0.48 | 0.69 | 1.59 | 0.99 | 2.01 | 23.06 |
| *Magelona filiformis* | 0.46 | 0.55 | 1.45 | 0.85 | 1.83 | 24.89 |
| *Chaetozone christiei* | 0.47 | 0.63 | 1.42 | 0.98 | 1.8 | 26.69 |
| NEMERTEA | 0.78 | 0.71 | 1.36 | 1.06 | 1.72 | 28.41 |
| *Dosinia lupinus* | 0.63 | 0.34 | 1.35 | 0.96 | 1.7 | 30.11 |
| *Amphiura filiformis* | 0.57 | 0.3 | 1.28 | 0.75 | 1.62 | 31.73 |
| *Nucula nitidosa* | 0.34 | 0.39 | 1.12 | 0.71 | 1.42 | 33.15 |
| *Glycera lapidum* | 0.48 | 0.33 | 1.1 | 0.73 | 1.39 | 34.54 |

| | Group Impact | Group Control | | | | |
|---|---|---|---|---|---|---|
| Species | Av.Abund | Av.Abund | Av.Diss | Diss/SD | Contrib % | Cum. % |
| *Thracia gracilis ?* | 0.37 | 0.36 | 1.02 | 0.82 | 1.3 | 35.84 |
| *Kurtiella bidentata* | 0.35 | 0.37 | 1.02 | 0.67 | 1.29 | 37.13 |
| *Lanice conchilega* | 0.15 | 0.45 | 1.02 | 0.77 | 1.29 | 38.42 |
| *Aonides paucibranchiata* | 0.39 | 0.36 | 0.98 | 0.75 | 1.24 | 39.66 |
| *Urothoe elegans* | 0.49 | 0.13 | 0.95 | 0.61 | 1.2 | 40.86 |
| *Cylichna cylindracea* | 0.32 | 0.25 | 0.93 | 0.58 | 1.17 | 42.04 |
| Polynoidae | 0.38 | 0.27 | 0.91 | 0.79 | 1.15 | 43.19 |
| *Branchiostoma lanceolatum* | 0.37 | 0.23 | 0.9 | 0.7 | 1.14 | 44.32 |
| *Sigalion mathildae* | 0.23 | 0.33 | 0.88 | 0.7 | 1.12 | 45.44 |
| *Owenia borealis* | 0.39 | 0.22 | 0.87 | 0.82 | 1.09 | 46.53 |
| *Polycirrus* | 0.31 | 0.31 | 0.86 | 0.68 | 1.09 | 47.62 |
| *Phoronis* | 0.26 | 0.33 | 0.84 | 0.77 | 1.06 | 48.69 |
| *Phaxas pellucidus* | 0.33 | 0.14 | 0.77 | 0.61 | 0.98 | 49.67 |
| *Pholoe baltica (sensu Petersen)* | 0.27 | 0.28 | 0.75 | 0.63 | 0.95 | 50.62 |

Management Area C – SIMPROF groups

| Taxa | Group a | Group b | Group c | Group d | Group e | Group f | Group g |
|---|---|---|---|---|---|---|---|
| *Notomastus* | 3.93 | 2.41 | 2.64 | 2.3 | | | |
| *Spiophanes bombyx* | 1.62 | | | | 2.54 | 1.48 | 1.38 |
| *Scoloplos armiger* | | | | | 3.63 | 1.38 | |
| *Glycera lapidum* | | 1.57 | 2.07 | 1.21 | | | |
| *Aonides paucibranchiata* | 1.82 | | 1.34 | 1.58 | | | |
| NEMERTEA | | 1 | 1.3 | 1 | 1.21 | | |
| *Echinocyamus pusillus* | | 1.41 | 2.67 | | | | |
| *Goniada maculata* | | | | | 1.64 | 1.12 | |
| *Tellina fabula* | | | | | | 1.79 | |
| *Dosinia lupinus* | 1.72 | | | | | | |
| Polynoidae | 1.72 | | | | | | |
| *Polititapes rhomboides* | 1.66 | | | | | | |
| *Laonice bahusiensis* | 1.61 | | | | | | |
| *Paramphinome jeffreysii* | | | | | 1.51 | | |
| Pholoe baltica (sensu Petersen) | | | | 1.42 | | | |
| *Ophelia borealis* | | | | | | | 1.38 |
| *Nephtys cirrosa* | | | | | | | 1.31 |
| *Magelona filiformis* | | | | | | 1.22 | |
| NUDIBRANCHIA | | | | 1.16 | | | |
| *Polycirrus* | | | 1.14 | | | | |
| *Chaetozone christiei* | | | | | | 1.09 | |

Management Area D: Impact v's Control

| | Group Impact | Group Control | | | | |
|---|---|---|---|---|---|---|
| Species | Av.Abund | Av.Abund | Av.Diss | Diss/SD | Contrib% | Cum.% |
| *Spiophanes bombyx* | 2.49 | 2.05 | 3.95 | 1.12 | 5.46 | 5.46 |
| *Bathyporeia elegans* | 2.01 | 2.54 | 3.87 | 1.04 | 5.36 | 10.81 |
| *Nephtys cirrosa* | 0.78 | 0.88 | 2.27 | 1.12 | 3.14 | 13.96 |
| *Bathyporeia guilliamsoniana* | 0.75 | 0.82 | 1.98 | 1.14 | 2.74 | 16.7 |
| *Ophelia borealis* | 0.59 | 0.73 | 1.93 | 0.92 | 2.67 | 19.36 |
| *Tellina fabula* | 0.69 | 0.61 | 1.8 | 0.99 | 2.49 | 21.85 |
| *Echinocyamus pusillus* | 0.38 | 0.75 | 1.78 | 0.91 | 2.46 | 24.31 |
| *Magelona filiformis* | 0.66 | 0.6 | 1.75 | 1.01 | 2.43 | 26.74 |
| *Magelona johnstoni* | 0.57 | 0.74 | 1.7 | 1.05 | 2.35 | 29.09 |
| *Owenia borealis* | 0.45 | 0.71 | 1.68 | 0.96 | 2.32 | 31.4 |
| *Donax vittatus* | 0.39 | 0.4 | 1.57 | 0.63 | 2.17 | 33.58 |
| *Chaetozone christiei* | 0.55 | 0.39 | 1.54 | 0.83 | 2.13 | 35.71 |
| *Notomastus* | 0.67 | 0.36 | 1.53 | 0.73 | 2.12 | 37.82 |
| *Sigalion mathildae* | 0.53 | 0.51 | 1.44 | 0.98 | 1.99 | 39.81 |
| *Goniada maculata* | 0.32 | 0.49 | 1.32 | 0.83 | 1.82 | 41.64 |
| *Urothoe poseidonis* | 0.3 | 0.5 | 1.26 | 0.75 | 1.75 | 43.38 |
| *Phoronis* | 0.42 | 0.27 | 1.11 | 0.63 | 1.54 | 44.92 |
| *Euspira nitida* | 0.3 | 0.38 | 1.08 | 0.76 | 1.5 | 46.42 |
| *Pisione remota* | 0.59 | 0.07 | 1.01 | 0.42 | 1.4 | 47.81 |
| SPATANGOIDA | 0.29 | 0.29 | 0.94 | 0.77 | 1.3 | 49.12 |
| NEMERTEA | 0.32 | 0.26 | 0.92 | 0.67 | 1.27 | 50.39 |

Management Area D: SIMPROF groups

| Taxa | Group d | Group e | Group f | Group h | Group i | Group j | Group k | Group l |
|---|---|---|---|---|---|---|---|---|
| *Spiophanes bombyx* | | | 2.39 | | 2.68 | 3.08 | 1.91 | 2.81 |
| *Pisione remota* | 6.38 | 2.33 | | | | | | |
| *Polygordius* | 7.88 | | | | | | | |
| *Bathyporeia elegans* | | | | | | 2.66 | 1.81 | 3.11 |
| *Ophelia borealis* | | 2.07 | 2.1 | | | 1.95 | | |
| *Protodorvillea kefersteini* | 3.96 | | | | | | | |
| *Glycera lapidum* | 3.56 | | | | | | | |
| *Magelona filiformis* | | | | 1.38 | 1.68 | | | |
| *Branchiostoma lanceolatum* | | 3.03 | | | | | | |
| *Tellina fabula* | | | | | | 1.39 | 1.03 | |
| *Urothoe poseidonis* | | | | 2.11 | | | | |
| *Lanice conchilega* | | | | 1.91 | | | | |
| *Echinocyamus pusillus* | | | 1.9 | | | | | |
| *Bathyporeia guilliamsoniana* | | | | 1.72 | | | | |
| *Nephtys cirrosa* | | 1.58 | | | | | | |
| *Spio filicornis* | | 1.41 | | | | | | |
| *Magelona johnstoni* | | | | | | | 1.23 | |

| Taxa | Group d | Group e | Group f | Group h | Group i | Group j | Group k | Group l |
|---|---|---|---|---|---|---|---|---|
| *Chaetozone christiei* | | | | | | 1.21 | | |
| NEMERTEA | | | | | | 1 | | |
| *Sigalion mathildae* | | | | | | | 0.95 | |

# Appendix 6 - Results of power analysis to support the investigative monitoring element of the survey design

**Table 24.** Results of power analyses using 'Species richness' (S) for proposed fishery closure zone 2260. Cells with a power value greater than or equal to 0.8 are highlighted in yellow, to show N values for each given level of change (%).

Management area D UK(2260)

| N | 5 | 8 | 11 | 14 | 17 | 20 | 23 | 26 | 29 | 32 | 35 | 38 | 41 | 44 | 47 | 50 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **10%** | 0.09 | 0.12 | 0.12 | 0.16 | 0.17 | 0.22 | 0.20 | 0.23 | 0.27 | 0.28 | 0.30 | 0.32 | 0.36 | 0.39 | 0.38 | 0.40 |
| **20%** | 0.18 | 0.25 | 0.34 | 0.43 | 0.51 | 0.53 | 0.62 | 0.67 | 0.73 | 0.77 | 0.80 | 0.85 | 0.87 | 0.88 | 0.90 | 0.94 |
| **30%** | 0.30 | 0.52 | 0.64 | 0.73 | 0.81 | 0.87 | 0.91 | 0.94 | **0.97** | 0.98 | 0.99 | 0.99 | 1 | 1 | 1 | 1 |
| **40%** | 0.52 | 0.70 | 0.84 | 0.93 | 0.96 | 0.98 | 0.99 | 0.99 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| **50%** | 0.65 | 0.87 | 0.95 | 0.99 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

**Table 25.** Results of power analyses using 'Species richness' (S) for proposed fishery closure zone 375. Cells with a power value greater than or equal to 0.8 are highlighted in yellow, to show N values for each given level of change (%).

Management area C UK( 375)

| N | 5 | 8 | 11 | 14 | 17 | 20 | 23 | 26 | 29 | 32 | 35 | 38 | 41 | 44 | 47 | 50 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **10%** | 0.08 | 0.11 | 0.13 | 0.14 | 0.17 | 0.19 | 0.20 | 0.23 | 0.27 | 0.29 | 0.31 | 0.33 | 0.32 | 0.37 | 0.42 | 0.41 |
| **20%** | 0.18 | 0.24 | 0.33 | 0.40 | 0.47 | 0.59 | 0.59 | 0.67 | 0.73 | 0.74 | 0.78 | 0.82 | 0.86 | 0.90 | 0.90 | 0.92 |
| **30%** | 0.32 | 0.46 | 0.60 | 0.74 | 0.80 | 0.86 | 0.91 | 0.94 | 0.96 | 0.98 | 0.99 | 0.99 | 0.99 | 1 | 1 | 1 |
| **40%** | 0.48 | 0.70 | 0.85 | 0.93 | 0.96 | 0.98 | 0.98 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| **50%** | 0.64 | 0.86 | 0.95 | 0.98 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

**Table 26.** Results of power analyses using 'Species richness' (S) for proposed fishery closure zone 1081. Cells with a power value greater than or equal to 0.8 are highlighted in yellow, to show N values for each given level of change (%).

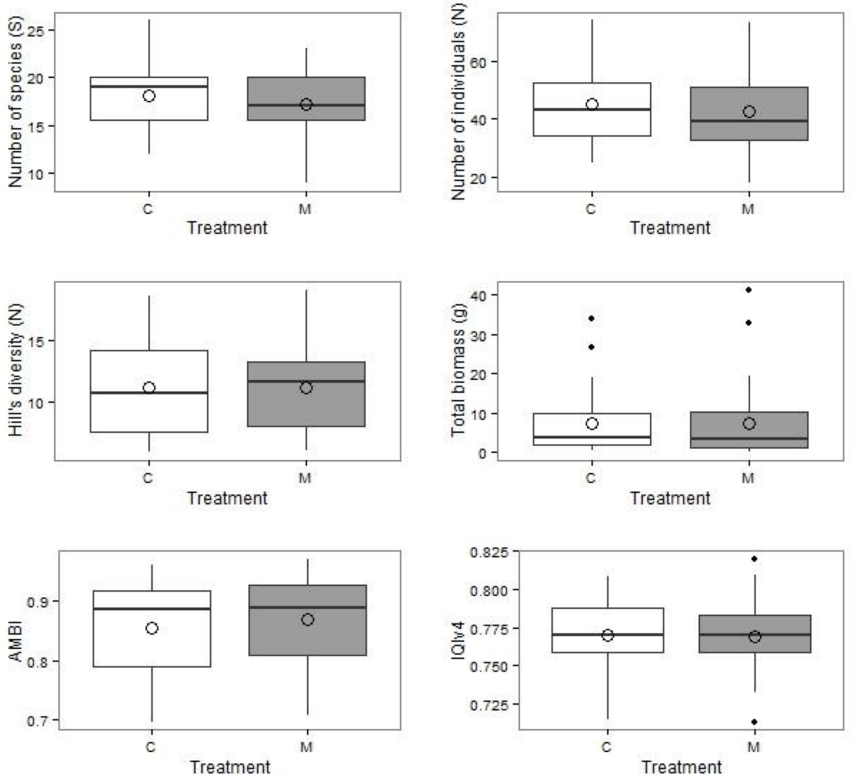
Management area B UK(1081)

| N | 5 | 8 | 11 | 14 | 17 | 20 | 23 | 26 | 29 | 32 | 35 | 38 | 41 | 44 | 47 | 50 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **10%** | 0.07 | 0.11 | 0.10 | 0.16 | 0.19 | 0.21 | 0.23 | 0.25 | 0.29 | 0.30 | 0.33 | 0.35 | 0.34 | 0.38 | 0.42 | 0.45 |
| **20%** | 0.19 | 0.28 | 0.36 | 0.43 | 0.50 | 0.61 | 0.65 | 0.72 | 0.74 | 0.78 | 0.83 | 0.88 | 0.88 | 0.90 | 0.93 | 0.93 |
| **30%** | 0.32 | 0.51 | 0.62 | 0.75 | 0.85 | 0.90 | 0.94 | 0.96 | 0.97 | 0.98 | 0.99 | 1 | 1 | 1 | 1 | 1 |
| **40%** | 0.51 | 0.75 | 0.88 | 0.94 | 0.97 | 0.99 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| **50%** | 0.68 | 0.88 | 0.97 | 0.99 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

# Appendix 7 - Box whisker plots and summary statistics

Investigative Monitoring: Infauna

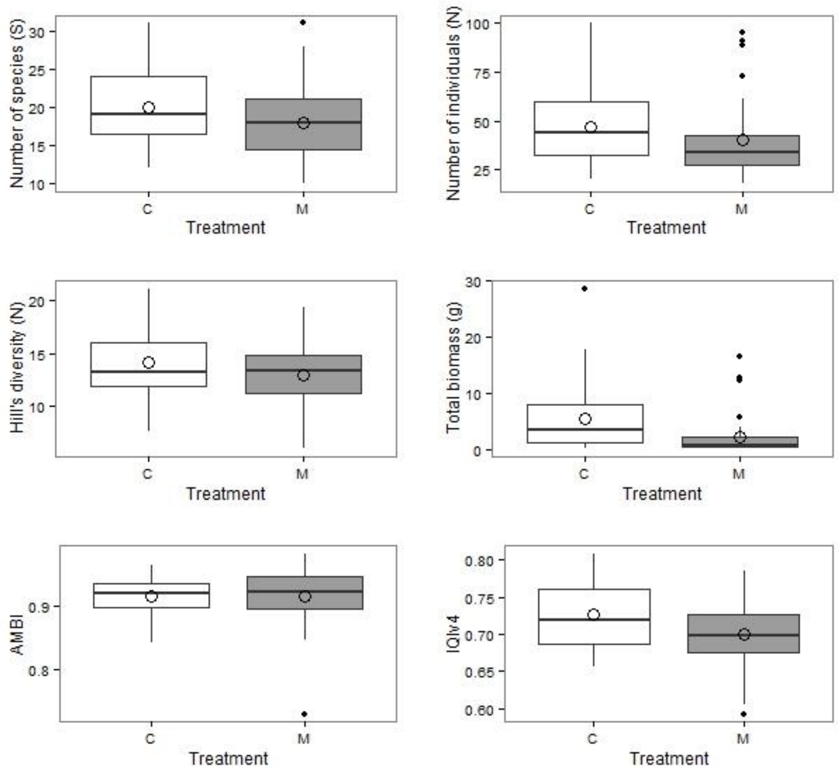
Comparison of univariate metrics between Impact (M) and Control (C) stations within Management area A.




| Control | S | N | Hill's | Total biomass (g) | EQR | AMBI |
|---|---|---|---|---|---|---|
| Range | 12 - 26 | 25 - 74 | 5.97 – 18.62 | 0.4206 – 33.9478 | 0.715 – 0.808 | 0.697 – 0.950 |
| Median | 19 | 43 | 10.74 | 3.8989 | 0.770 | 0.885 |
| Mean | 18 | 45 | 11.17 | 7.3898 | 0.770 | 0.855 |
| Variance | 12.26 | 171.22 | 13.28 | 59.89 | 0.0005 | 0.0068 |
| Standard deviation | 3.50 | 13.08 | 3.64 | 7.74 | 0.02 | 0.08 |

| Management (Impact) | S | N | Hill's | Total biomass (g) | EQR | AMBI |
|---|---|---|---|---|---|---|
| Range | 9 - 23 | 18 - 73 | 6.10 – 19.11 | 0.0666 – 41.3351 | 0.713 – 0.759 | 0.707 – 0.970 |
| Median | 17 | 39 | 11.64 | 3.4642 | 0.770 | 0.889 |
| Mean | 17 | 42 | 11.21 | 7.3792 | 0.769 | 0.870 |
| Variance | 10.56 | 180.67 | 11.25 | 84.4433 | 0.0005 | 0.0051 |
| Standard deviation | 3.25 | 13.44 | 3.35 | 9.1893 | 0.02 | 0.07 |

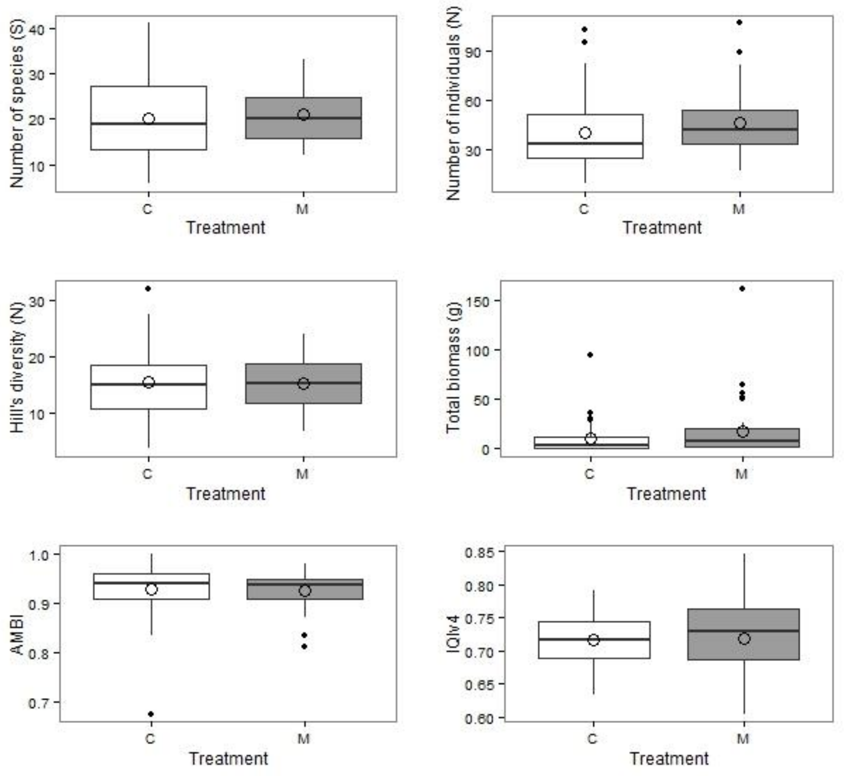
Comparison of univariate metrics between Impact (M) and Control (C) stations within Management area B.




| Control | **S** | **N** | **Hill's** | **Total biomass (g)** | **EQR** | **AMBI** |
|---|---|---|---|---|---|---|
| Range | 12 - 31 | 20 - 100 | 7.7 – 21.0 | 0.1205 – 28.6844 | 0.66 – 0.81 | 0.84 – 0.96 |
| Median | 19 | 44 | 13.2 | 3.3295 | 0.72 | 0.92 |
| Mean | 20 | 47 | 14.1 | 5.5643 | 0.73 | 0.92 |
| Variance | 24.02 | 333.42 | 10.03 | 37.49 | 0.0019 | 0.0009 |
| Standard deviation | 4.90 | 18.25 | 3.17 | 6.12 | 0.04 | 0.03 |

| Management (Impact) | **S** | **N** | **Hill's** | **Total biomass (g)** | **EQR** | **AMBI** |
|---|---|---|---|---|---|---|
| Range | 10 - 31 | 18 - 95 | 6.1 – 19.3 | 0.1186 – 16.6337 | 0.59 – 0.79 | 0.73 – 0.98 |
| Median | 18 | 34 | 13.3 | 0.5833 | 0.70 | 0.92 |
| Mean | 17.9 | 40.2 | 13.0 | 2.2995 | 0.70 | 0.92 |
| Variance | 24.58 | 395.11 | 9.56 | 14.96 | 0.0019 | 0.0022 |
| Standard deviation | 4.96 | 19.88 | 3.09 | 3.87 | 0.0440 | 0.0471 |

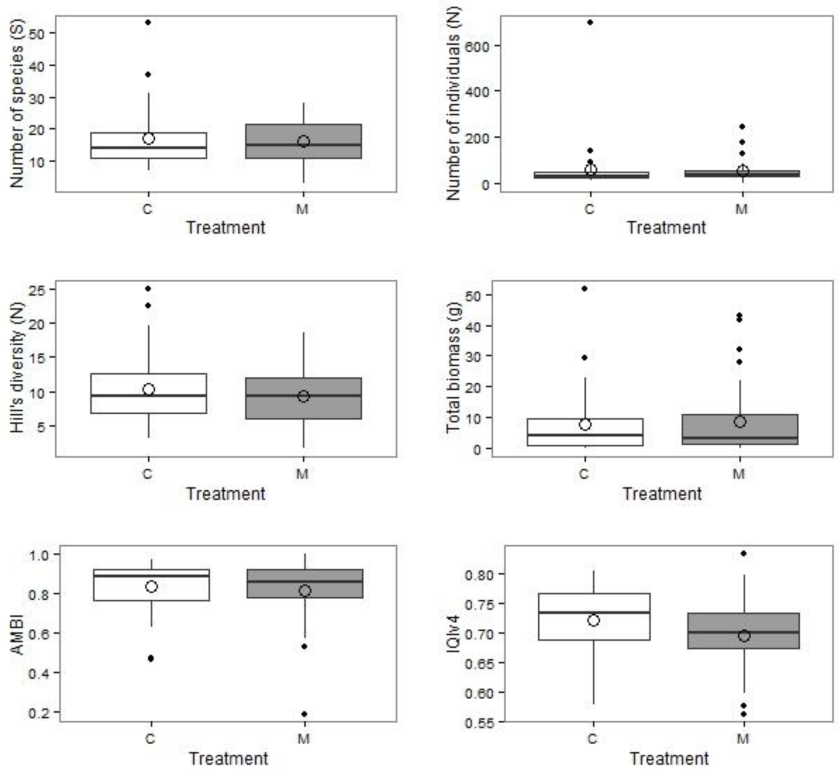
Comparison of univariate metrics between Impact (M) and Control (C) stations within Management area C.




| Control | **S** | **N** | **Hill's** | **Total biomass (g)** | **EQR** | **AMBI** |
|---|---|---|---|---|---|---|
| Range | 6 – 41 | 9 - 103 | 3.7 – 32.0 | 0.1181 – 94.0036 | 0.63 – 0.79 | 0.68 – 1.00 |
| Median | 19 | 33 | 14.9 | 3.0716 | 0.7164 | 0.9401 |
| Mean | 20 | 40 | 15.5 | 9.8485 | 0.7159 | 0.9278 |
| Variance | 89.88 | 518.31 | 45.26 | 294.21 | 0.0015 | 0.0030 |
| Standard deviation | 9.48 | 22.77 | 6.73 | 17.15 | 0.0392 | 0.0550 |

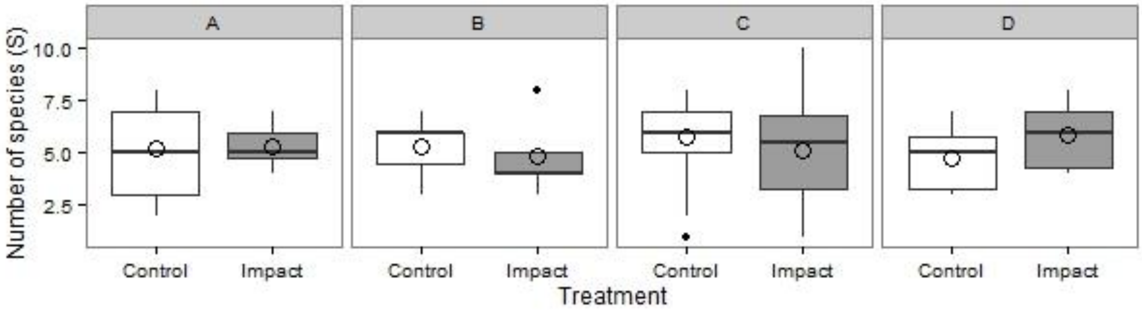
| Management (Impact) | **S** | **N** | **Hill's** | **Total biomass (g)** | **EQR** | **AMBI** |
|---|---|---|---|---|---|---|
| Range | 12 - 33 | 17 - 107 | 6.68 – 23.96 | 0.1284 – 161.4833 | 0.6044 – 0.8461 | 0.81 – 0.98 |
| Median | 20 | 42 | 15.29 | 7.1853 | 0.7294 | 0.9365 |
| Mean | 21 | 46 | 15.24 | 17.0612 | 0.7185 | 0.9255 |
| Variance | 35.16 | 413.29 | 17.24 | 858.71 | 0.0037 | 0.0013 |
| Standard deviation | 5.93 | 20.33 | 4.15 | 29.30 | 0.0610 | 0.0363 |

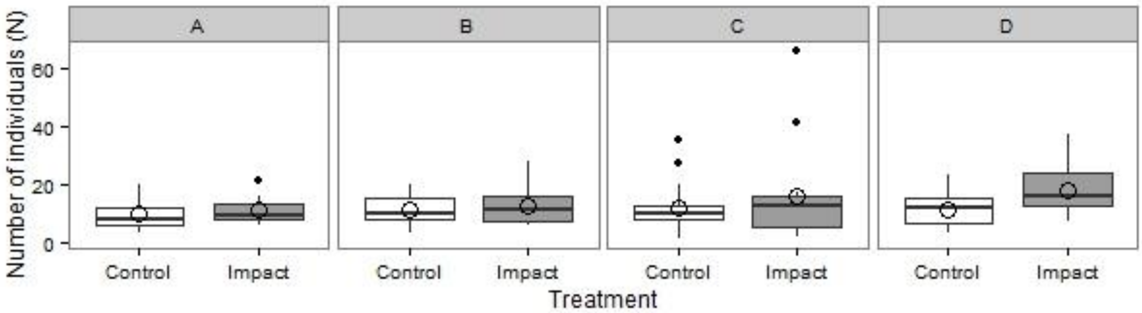
Comparison of univariate metrics between Impact (M) and Control (C) stations within Management area D.

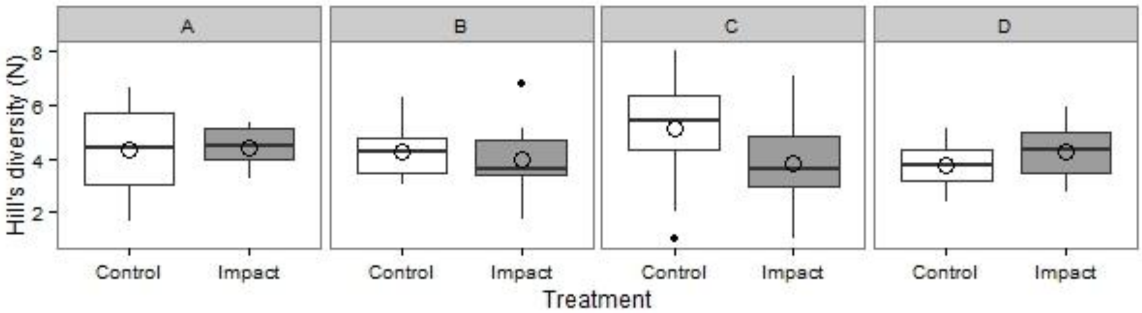



| Control | S | N | Hill's | Total biomass (g) | EQR | AMBI |
|---|---|---|---|---|---|---|
| Range | 7 - 53 | 14 - 692 | 3.2 – 25.1 | 0.1290 – 51.7532 | 0.58 – 0.81 | 0.47 – 0.97 |
| Median | 14 | 35 | 9.3 | 4.1385 | 0.73 | 0.88 |
| Mean | 17 | 61 | 10.3 | 7.9332 | 0.72 | 0.84 |
| Variance | 85.81 | 12736.10 | 26.39 | 109.66 | 0.0030 | 0.0160 |
| Standard deviation | 9.26 | 112.85 | 5.14 | 10.47 | 0.0551 | 0.1263 |

| Management (Impact) | S | N | Hill's | Total biomass (g) | EQR | AMBI |
|---|---|---|---|---|---|---|
| Range | 3 - 28 | 3 - 243 | 1.6 – 18.6 | 0.0612 – 42.9916 | 0.56 – 0.83 | 0.19 – 1.0 |
| Median | 15 | 38 | 9.3 | 3.5235 | 0.70 | 0.86 |
| Mean | 16 | 55 | 9.4 | 8.7295 | 0.70 | 0.81 |
| Variance | 37.37 | 2118.24 | 18.62 | 130.60 | 0.0038 | 0.0252 |
| Standard deviation | 6.11 | 46.02 | 4.32 | 11.42 | 0.0620 | 0.1587 |

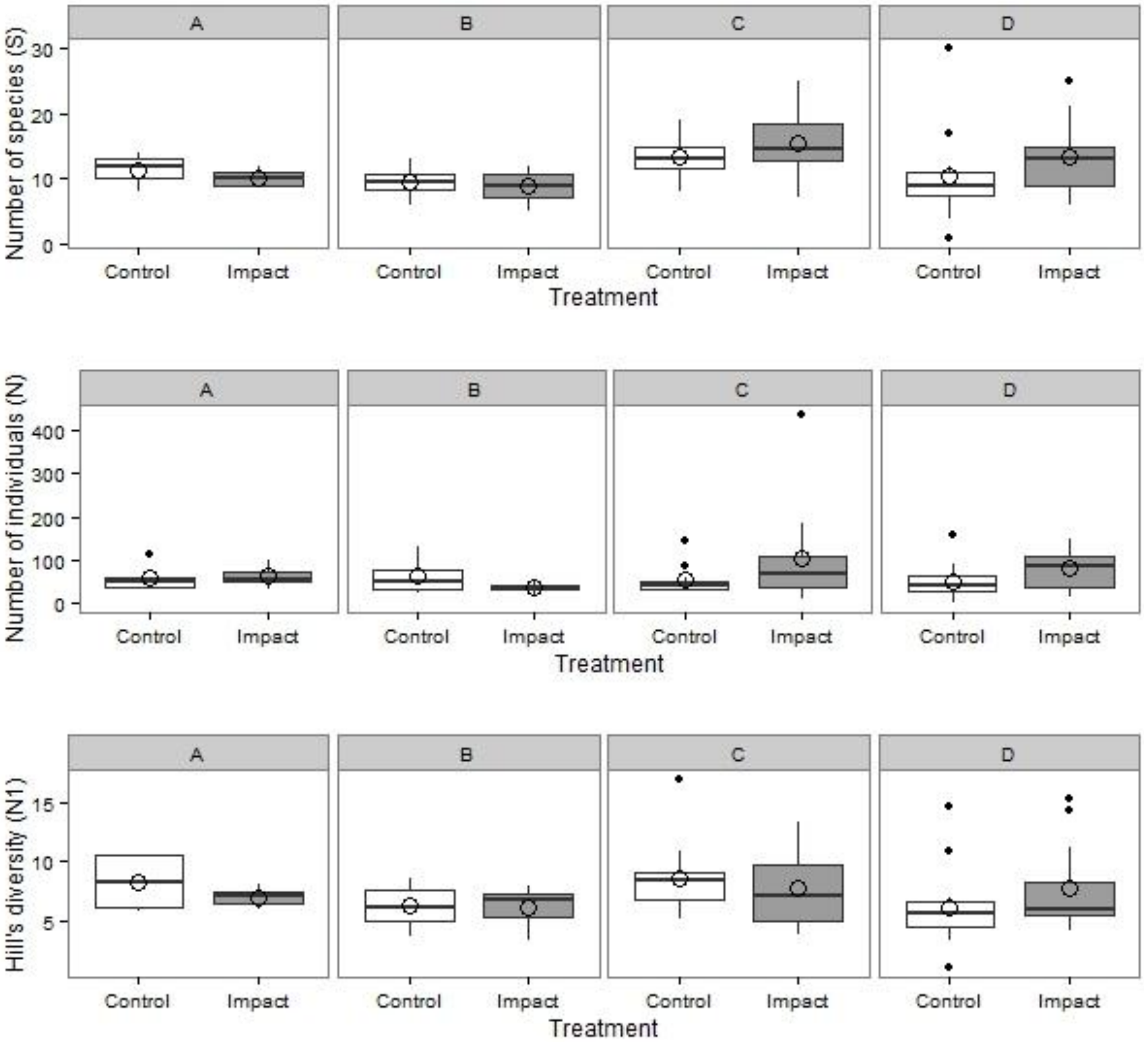

A
B
C
D
Number of species (S)
10.0
7.5
5.0
2.5
Control
Impact
Treatment


A
B
C
D
Number of individuals (N)
60
40
20
0
Control
Impact
Treatment


A
B
C
D
Hill's diversity (N)
8
6
4
2
Control
Impact
Treatment

| | | | | |
|---|---|---|---|---|
| **Management Area A** | **Control** | **S** | **N** | **N1** |
| | Range | 2 – 8 | 3 – 20 | 1.65 – 6.64 |
| | Median | 5 | 8 | 4.37 |
| | Mean | 5 | 10 | 4.36 |
| | Variance | 4.0 | 27.3 | 2.4 |
| | Standard deviation | 2.0 | 5.2 | 1.6 |
| | **Impact** | | | |
| | Range | 4 - 7 | 6 - 21 | 3.21 – 5.35 |
| | Median | 5 | 9 | 4.48 |
| | Mean | 5 | 11 | 4.42 |
| | Variance | 1.2 | 19.4 | 0.6 |
| | Standard deviation | 1.1 | 4.4 | 0.8 |
| **Management Area B** | **Control** | | | |
| | Range | 3 - 7 | 3 - 20 | 3.00 – 6.26 |
| | Median | 6 | 10 | 4.22 |
| | Mean | 5 | 11 | 4.27 |
| | Variance | 1.9 | 36.1 | 1.3 |
| | Standard deviation | 1.4 | 6.0 | 1.1 |
| | **Impact** | | | |
| | Range | 3 - 8 | 6 - 28 | 1.76 – 6.74 |
| | Median | 4 | 11 | 3.60 |
| | Mean | 5 | 13 | 4.00 |
| | Variance | 3.6 | 50.0 | 2.27 |
| | Standard deviation | 1.9 | 7.1 | 1.5 |
| **Management Area C** | **Control** | | | |
| | Range | 1 - 8 | 1 - 35 | 1.00 – 8.00 |
| | Median | 6 | 10 | 5.39 |
| | Mean | 6 | 12 | 5.12 |
| | Variance | 4.2 | 80.0 | 3.4 |
| | Standard deviation | 2.0 | 8.9 | 1.9 |
| | **Impact** | | | |
| | Range | 1 - 10 | 2 - 66 | 1.00 – 7.07 |
| | Median | 6 | 13 | 3.63 |
| | Mean | 5 | 16 | 3.84 |
| | Variance | 6.9 | 304.9 | 2.6 |
| | Standard deviation | 2.6 | 17.5 | 1.6 |
| **Management Area D** | **Control** | | | |
| | Range | 3 - 7 | 3 - 23 | 2.38 – 5.11 |
| | Median | 5 | 12 | 3.77 |
| | Mean | 5 | 11 | 3.77 |
| | Variance | 1.8 | 38.0 | 0.6 |
| | Standard deviation | 1.3 | 6.2 | 0.8 |
| | **Impact** | | | |
| | Range | 4 - 8 | 7 - 37 | 2.77 – 5.91 |
| | Median | 6 | 16 | 4.31 |
| | Mean | 6 | 18 | 4.27 |
| | Variance | 2.1 | 69.7 | 0.8 |
| | Standard deviation | 1.5 | 8.3 | 0.9 |

Investigative Monitoring: Epifauna assemblages: 2 m beam trawl
Comparison of univariate metrics between Impact and Control stations within Management areas A–D.



| | | | | |
|---|---|---|---|---|
| **Management Area A** | **Control** | **S** | **N** | **N1** |
| | Range | 8 - 14 | 37 - 114 | 5.80 – 10.53 |
| | Median | 12 | 48 | 8.20 |
| | Mean | 11 | 59 | 8.23 |
| | Variance | 5.8 | 1028.7 | 5.2 |
| | Standard deviation | 2.4 | 32.1 | 2.3 |
| | **Impact** | | | |
| | Range | 9 - 12 | 32 - 100 | 5.92 – 8.03 |
| | Median | 10 | 55 | 7.14 |
| | Mean | 10 | 62 | 7.00 |
| | Variance | 1.7 | 653.3 | 0.7 |
| | Standard deviation | 1.3 | 25.6 | 0.8 |
| **Management Area B** | **Control** | | | |
| | Range | 6 – 13 | 23 - 130 | 3.73 – 8.51 |
| | Median | 10 | 52 | 6.17 |
| | Mean | 10 | 62 | 6.21 |
| | Variance | 5.9 | 1593.5 | 3.4 |
| | Standard deviation | 2.4 | 40.0 | 1.8 |
| | **Impact** | | | |
| | Range | 5 - 12 | 15 -53 | 3.34 – 7.87 |
| | Median | 9 | 36 | 6.72 |
| | Mean | 9 | 36 | 6.17 |
| | Variance | 7.0 | 168.8 | 3.0 |
| | Standard deviation | 2.6 | 13.0 | 1.7 |
| **Management Area C** | **Control** | | | |
| | Range | 8 - 19 | 31 - 142 | 5.19 – 16.91 |
| | Median | 13 | 41 | 8.38 |
| | Mean | 13 | 53 | 8.64 |
| | Variance | 11.6 | 1118.9 | 10.0 |
| | Standard deviation | 3.4 | 33.4 | 3.2 |
| | **Impact** | | | |
| | Range | 7 - 25 | 12 - 437 | 3.83 – 13.35 |
| | Median | 15 | 66 | 7.01 |
| | Mean | 15 | 103 | 7.69 |
| | Variance | 28.6 | 13363.2 | 9.2 |
| | Standard deviation | 5.4 | 115.6 | 3.0 |
| **Management Area D** | **Control** | | | |
| | Range | 1 - 30 | 1 - 157 | 1.00 – 14.56 |
| | Median | 9 | 42 | 5.69 |
| | Mean | 10 | 50 | 6.14 |
| | Variance | 43.1 | 1437.3 | 9.9 |
| | Standard deviation | 6.6 | 38.0 | 3.2 |
| | **Impact** | | | |
| | Range | 6 - 25 | 13 - 148 | 4.22 – 15.28 |
| | Median | 13 | 86 | 5.88 |
| | Mean | 13 | 83 | 7.77 |
| | Variance | 31.9 | 1668.3 | 13.2 |
| | Standard deviation | 5.7 | 40.8 | 3.6 |

Cefas

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JNCC/Cefas Partnership Report Series. *Dogger Bank SCI 2014 Monitoring R&D Survey Report*, **No. 11**. Eggleton, J., Murray, J., McIlwaine, P., Mason, C., Noble-James, T., Hinchen, H., Nelson, M., McBreen, F., Ware, S. & Whomersley, P.
December 2016. ISSN 2051-6711