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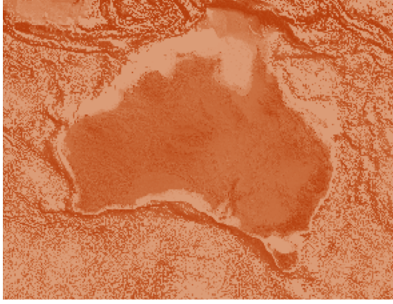

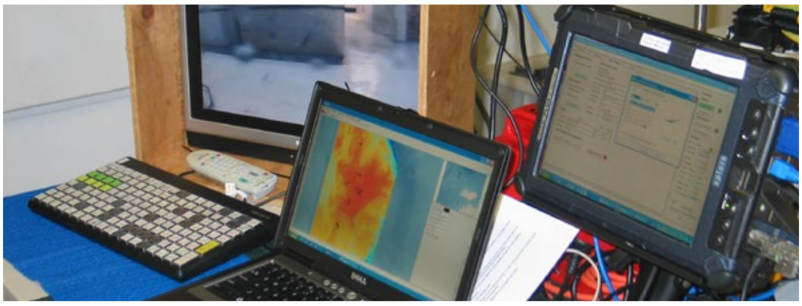

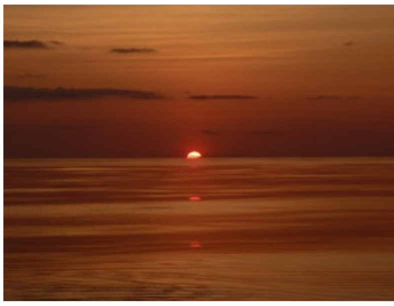

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Comparison of sampling methods to assess benthic marine biodiversity

Are spatial and ecological relationships consistent among sampling gear?

Emma Flannery and Rachel Przeslawski

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Contents

Executive Summary

Marine benthic biodiversity can be measured using a range of sampling methods, including benthic sleds or trawls, grabs, and imaging systems, each of which targets a particular community or habitat. Due to the high cost and logistics of benthic sampling, particularly in the deep sea, studies are often limited to only one or two biological sampling methods. Results of biodiversity studies are used for a range of purposes, including species inventories, environmental impact assessments, and predictive modelling, all of which underpin appropriate marine resource management. However, the generality of marine biodiversity patterns identified among different sampling methods is unknown, as are the associated impacts on management decisions.

This report reviews studies that have used two or more sampling methods in order to determine the consistency of their results among gear types, as well as the optimum combination of gear types. In addition, we directly analyse data that were acquired using multiple gear types to examine the consistency of biodiversity patterns among different gear types. These data represent two regions: 1) Joseph Bonaparte Gulf (JBG) in northern Australia, and 2) Icelandic waters as part of the Benthic Invertebrates of Icelandic Waters (BIOICE) program. For each dataset, we investigate potential patterns of biodiversity (measured by species richness, diversity indices, abundance, and community structure) in relation to environmental variables such as depth, geomorphology, and substrate.

Our synthesis confirms that the availability of worldwide data from benthic marine biodiversity surveys reporting the results of two or more gear types is generally poor. Surveys were concentrated in the coastal regions of UK, Norway and Australia, with limited or no studies elsewhere and only 13% including the slope or deep sea.

Our review of published literature and our analysis of datasets from two regions (northern Australia and Iceland) demonstrate there is little consistency in marine biodiversity trends between different gear groups, with only one study yielding consistent ecological patterns between sampling gear groups (imagery and epifaunal). This indicates that ideal gear combinations cannot easily be generalised among studies and regions. In addition, the lack of consistency between sampling gear groups highlights the need to analyse gear-specific data and avoid amalgamation. Even among gear that yielded relatively consistent ecological relationships, results varied across biological or environmental factors. Within a gear group, there are more consistencies in ecological relationships, with only two out of the eight studies compiled showing inconsistent ecological relationships

A lack of gear-specific studies precluded the determination of the optimal combination of gear types for a particular regions or environments. Nevertheless, based on our findings, we provide preliminary recommendations and inform further research: 1) If general biodiversity patterns are to be investigated, sampling for marine benthic surveys should be carried out using multiple gear types that are concurrently deployed; 2) Target measures of biodiversity need to be decided *a priori* and appropriate gear used; 3) Preliminary data will help determine the optimal combination of gear types used to sample that region and address a given hypothesis; and 4) If only two gear types are able to be deployed, a grab or corer should be one of them, as this sampling gear type samples a different habitat than other gear groups.

1 Introduction

1.1 Background

Biodiversity studies encompass a range of purposes, including species inventories, environmental impact assessments, and predictive modelling, all of which underpin appropriate marine resource management (Katsanevakis et al. 2011). For all of these purposes, data is collected from marine surveys to establish environmental baselines and to identify species and communities in the region. In addition, environmental data collected on marine surveys can reveal key environmental controls on biodiversity such as temperature, substrate type, topography and oxygen levels. An understanding of the links between these factors in turn allows an understanding of the processes that affect biodiversity through time and space. This in turn raises the prediction accuracy of biodiversity patterns in areas lacking biological data (Heap et al. 2010).

Marine benthic biodiversity can be quantified with a range of sampling equipment, including those designed to sample epifauna (sleds, trawls, and dredges) and infauna (grabs and boxcores), as well as non-invasive underwater imaging systems (Bergman et al. 2009). The large range of sampling gear available reflects the suitability of equipment for a particular environment and fauna. Sampling gear types differ in terms of the habitat targeted, major taxa sampled, desired spatial coverage and optimal substrate conditions (Buhl-Mortensen et al. 2012a). Research studies frequently incorporate only one of these sampling methods in published results, and the generality of marine biodiversity patterns identified among different sampling methods remains unknown.

Historically, our understanding of marine biodiversity has been limited due to logistical difficulties and the high costs involved in sampling, particularly in the deep sea and remote areas. An increased understanding of the limitations of sampling methods as well as the advent and application of new sampling methods has been responsible for paradigm shifts in marine ecology. For example, the late 1960s saw a change in sampling method from the anchor dredge to the epibenthic sled which revealed that biodiversity does not necessarily decline with depth (Hessler and Sanders 1967). The apparent lack of organisms in many deep marine environments was solely due to the lack of appropriate sampling methods to target the small macrofauna and meiofauna prevalent in deep-sea environments.

Biodiversity surveys of marine benthos generate the most accurate results when multiple sampling methods are used (Uzmann et al. 1977, Jorgensen et al. 2011). The deployment of multiple gear types is becoming more common (Clark and Rowden 2004, Colquhoun and Heyward 2008, Bowden 2011), but the optimal combination of sampling methods to accurately quantify biodiversity patterns remains unknown and likely varies among habitats and biological metrics. In addition, it is still common to collect or analyse biological data from only one sampling gear type, and management decisions can be made as a result of biological data collected from only one sampling method. The generality of ecological patterns among gear types therefore needs to be assessed.

1.2 Study Objectives

Marine management often focuses on areas of high diversity as indicated by numbers of species, abundance, or diversity indices, as well as representative communities as indicated by differentiation in regional community structure. To that end, this study investigates how ecological and spatial patterns of species richness, abundance, diversity, and community structure compare among sampling methods. The objectives of this study are to 1) Conduct a thorough review and synthesis of results from published studies that use multiple benthic sampling methods to analyse spatial or ecological relationship, 2) Perform discrete analyses of datasets collected from marine surveys on which multiple gear types were deployed.

Results will determine if broad scale biodiversity patterns are consistent among datasets derived from different sampling equipment and which combination of sampling gear provides the most reliable results for biodiversity assessments. It is hoped that this study will facilitate more informed decisions regarding the selection of biological sampling methods of marine benthic biodiversity surveys.

1.3 Benthic Sampling Gear

Each sampling gear type is associated with specific advantages and limitations (Jorgensen et al. 2011). The selection of sampling gear for marine benthic biota depends upon the required spatial extent and target organisms, with ‘trade-offs’ between taxonomic resolution, time and coverage (Bowden and Hewitt 2012). Optimal performance also depends upon substrate type, and acoustic mapping is thus useful prior to sampling to determine the most suitable sampling equipment for a given location (Clark and Rowden 2004).

Descriptions of the most frequently used equipment for remote and direct sampling of the marine benthic biota are outlined below. We also discuss the advantages and disadvantages of each gear type, biota targeted and extractable data types (i.e. richness, biomass, abundance, assemblages).

For the purposes of this report, gear type is defined broadly as epibenthic samplers (sled, trawls, dredges), infaunal samplers (grabs, boxcores), marine image systems, and other.

1.3.1 Epibenthic samplers (sleds, trawls, and dredges)

A benthic sled is comprised of a metal frame with an attached net that is trailing or encased within the frame (Figure 1.1a). In order to collect benthic organisms from the sediment water interface the sled is towed by a chain or wire along the seafloor for a predetermined distance and fauna are collected within the net (Blomqvist and Lundgren 1996). Sleds are employed when epibenthic organisms, such as mobile crustaceans or sessile sponges, are targeted (Bergman et al. 2009). However, they are less suitable for targeting very mobile organisms that are able to move out of the sled’s trajectory (Jorgensen et al. 2011).

A trawl consists of a rope or wire towing a metal frame with a large trailing net that glides over the sediment surface. Two commonly used trawls are: the beam trawl, a large trawl used by commercial fisheries, and the Agassiz or Blake trawl, a two-sided trawl that is able to collect samples regardless of the side which lands on the sediment (Eleftheriou and Moore 2005) (Figure 1.1b,c).

Areas of coarse and rocky substrate are not suitable for most sleds and trawls (Clark and Rowden 2004) and in these cases a dredge is usually required for sampling.

A dredge is sturdier than a sled or a trawl and has a heavy metal frame (Figure 1.1d,e). Samples of broken rock are collected and biota are able to be scraped off the hard substrate (Eleftheriou and Moore 2005). Large and uncommon infauna that reside in coarse sediments are commonly targeted using an anchor dredge (Kaiser et al., 2000).

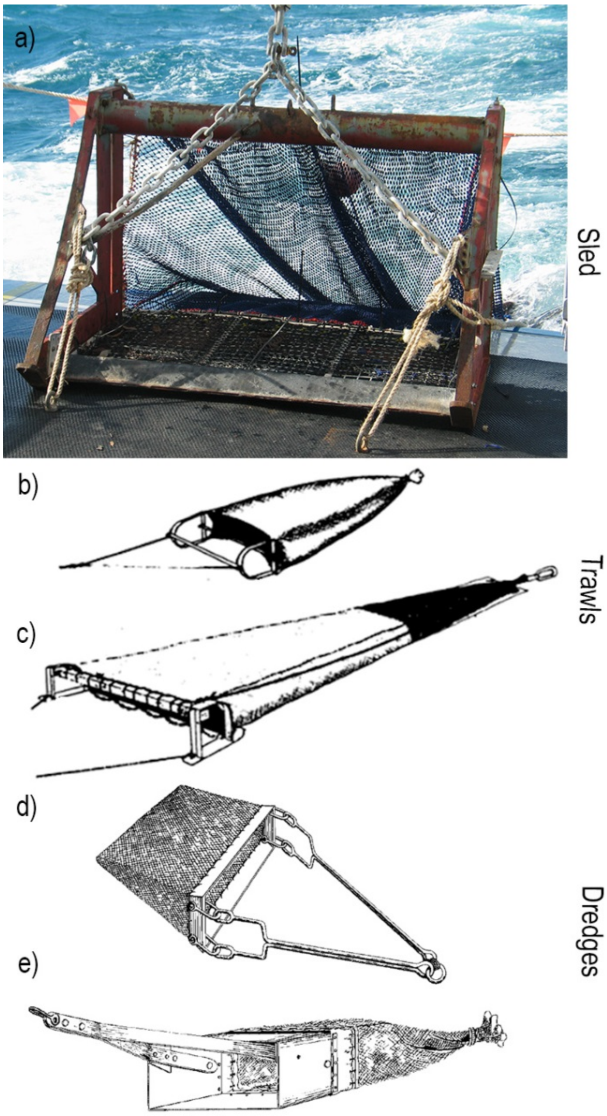

Figure 1.1 Examples of epibenthic samplers, including a) benthic sled, showing the metal frame, net, and towing chain; b) a double sided Agassiz trawl; c) wide beam trawl (Gage and Tyler 1991); d) naturalist's or rectangular dredge; and e) double sided anchor dredge (Eleftheriou and Moore 2005).

Benthic sleds and trawls are most advantageous when large spatial coverage is desired as they collect information over transects. Limitations of sleds and trawls is that they may skip over large sections of the sea floor, and do not give any indication of faunal distribution changes within the transect area (McIntyre 1956). As such, sleds are limited to providing qualitative data (Table 1.1).

Table 1.1 An assessment of sampling benthic biota using sleds, trawls, or dredges.

Advantages	Disadvantages
Targets large epifauna (except anchor dredge which targets infauna within coarse sediment), able to cover large area and sample organisms that are rare or widely dispersed	Qualitative, one haul covers a large area and fauna distribution within the haul area is unobtainable
Quick metrics able to be generated (richness, biomass)	Can be destructive
Transects conducive to broadscale inventories	Effectiveness based on substrate type and bathymetry (substandard on coarse substrate)
Allows species level and genetic analysis	Size of beam can cause collection bias in demersal fish populations (Rees et al. 1999)
Quick processing on deck	Can preferentially select larger particles and consequently attached species (Rees et al. 1999) and avoid cryptic or small fauna.
Covers large area	Very motile organisms can move out of the way (Jorgensen et al. 2011).

1.3.2 Grabs and boxcores

A grab is vertically lowered into the ocean from a stationary vessel and as it reaches the seafloor two facing containers are pulled shut, trapping sediment and biota inside (Gosling 2004) (Figure 1.2a). Grabs are mainly used to extract infauna (Bergman et al. 2009) and small sedentary epifauna (McArthur et al. 2010). They are not ideal for use on coarse grained sediments as the grains can prevent closure (Jorgensen et al. 2011) which results in sample loss and underestimation of the density or richness of taxa (Lozach et al. 2011). Certain types of grabs are also difficult to successfully deploy in consolidated muds as the grab jaws can not penetrate the cohesive materials to obtain a sample. Furthermore, larger organisms that are able to burrow deeply within the sediment are prone to abundance underestimation (Kendall and Widdicombe 1999), and widely dispersed or rare fauna are susceptible to being overlooked (McIntyre 1956). Most grabs disrupt sedimentary layers so that fragile organisms may be damaged, and this disturbance also precludes association of fauna to a particular sediment depth and/or layer.

A box corer is a coring device that allows for relatively undisturbed penetration of the sediment (Hessler and Jumars 1974) (Figure 1.2b). Consequently, biota can be analysed *in situ* and geochemical analyses undertaken within sedimentary layering. Several types of box corers are available for sampling including the Reineck box sampler, multibox corer and ISOS box corer, each sampling differing volumes of sediments and possessing differing closing mechanisms (Eleftheriou and Moore 2005, Gray and Elliot 2009).

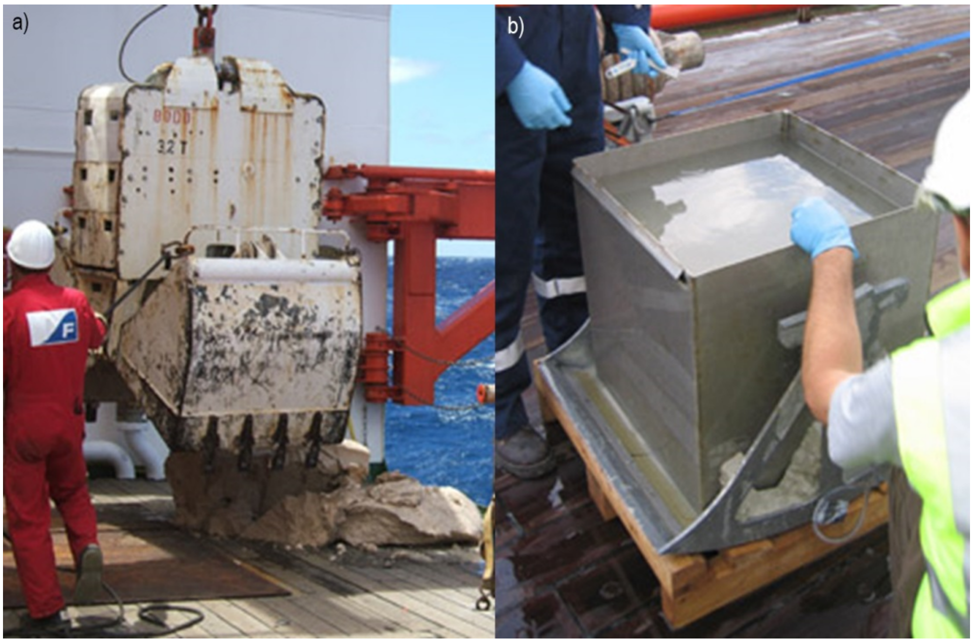

Figure 1.2 Examples of infaunal samplers, including a) a large grab used to extract sediment and biota from the seafloor (BODO grab from R.V. Sonne) and b) a box corer with enclosed undisturbed sample.

Grabs and boxcorers survey a single point so overall sampling coverage is far less than sleds, trawls or dredges. Data can be extrapolated between sites, but caution should be exercised in doing this as infauna and geochemistry can vary in sediments at very fine spatial scales (Drake, 1999; Przeslawski et al. 2013). Unlike data acquired from most epibenthic samplers, data acquired using grabs/box corers is quantitative (Table 1.2).

Table 1.2 An assessment of sampling benthic biota using grabs or boxcores.

Advantages	Disadvantages
Quantitative	Highly dependent on equipment/methods
Ability to detect fauna that is otherwise overlooked, i.e. targets infauna	Time consuming (sorting and identifying)
Allows species-level and genetic analysis	Limited data for broad spatial scales. Sampling unit can be too small for adequately characterising a complex region (Rees et al. 1999). Sample from small survey point may provide underestimate of environmental complexity (Rees et al. 1999).
Potential for co-located physical data, e.g. sediment type	Effectiveness based on sediment type, coarse sediments prevent closure of grab (Jorgensen et al. 2011).
Box corers allow for sampling of undisturbed sediment	Is a poor instrument for sampling rare or widely dispersed fauna (McIntyre 1956) (due to small area sampled).

1.3.3 Underwater Imagery

Underwater imagery systems can be stand-alone units or can be attached to epifaunal or infaunal sampling gear such as sleds or grabs. Types of stand-alone imagery systems include towed video (~1m above the substrate) (Ierodiaconou et al. 2011), remotely operated vehicles (ROV) (Lam et al. 2007) (Figure 1.3), baited remote underwater video systems (BRUVs) and autonomous underwater vehicles (AUV), where navigation is pre-programmed (Smith and Rumohr 2005).

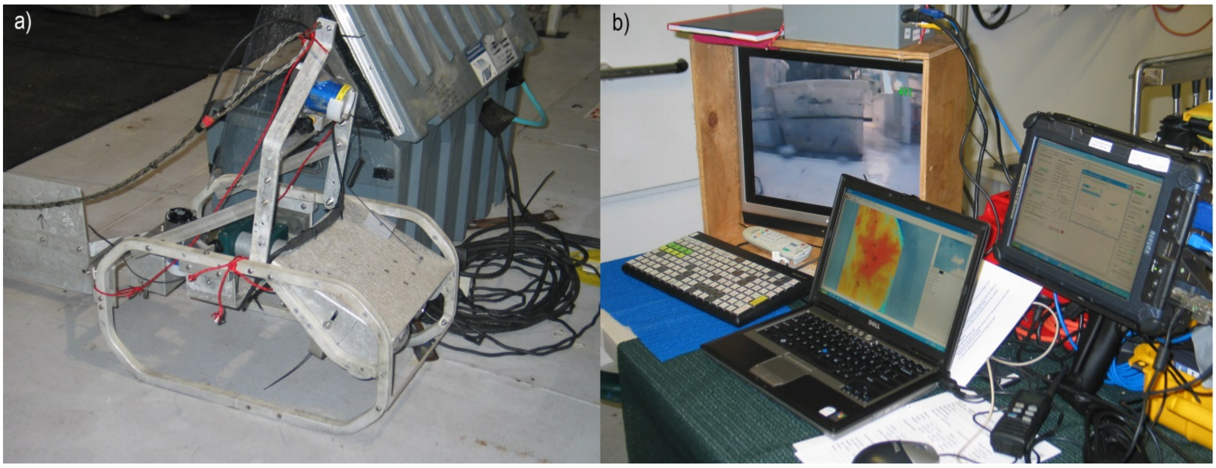

Figure 1.3 Example of marine imagery system, including a) underwater towed video system (Australian Institute of Marine Science) and b) onboard video and georeferencing system in real-time.

Underwater imagery is a useful sampling method to use when non-destructive sampling methods and *in situ* information are desired. Underwater imagery is often the sole option where destructive methods are prohibited, such as in many marine protected areas (Lipej et al. 2003). A significant problem when using these methods is the variable data quality due to environmental conditions (i.e. turbidity) and the considerable difficulty in classifying higher-level biota. Due to the lack of biological specimens, species-level identifications are difficult and genetic analysis impossible with marine imagery systems. Furthermore, imagery systems such as BRUVs can alter fish behaviour, attract certain types of organisms including large predatory fish, and repel others (Watson et al. 2005, Seiler 2013). The use of ROVs may be associated with other problems including increased cost, limitations of sampling depth by the attached cable, instability of the ROV in rough waters and observer bias (Azis et al. 2012).

The introduction of a second camera that is positioned to allow stereoscopic vision, as well as the use of lasers, has improved accuracy and identification by permitting size estimates. Similarly, increased resolution in newly developed cameras has allowed for both cryptofauna and microfauna to be more accurately identified (Solan et al. 2003). Infauna are not able to be identified unless a sediment profile imaging (SPI) system is in place (Smith and Rumohr 2005). SPI systems provide a cross section of the sediment and sediment-water interface. Identified biota are usually limited to shallow infaunal organisms, however physical and chemical characteristics, such as grain size and redox area, can also be determined (Rhoads and Germano 1982). Forms of acquired data include epifaunal richness, assemblages, substrate type, percent cover of taxa, and presence of key taxa. The benefits and disadvantages of using underwater imagery sampling are outlined in Table 1.3. In comparison with physical sampling from sleds, grabs and similar equipment, the collection of marine imagery offers a less destructive method but generally yields lower-resolution data.

Table 1.3 An assessment of sampling benthic biota using underwater imagery.

Advantages	Disadvantages
Range of metrics can be measured	Highly dependent on video system and water column conditions
Association of *in situ* physical data with biological	Species level identification challenging
Non-destructive, *in situ*, observations	Not supportive of genetic analysis
Can perform repeated sampling at precisely the same location (Smith and Rumohr 2005).	Potential observer bias
Transects conducive to broad scale inventories	Baited systems can alter fish behaviour (Seiler 2013)
Towed video allows for speedy sampling and concurrent analysis (Seiler 2013)	Towing video over uneven seafloor can cause Inconsistent sampling space
Archived video for repeat analysis using multiple observers	Stability issues and low resolution

1.3.4 Suction Samplers

Suction samplers are tubes that use suction to either penetrate the substrate or extract sediment into an overlying tube (Hopkins 1964). These systems can either be diver operated or remotely operated, but most suction samplers are only suitable for use in shallow and relatively calm waters (Eleftheriou and Moore 2005). They are valuable for sampling in coarse sediments and for obtaining deep burrowing biota, but their use may artificially increase abundance data where surrounding biota are sucked into the sampling area (Munro 2005) (Table 1.4). Furthermore, sedimentary layering is not preserved.

Table 1.4 An assessment of sampling benthic biota using suction samplers.

Advantages	Disadvantages
Obtains infaunal biota	Generally only used in shallow water
Penetrating suction samplers leave sediment relatively undisturbed	Fragile sedimentary structures often not preserved
Useful for coarse sediments, where grabs or corers would have difficulty penetrating	Generally only small samples
Useful for obtaining large deep samples, e.g. deep burrowing megafauna	Animals from surrounding areas may be suctioned in, artificially increasing abundance estimates
	Biota can be damaged by suction action

1.3.5 Direct Sampling

If water depth, environmental conditions, and logistics allow, specimens can be collected directly by walkers, swimmers or divers. Direct sampling is particularly useful in areas of high biodiversity and shallow or intertidal waters. For shore surveys, the Riley push-net can be used to collect fast, active biota. For both shore and shallow water surveys, square frames (quadrats) placed upon the substrate can be used as boundaries in which organisms can be counted and surveying can also be completed by the use of a transect (Eleftheriou and Moore 2005). Divers can undertake written, audio, photographic or video recordings of benthic biota, as well as collecting specimens (Munro 2005) (Table 1.5).

Table 1.5 An assessment of direct sampling of benthic biota.

Advantages	Disadvantages
Can be non-destructive	Limited by depth and conditions
Quantitative data can be collected	Risk of collector/observer bias
Sampling design flexible and able to be changed mid-transect	Requires diver certification and workplace safety considerations
	Positional accuracy is poor compared to USBL or ship nav systems used in other sampling techniques.

1.4 Sample Processing

As described in the previous section, the selection of sampling equipment can affect sampling results. Other causes of sampling bias in marine surveys include the treatment of the sample once retrieved. For example the sieve size used for elutriation (the washing of sediment to remove biological material) selects for biota above a certain size. Diversity indices can also be affected by post-sampling methods; for example, evenness decreases at sieve sizes below 1.00 mm (Gage and Bett 2005).

Different identification methods can also produce bias. Organisms can be sorted to species level or via an operational taxonomic unit (OTU), where morphospecies are grouped. Without expert taxonomic knowledge, misidentification problems can occur both with juveniles and sexually dimorphic species, and this can result in an overestimation of species richness. On the other hand cryptic species that look almost identical or species that closely related are often misidentified as a single species, which can result in an underestimation of species richness.

1.5 Quantifying and analysing biodiversity

Diversity can be quantified and compared using richness, diversity indices, or species assemblages. Diversity indices use the number of taxa present in an area and their relative proportionality to produce a single number, which can then be compared between sites (Magurran 2004).

Common univariate metrics for biological data are taxonomic richness, Shannon’s diversity index, Simpson’s diversity index, and species evenness. These data are often analysed using a range of statistical tests, including analysis of variance (ANOVAs), regressions, and correlations.

The most common metric for multivariate analyses is a species matrix. Often related to species composition and community structure, these matrices can include the abundance, biomass, or presence/absence of species. Coarser taxonomic groups (e.g. family) or functional groups can also be used instead of, or in addition to, species. These data are most often analysed using analysis of similarities (ANOSIM), ordinations (e.g. principal component analysis, multidimensional scaling plots) (Pearson 1901), canonical correspondence analysis (Gotelli and Ellis 2004), permutational analysis of variance (PERMANOVA) (Anderson 2005), or distance-based linear models (Anderson et al. 2008).

2 Methods

2.1 Literature Review

Survey results were retrieved via electronic searches of published literature from the databases ‘Web of Science’ and ‘ScienceDirect’ using the following terms of search: ‘benthic biodiversity’, ‘benthic sled trawl’, ‘benthic video sled’, ‘benthic sled grab’, benth* *diversity *sled*, benth* *diversity trawl*, with asterisks denoting root word searches. Searches of unpublished reports, government reports and theses were also undertaken, and relevant references cited in these publications were inspected. Finally, an email requesting data from relevant surveys was circulated among researchers of the National Environmental Research Program (NERP) Marine Biodiversity Hub.

In order to be included in the review the studies were required to meet the following criteria:

- Multiple gear types were used in a benthic biodiversity survey.
- Diversity or abundance were related to an environmental variable (i.e. relationship between biotic and abiotic factors).
- Results were analysed in a gear-specific manner.

2.2 Data analysis

The literature review and associated contact with authors yielded two datasets appropriate for use in the second component of this study. These two datasets are analysed to determine 1) the differences between sampling gear groups (sled/trawl/dredge vs grab vs imagery) and 2) the differences within a sampling gear group (sled vs trawl vs dredge).

2.2.1 Dataset 1 (comparison between sampling gear groups)

The first dataset was collected on two surveys within the Joseph Bonaparte Gulf (JBG) (SOL4934 (Heap et al. 2010)) and 2010 (SOL5117 (Anderson et al. 2011a)). The data include a variety of univariate and multivariate metrics from sled, grab and video (Table 2.1). Video was used to analyse both epifauna and *Lebensspuren* (traces of organisms in sediments, including trails and tracks (Häntzschel 1962)). Biological variables include richness, Shannon diversity index (H’), abundance, and assemblages, although these were not available for all gear types (Table 2.1). Environmental variables include depth, latitude, longitude, backscatter, and geomorphology. Backscatter measures seabed acoustic reflectance and is used as an estimate for the hardness of substrate; the more negative the value, the softer the substrate. Descriptions of the acquisition or derivation of these variables can be found in associated post-survey reports (Heap et al. 2010, Anderson et al. 2011b).

Table 2.1 *Biological variables determined for each gear type in data from the JBG.*

	Sled	**Grab**	**Video (epifaunal)**	**Video (Lebensspuren)[1]**
Richness	✓	✓	✓[2]	✓
H’		✓	✓	✓
Abundance		✓	✓	✓
Assemblage	✓[4]		✓[3]	

[1] Literally ‘life traces’, sedimentary structures formed by macrofauna (e.g. mounds, burrows), [2] For each station standardised epifaunal richness was calculated based on the average number of broad taxonomic groups (e.g. sponges, brittle stars etc) per 15 second video characterisation, [3] Based on presence of taxonomic groups per 15 second video characterisation. [4] Presence data of sponges.

2.2.1.1 Survey area

The Joseph Bonaparte Gulf (JBG) is a carbonate-dominated shelf located off north western Australia (Figure 2.1) (Lees 1992). Data analysed here are from two surveys undertaken within the JBG and adjacent Timor Sea: SOL4934 during August and September 2009 (Heap et al. 2010) and SOL5117 (Anderson et al. 2011a) during July and August 2010. Both surveys were undertaken in collaboration with the Australian Institute of Marine Science and the Museum and Art Gallery of the Northern Territory, and they targeted similar biological and physical data using the same gear and methods.

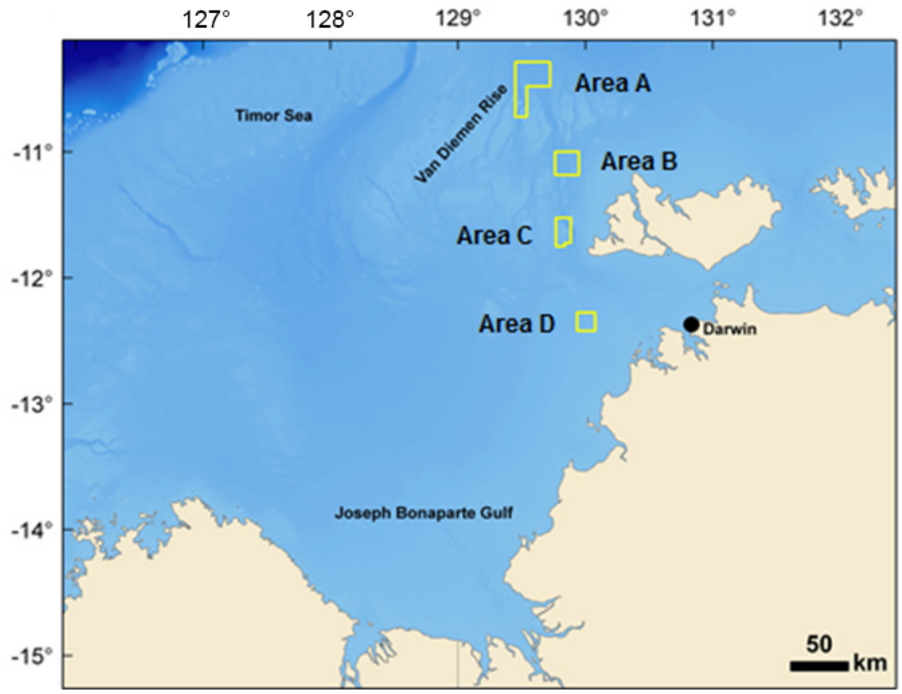

Figure 2.1 Location of the survey areas within the Joseph Bonaparte Gulf from which Dataset 1 was collected.

2.2.1.2 Geomorphic features

High-resolution bathymetric grids were used to map the geomorphic features of the study area at a local scale, which provided a detailed understanding of geomorphology of the area (Figure 2.2). The seabed was characterised into five geomorphic units: banks, terraces, ridges, plains and valleys. Biological and physical characteristics of each geomorphic feature can be found in Przeslawski et al. (2011).

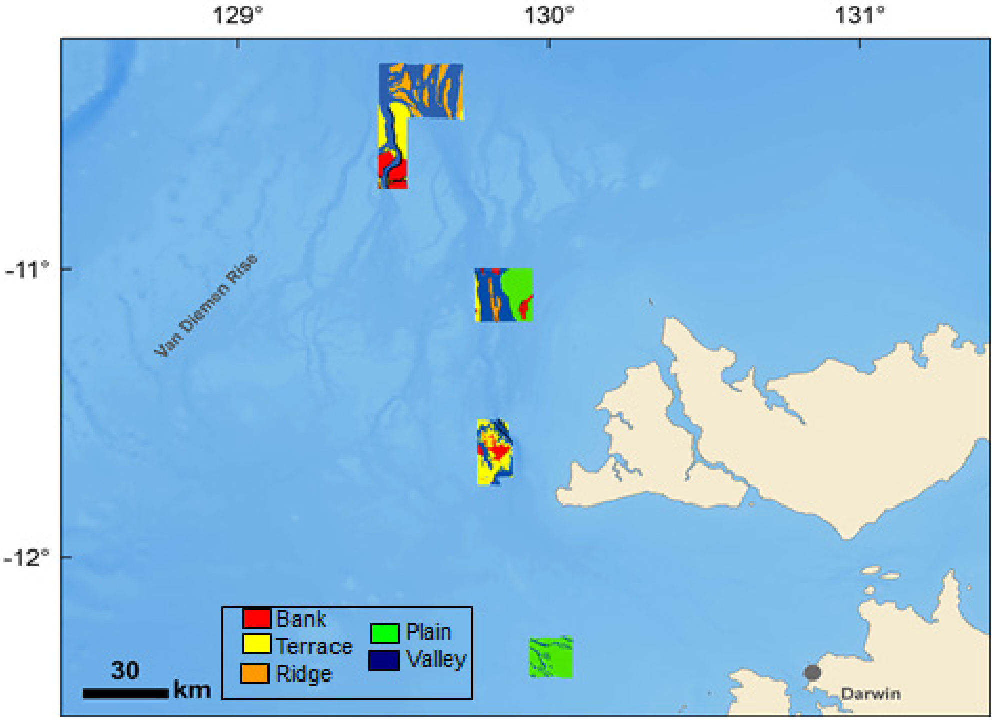

Figure 2.2 Geomorphic features of the survey areas within the Joseph Bonaparte Gulf from which Dataset 1 was collected.

2.2.2 Dataset 2 (comparison within a sampling gear group)

The second dataset is composed of amphipod species (ampeliscids) that were collected around the coast of Iceland between 1991-2004, using either a trawl, sledge or dredge (all epifaunal samplers). The data were collected as part of the BIOICE (Benthic Invertebrates of Icelandic Waters) program (Sigvaldadóttir et al. 2000a, Omarsdottir et al. 2013) which aimed to better understand the effects of environmental variables on biodiversity in Icelandic waters. Biological variables include richness, Shannon diversity index (H'), and abundance (Table 2.2). Environmental variables include depth, latitude and longitude.

Table 2.2 Biological variables determined for each gear type in data from the BOICE program

	Trawl	Sledge	Dredge
Richness	✓	✓	✓
H'	✓	✓	✓
Abundance	✓	✓	✓

2.2.2.1 Survey area

The marine area surrounding Iceland is of great interest due to the considerable variation in physical parameters such as depth and temperature (Sigvaldadóttir et al. 2000b). Furthermore, the exclusive economic zone within Icelandic waters is one of the most productive marine environments on Earth and of great importance to the economy of Iceland. Sampling for the BIOICE study was undertaken during 19 cruises between the years 1991-2004 around the coast of Iceland, in total 1412 samples were collected. Ten different gear types were used in sampling, however for this analysis only samples collected from the Agassiz trawl, Sneli sledge, RP sledge and Triangle dredge are analysed (Figure 2.3).

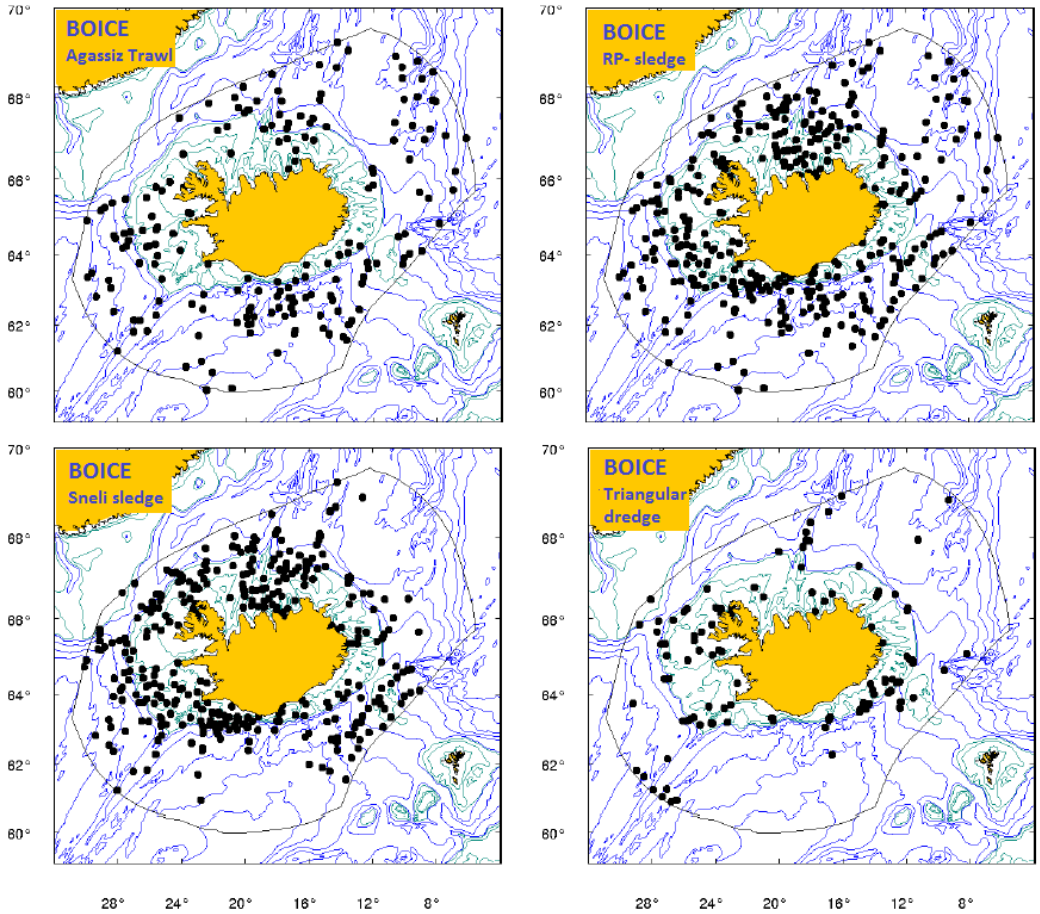

Figure 2.3 A map of Iceland showing the gear specific geographic distribution of collected samples.

2.2.3 Statistical Analyses

For both Dataset 1 and Dataset 2, univariate analyses were performed to investigate the relationships between environmental factors (geomorphology, depth, backscatter, latitude, longitude) and univariate biological factors (richness, H', abundance) collected from various gear types. Regressions were undertaken using depth, latitude, longitude, and backscatter. Single-factor analysis of variance (ANOVAs) were performed on dataset 1 to investigate the relationship between univariate biological variables and geomorphology where available for a given sampling gear type. ANOVA assumptions of normal distributions and homogeneous variances were tested using Shapiro-Wilk's and Levene's tests, respectively. Data were subsequently square-root or log-transformed to meet these assumptions. Significance was determined using a Bonferroni Corrected p value. For the Bonferroni Correction, the target alpha value (0.05) was divided by the total number of significance tests (32 in Dataset 1, 36 in Dataset 2), which resulted in a Bonferroni adjusted target alpha of 0.0016 for Dataset 1 and 0.0014 for Dataset 2. Univariate statistical tests were performed in Excel (MS Office 2010), with validation in the R statistical platform (version 3.0.0). Significant pairwise relationships were determined based on the Tukeys HSD tests performed in the R statistical platform.

For Dataset 1, multivariate analyses were performed to investigate the relationships between environmental factors (geomorphology, depth, backscatter, latitude, longitude) and assemblages collected from various gear types. Assemblages were defined for each gear type as follows:

1. Grab: the abundance and type of macrofauna collected in the grab identified to species (mollusc) and operational taxonomic unit (all other species), excluding worms and echinoderms for which identifications were unavailable.
2. Sled: the presence or absence of sponges in the sled identified to species
3. Video (epifaunal): the type and standardised abundance of sponge and octocoral morphologies as recorded from towed video
4. Video (*Lebensspuren*): the type and standardised abundance of *Lebensspuren* as recorded from towed video. To reduce the effect of dominant species, all assemblage data were square-root transformed except the sled assemblages since these were in presence/absence form.

For each assemblage, permutational analyses of variance (PERMANOVAs) were performed on geomorphological data, while the BIO-ENV procedure was used on depth, latitude, longitude and backscatter (Anderson et al. 2008). Multivariate statistical tests were performed in the statistical software PRIMER 6 + PERMANOVA.

3 Results

3.1 Literature Review

A total of 17 marine biodiversity studies met the criteria outlined in Section 2.1. These studies are listed below (Table 3.1), with each paragraph in this section describing a given survey or study with a focus on the particular gear types deployed and biological and ecological differences depending on gear types.

The 17 selected studies spanned the years 1990-2013. Published reports comprised 74% of the literature, with government reports and unpublished data comprising 13% and 13% of the literature respectively. Statistics used to determine how biological factors relate to environmental factors (such as depth, substrate type, dissolved oxygen etc.) varied considerably, and included generalised linear models (GLMs) and other univariate analyses, as well as gradient forest analysis (GF), generalized dissimilarity modelling (GDM), species distribution models (SDM), ordination methods such as TWINSPAN and DECORANA, and canonical correspondence analysis (CCA).

Table 3.1 List of all research reviewed, including location of study and sampling methods used. S=epibenthic/benthic sled, SP=SP-sledge, SS= Sneli Sledge, AT=Agassiz trawl, BT= beam trawl, ORT= orange roughy trawl, BOT= bottom otter trawl, D=Dredge, V=video, P=Camera G=grab, B= Box corer, C= Craib Corer M= Multiple box corer, DV= diver operated video, BUV= baited underwater video, UUV= unbaited underwater video, ROV= remotely operated vehicle, SSS= side scan sonar.

Source	Location	Variable	Multivariate Statistical Procedure (if applicable)	Sampling Methods	Results (Consistent or Inconsistent with each gear type)
(Compton et al. 2013)	Continental margins: Challenger Plateau and Chatham Rise, New Zealand	Topography/oceanographic complexity (tidal current speed, sea surface temperature, temperature residuals, bathymetry, slope productivity, particulate organic carbon flux and mixed layer depth)	Generalized dissimilarity modelling (GDM), Gradient forest analysis (GF and Species distribution models (SDM)	S, V	RESULTS: Inconsistent for SDM, Consistent for GDM and GF SLED: SDM (temperature residuals and bathymetry), GSM (temperature residuals & bathymetry), GF (temperature residuals and mixed layer depth) VIDEO: SDM (bathymetry and sea surface temperature) GSM (temperature residuals & bathymetry), GF (temperature residuals and mixed layer depth)
(Buhl-Mortensen et al. 2012a)	Continental shelf and slope, Tromsoflaket and Nordland/Troms area, Norway	Depth, habitat heterogeneity, substrate (fine scale mesohabitat10s m-1km and broad scale megahabitat 1-10s km)	Detrended correspondence analysis (DCA)	V, B, G, S, BT	RESULTS : Largely Inconsistent
(Basford et al. 1990)	Scottish, Norweigan and Danish Coasts (between 56o15'N and 60o45'N)	Sediment type and depth.	DECORANA and TWINSPAN	G, C, AT	RESULTS: Inconsistent (between gear types). Consistent (within gear types) GRAB and CORER: Diversity correlated with sediment characteristics and depth TRAWL: Diversity mainly correlated with depth
(Rees et al. 1999)	United Kingdom coastline and offshore (North Sea, English Channel and Celtic Seas)	Depth, tidal current velocity, temperature and sediment type	Primitive BIO-ENV procedure as described in Clarke and Ainsworth (1993)	G, BT	RESULTS: Inconsistent GRAB: Tidal current velocity and sediment type BEAM TRAWL: Multiple coastal influences, including sediment type, depth, tidal current velocity and temperature
(Ganesh and Raman 2007)	Bay of Bengal, northest India (between 16o and 20oN in shelf waters)	Depth, sediment texture, organic content, sea water temperature, salinity and dissolved oxygen.	Canonical correspondence analysis (CCA)	G, D	RESULTS: Inconsistent GRAB: Depth, salinity, temperature, depth and sediment characteristics (mean particle diameter and % sand) DREDGE: Depth and sediment characteristics (sediment organic matter, sediment mean size, % sand)

Source	Location	Variable	Multivariate Statistical Procedure (if applicable)	Sampling Methods	Results (Consistent or Inconsistent with each gear type)
(Currie et al. 2009)[1]	Great Australian Bight	Depth (including inner shelf vs shelf break etc), upwelling, latitude, longitude	Cluster analysis (ANOSIM and multidimensional scaling (MDS)) and BIO-ENV.	G	RESULTS: Inconsistent GRAB: Cluster analysis resulted in three infaunal assemblages robustly correlated with depth (☐ highest correlation was due to the combined physical variables of depth, % O2 saturation, chlorophyll concentration and latitude (☐w=0.27). Richness and abundance significantly correlated with latitude (pearson correlation coefficient r=-0.30 and r=-0.34 respectively) and longitude (r=-0.26 and r=-0.24 respectively) and positively correlated with increased oxygen levels (r=0.29 and 0.32 respectively) at the 5% level (and 1% level for abundance vs oxygen).
(Ward et al. 2006)2	Great Australian Bight	Depth, % mud sediments	Cluster analysis (ANOSIM and BIO-ENV	S	SLED: Cluster analysis showed six station epifaunal groupings correlated primarily with depth, as well as depth combined with % mud and longitude. Biomass was significantly correlated with % mud (r=-0.247, p<0.01) and depth (r=0.268, p<0.01) (using pearson correlation coefficients). PCA shows that crustacean biomass was positively correlated with % mud (r=0.488, p<0.005), porifera biomass negatively correlated with latitude (r=-0.301, p<0.01) and positively correlated with longitude (r=0.261, p<0.01).
(Williams et al. 2011)[2]	Lord Howe Rise and Norkfolk Ridge	Depth, temperature, salinity, hydrography, oxygen, silicate, phosphate and nitrate concentrations.	ANOSIM and non-metric Multidimensional Scaling (NMDS)	ORT T, BT, S	RESULTS : Inconsistent (with community analysis) SLED: Groups separated based on depth and nutrient variance TRAWL: Groups separated based on O2 levels and depth.

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[1] These two studies reported results from a single gear type from the same survey in separate reports.

[2] These studies are reporting from data obtained during the same survey.

Source	Location	Variable	Multivariate Statistical Procedure (if applicable)	Sampling Methods	Results (Consistent or Inconsistent with each gear type)
(Williams et al. 2006)3	Lord Howe Rise and Norkfolk Ridge	Depth, latitude, longitude	ANOSIM and BIO-ENV	ORT T, BT, S	RESULTS : Consistent with biodiversity patterns and Inconsistent with community structure SLED: For biodiversity patterns: Depth major environmental variable, followed by latitude and to a lesser extent longitude. For invertebrate community structure: weak correlation with depth and mean latitude (r=0.38,sig 0.1%) TRAWL: For biodiversity patterns: Depth major environmental variable, followed by latitude and to a lesser extent longitude. For invertebrate community structure: no clear correlation. For fish community structure: ORT- depth (r=0.574, 1% sig) for ANOSIM and depth (r=0.671) for BIO-ENV. And for Ratcatcher trawl- depth (r=0.835, 0.1% sig) for ANOSIM and depth (r-0.89) for BIO-ENV.
(Ellingsen et al. 2007)	Atlantic sector of Southern Ocean	Depth, longitude and latitude	Akaike's Information Criterion (AIC)	B, S	RESULTS: Inconsistent Box Corer: Depth (r2=0.59) SLEDGE: No correlation of species richness with depth and bell curve type correlation with highest species richness in the middle depths (r2=0.21).
(Watson et al. 2005)	3 locations in Hamelin Bay, south western Australia	High relief vs low relief	PERMANOVA	DV, BUV, UUV	RESULTS : Inconsistent DIVER VIDEO: 2nd highest # species and individuals in high relief areas only BAITED VIDEO: Significantly higher # species and individuals for both high and low relief areas UNBAITED VIDEO: 2nd highest # species and individuals in low relief areas only.
	Isle of Man, UK	Sediment size, sediment organic content, depth, weight of stones and weight of broken shell	ANOSIM and BIO-ENV	BT, D	RESULTS : Largely consistent BEAM TRAWL: BIO-ENV: Sediment size and depth correlated with biomass R= 0.49, p<0.001. ANOSIM: Habitat type and fishing intensity correlated with biomass R=0.34 p< 0.001 and abundance R=0.24, p<0.001. DREDGE: BIO-ENV: Sediment size and depth correlated with biomass R=0.32, p<0.001. ANOSIM: Habitat type and fishing intensity correlated with biomass R=0.16, p<0.5) but not abundance (R=0.09, p>0.05).

Source	Location	Variable	Multivariate Statistical Procedure (if applicable)	Sampling Methods	Results (Consistent or Inconsistent with each gear type)
(Barbera et al. 2012)	Continental shelf between 50-100 m in Depth (Balearic Islands, NW Mediterranean Sea, Spain)	Latitude, longitude, depth, grain size, organic matter, acoustic features of substrate (rugosity, consolidation, reflectivity, homogeneity/heterogeneity), benthic habitat classification, algal cover	RELATE and BIO-ENV	SSS, G/B, BT, P, ROV, BOT	RESULTS: Inconsistent BEAM TRAWL: Not significant correlations between environmental variables and diversity index. Significant correlation between the composition of the species and functional groups and the environmental variables (RELATE and BIO-ENV procedure). OTTER TRAWL and BEAM TRAWL: Dissimilarities in the total number of species, more evident for some taxonomic groups (e.g. algae, fish, crustaceans). VIDEO: No significant relationships between algal cover (camera and ROV images) and algal biomass (BT).
(Pitcher et al. 2007a)	Torres Strait	Sediment characteristics (grain size), dominating flora	N/A	V, S, T	RESULTS: Consistent SLED: Increase in species richness in areas of high density algal seagrass beds and stronger currents. Low species diversity occurred in areas on high mud and in some cases sandier areas. TRAWL: Patterns were comparable but less obvious.
(Pitcher et al. 2007b)	Great Barrier Reef	Depth, sediment characteristics (% mud, sand, gravel, carbonate), 20 physico-chemical parameters	N/A	V, P, BUV, S, T	RESULTS: Consistent SLED: High species richness in sled samples included areas of mixed-algal-seagrass beds and strong currents, low richness was associated with areas of high mud % and inshore areas Trawl: Patterns in trawl data were comparable but less obvious
Przeslawski, unpublished data (from SOL4934 and SOL5117)	Joseph Bonaparte Gulf, northern Australia	Depth, latitude, longitude, backscatter, geomorphology	PERMANOVA, BIO-ENV	S, G, P	RESULTS: Inconsistent See Section 3.2
Guðmundsson, unpublished data (from BIOCE)	Icelandic Waters	Depth, latitude, longitude	N/A	AT, D, SP, SS	Results : Consistent See Section 3.3

Compton et al. (2013) explored how changes in oceanographic complexity, including topographical changes, impacted benthic diversity in two areas of New Zealand. Two types of equipment, the epibenthic sled (1 m mouth width, 25 mm mesh net) and towed video system (deep towed imaging system, DTIS) were used to survey Chatham Rise and the Challenger Plateau. Both survey sites had similar depth ranges and latitudes but distinct oceanographic environments. The two sampling methods targeted larger biota >25 mm in size, with the sled more capable of sampling smaller organisms and allowing greater taxonomic resolution. Data from the epibenthic sled had greater Bray-Curtis dissimilarity values between sites in comparison to the video data. This resulted in discrepancies in their models and maps depending on the data source used (i.e. sled or video). Beta diversity was modelled with operational taxonomic units (OTUs) for each equipment type, using Generalized Dissimilarity Modelling (GDM) and Gradient Forest analysis (GF) (Table 3.2). The environmental variables that contributed most to community level modelling (GDM and GF) were the same in both the deep tow imaging system and the epibenthic sled (for GDM temperature residuals and bathymetry and for GF temperature residuals and mixed layer depth). However, the highest contributing environmental variable for species distribution models (SDM) differed depending on the gear type used, with bathymetry and sea surface temperature having a more substantial contribution for the DTIS and temperature residuals and bathymetry having a more substantial contribution for the epibenthic sled. Only 30% of total variation in the raw data was explained by models (based on environmental factors), which suggests other unmeasured variables including historical events and species interactions may play significant roles.

Table 3.2 Data from Compton et al. (2013) showing overall contribution (%) of environmental variables to the boosted regression tree (BRT) species distribution models (SDMs) and the community level modelling approached (GDM and GF) from the video and sled across Chatham Rise and Challenger Plateau.

	Deep Tow Imaging System	Epibenthic Sled
SPECIES DISTRIBUTION MODEL		
Temperature residuals	12	26
Mixed layer depth	12	10
Productivity	12	14
Bathymetry	22	15
Tidal current speed	8	8
Particulate organic carbon flux	12	7
Sea surface temperature	13	11
Slope	9	9
GENERALISED DISSIMILARITY MODEL		
Temperature residuals	19	14
Mixed layer depth	10	14
Productivity	12	3
Bathymetry	42	45
Tidal current speed	4	7
Particulate organic carbon flux	7	5
Sea surface temperature	0	0
Slope	5	12

	Deep Tow Imaging System	Epibenthic Sled
GRADIENT FOREST		
Temperature residuals	17	21
Mixed layer depth	17	17
Productivity	13	15
Bathymetry	13	10
Tidal current speed	9	10
Particulate organic carbon flux	9	9
Sea surface temperature	10	8
Slope	11	10

Buhl-Mortensen et al. (2012b) conducted an extensive survey as part of the MAREANO (Marine AREA database for Norwegian coast and sea areas) mapping programme to investigate benthic biodiversity trends off the North West Norwegian coast. Five survey sampling methods were employed to create habitat maps and determine diversity trends based on depth and habitat heterogeneity; underwater video, box corer, grab, epibenthic sled and a beam trawl. Video was deployed at every sampling station, while the grab, beam trawl and epibenthic sled were used at 25% of the stations. Different equipment was used to sample different biota: video was used to sample megafauna, both the grab and box corers were used to sample infauna, the beam trawl was used to sample epifauna and the sled was used to sample hyperfauna. The use of an extensive array of equipment allowed for the thorough characterisation of benthic faunal assemblages and identification of substrate type. For the video data, detrended correspondence analysis (DCA) was used to determine the relationship between assemblages and environmental variables. Spearman rank correlation showed that in general, along with depth, heterogeneity of the substrate was found to be an important variable for species richness. Areas of the sea floor with mixed sediment types were consistently found to have the highest benthic diversity. However the environmental factors that most contributed to variation in species richness, expected number of species, H', evenness, abundance and biomass, differed considerably depending on which equipment was used (and hence which biota type sampled).

Basford et al. (1990) also found that the distribution of infaunal and epifaunal communities collected by different sampling gear were controlled by different environmental factors. Over 5 years of data collected in the North Sea off the Scottish, Norwegian and Danish Coasts, were analysed for biodiversity trends. Three sampling methods were employed; Smith-McIntyre grab, Craib corer (samples sieved with 500µm mesh) and Agassiz trawl, with the grab and corer providing infaunal specimens and the trawl providing epifaunal specimens. Comparisons between fauna were undertaken using the ordination method DECORANA (Detrended Correspondence Analysis) and TWINSPAN (Two-Way Indicator Species Analysis). Community distributions determined by specimens collected by the trawl (epifaunal), grab and corer (infaunal) were shown to have differing controlling environmental factors that are complexly intertwined. The diversity and type of communities collected by the grab and corer were found to have a close association with sediment type (sediment granulometry) (axis 1-silt content, grain size and organic carbon, with depth as a less important factor), whereas changes in community structure of specimens collected from the trawl were found to correlate mainly with depth (axis 1, depth and sediment sorting, axis 2 only depth $p<0.05$). Specimens collected from each gear type were found to respond in dissimilar ways to changes in depth and sedimentology. Furthermore, the samples from the grab provided more quantitative and precise data than those of the trawl, and the trawl was unable to provide accurate sediment analyses due to the fact that multiple environments were accumulated in a single sample.

Rees et al. (1999) surveyed benthic populations over a broad geographic range using both a grab (to sample infauna) and a Lowestoft beam trawl (to sample epifauna). As part of the National Monitoring Program (NMP) of the UK, surveys were undertaken along the United Kingdom coastline to determine the major environmental and spatial controls on epifaunal and infaunal community distribution. Biota were identified to species level, and substratum type, tidal current strength, surface water temperature, depth and salinity were determined for each sample site. The association between infaunal community structure and environmental factors was ascertained using the method outlined in Clarke and Ainsworth (1993) (a precursor to the BIO-ENV procedure) and differed depending on the equipment used. The best correlation for infaunal communities collected with the grab (p_w=0.64) was produced by an amalgamation of 4 variables: maximum spring tidal current strength (0.41), median sediment diameter (0.40), longitude (0.18) and sorting coefficient (0.23). The best correlation for epifaunal communities collected with the sled (p_w=0.47) was produced by an amalgamation of 5 variables: winter temperature (0.26), log of depth (0.27), latitude (0.30), maximum spring tidal current strength (0.14) and sediment type (0.29).

Ganesh and Raman (2007) extensively characterised benthic faunal assemblages in the Bay of Bengal in northeast India using both a Smith-McIntyre grab to collect infauna and dredge (40 x 40 cm) to collect epifauna. They used canonical correspondence analysis (CCA) to determine the most influential environmental parameters on taxa distribution. Specimens collected using the grab and dredge had community distributions controlled by differing environmental factors. For specimens collected with the dredge (epifauna), depth (r=0.81) and sediment characteristics such as sand abundance (r=-0.50) and presence of organic matter (r=0.55) were the most controlling factors. However, for specimens collected with the grab (infauna), the most controlling factors were depth (r=0.88), salinity (r=-0.45), temperature (r=-0.44) and sediment characteristics such as mean particle diameter (r=-0.562). Results varied depending on the CCA axis, and all correlations were significant (p<0.05).

Currie et al. (2009) and Ward et al. (2006) reported on patterns of epifaunal and infaunal communities as related to environmental variables in the Great Australian Bight (GAB), one of the world's largest temperate carbonate shelfs. Ward et al. (2006) reported on the results of the specimens collected with an epibenthic sled (1.8 m wide, 0.6 m high, 50 mm mesh bag), and Currie et al. (2009) reported on the results of the specimens collected with a Smith-McIntyre grab, both of which were deployed on the same survey. For infaunal taxa, cluster analysis (using ANOSIM and BIO-ENV) resulted in three assemblages robustly correlated with depth (ρw=0.22). The highest correlation was due to the combined physical variables of depth, % O_2 saturation, chlorophyll concentration and latitude (ρw=0.27). Benthic species richness and abundance from the grabs were significantly negatively correlated (at the 5% level or 1% level in the case of abundance vs oxygen) with latitude (pearson correlation coefficient r=-0.30 and r=-0.34 respectively) and longitude (r=-0.26 and r=-0.24 respectively) and positively correlated with increased oxygen levels (r=0.29 and 0.32 respectively). For epifaunal taxa, cluster analysis showed six station groupings correlated primarily with depth (ρw=0.39) and depth combined with % mud and longitude (ρw=0.44). Epifaunal biomass from the sled was negatively correlated with % mud (r=-0.247, p<0.01) and depth (r=0.268, p<0.01) (using pearson correlation coefficients). Partial correlation analysis shows that crustacean biomass was positively correlated with % mud (r=0.488, p<0.005), porifera biomass negatively correlated with latitude (r=-0.301, p<0.01) and positively correlated with longitude (r=0.261, p<0.01).

Williams et al. (2011) and Williams et al. (2006) conducted extensive benthic surveys of seamounts of Lord Howe Rise and Norfolk Ridge to investigate the relationships between species distribution and environmental features, such as depth, temperature, topography, oxygen levels and seabed type. Biota were collected using several different trawls (two large demersal fish trawls, orange roughy trawl, full-wing bottom trawl) and epibenthic sleds. Williams et al. (2011) showed that the assemblage structure of samples was found to significantly differ between both sampling sites for both gear types (R=0.307, P=0.0001, two-way crossed ANOSIM). Furthermore, the two-way ANOSIM showed a significant difference between sleds and trawls across both regions (R=0.345, P=0.001), based on depth, variance in phosphates and silicates, or low oxygen (Figure 3.1). Williams et al. (2006) showed that invertebrate fauna were periodically dispersed with limited ranges and high endemism, a pattern prevalent in each separate gear type. Despite significant differences in community structure between gear types, biodiversity patterns were fairly consistent. Although gear types were highly preferentially selective for different inveterate phyla, consistent correlations were found with depth and to a lesser extent latitude and minimally longitude (i.e. between ridges). Similarly, fish biodiversity was found to be strongly related to depth and to a lesser extent latitude and even lesser longitude, with the two trawls (orange roughy and Ratcatcher trawl exhibiting similar trends). Analysis of data gathered from the beam trawl and orange roughy trawl resulted in no evident correlations and no differences between ridges and provided no clear groups. Fish data from both the orange roughy trawl and the ratcatcher trawl were associated with depth.

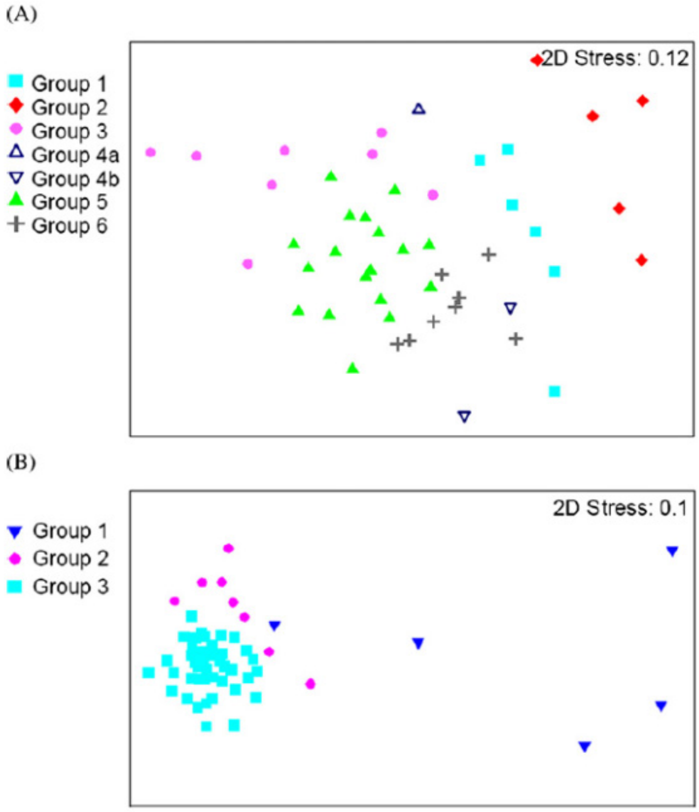


Figure 3.1 Non-metric multidimensional scaling plot (n-MDS) of A) sled and B) trawl data. Increasing distance between points indicates decreasing similarities between biological assemblages. Symbols relate to identified groupings from Linktree analysis derived from environmental covariates (reprinted from Williams et al., 2011).

Ellingsen et al. (2007) surveyed the Atlantic sector of Southern Ocean, within the Weddell and Scotia seas, to determine patterns of species richness of polychaetes, isopods and bivalves. Two sampling methods were used: a box corer to collect polychaetes and a sled to collect isopods and bivalves. Depth did not show consistent trends between the taxon groups and therefore gear types (Figure 3.2). Polychaete species richness was negatively correlated with depth, whereas isopods had maximum species richness in mid-range depths (2-4 km) and bivalves had no correlation. Neither the results from the multi boxcorer, nor the sled, showed any correlation with latitude or longitude.

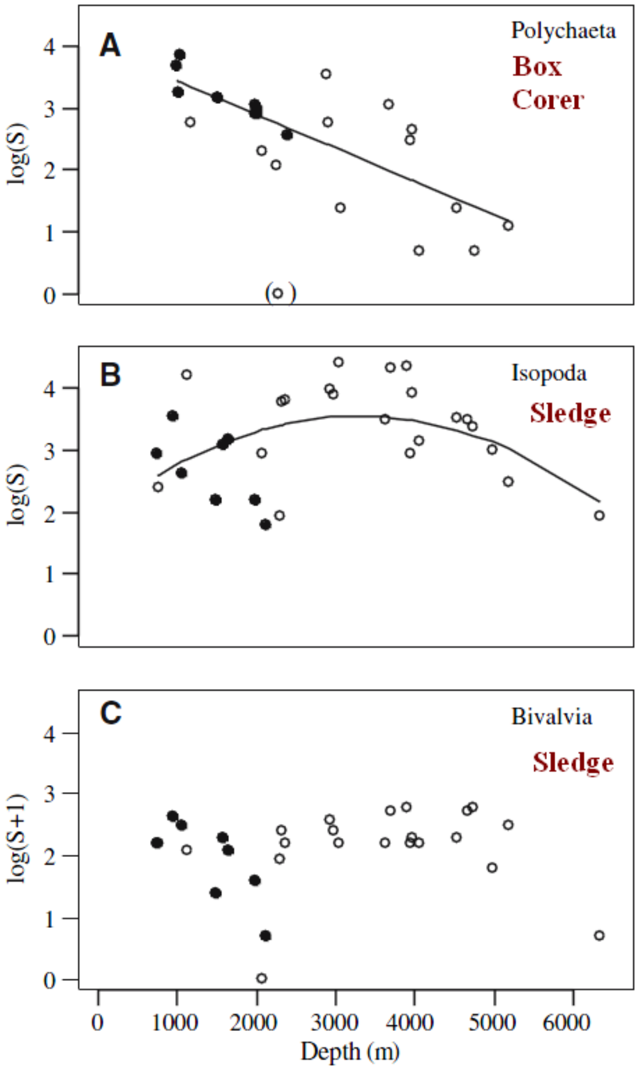


Figure 3.2 Species richness (S) compared to depth depending on taxa and sampling equipment used. A) R^2=0.59, b) R^2=0.21 c) n.s. (reprinted from Ellingsen et al. 2007)

Watson et al (2005) undertook demersal fish surveys in three locations in Hamelin Pool, Western Australia, representing two reef environments: high relief (crevices, caves etc.) and low relief (flat). Three underwater imagery methods were used to gather data: diver operated stereo-video strip transects, baited remote stereo-video and a baited remote stereo-video. The mean number of species and individuals in both high relief and low relief areas differed significantly depending on equipment type used (Figure 3.3) as well as relative abundance of certain fish species. Furthermore, depending on the equipment used, the influence of reef relief on faunal assemblage composition differed. The authors suggest that diver operated systems in low relief reef areas may have a larger impact on fish behaviour and remotely controlled techniques would have likely produced a more accurate representation of fish diversity.

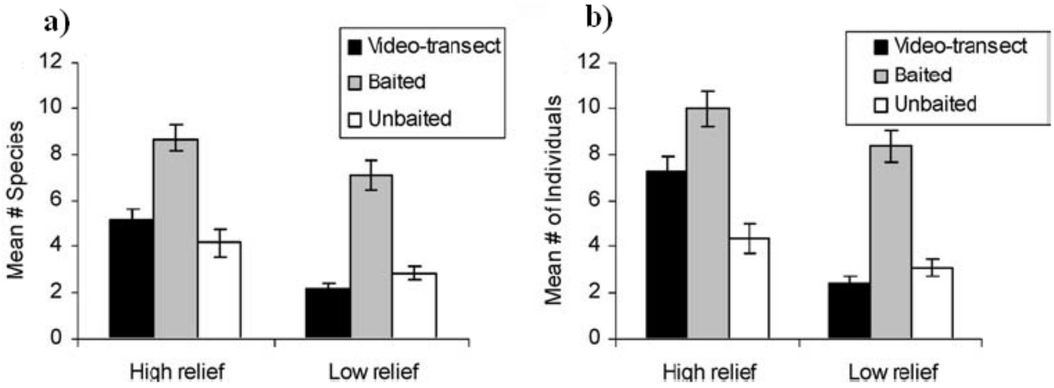


Figure 3.3 Mean (+/- SE) number of species a) and individuals b) recorded by the three equipment types at high and low relief reefs (reprinted from Watson et al. 2005).

Barbera et al. (2012) undertook a survey of the continental shelf between 50-100 m in Menorca Channel (Balearic Islands, NW Mediterranean Sea, Spain) to determine if abundance and diversity (richness, Shannon diversity and evenness) of species and functional groups changed with particular environmental factors, such as latitude, longitude, depth, grain size, organic matter, acoustic features of substrate (rugosity, consolidation, reflectivity, homogeneity/heterogeneity), benthic habitat classification and algal cover. Multiple sampling methods were used, including a grab, box corer, beam trawl, camera, remotely operated vehicle and a bottom otter trawl. Results between gear groups were generally dissimilar. Data from the beam trawl showed no significant correlations between environmental variables and diversity index (Pearson correlation); however, a significant correlation between species composition and functional groups and the environmental variables were found with data from the beam trawl (RELATE and BIO-ENV procedure). The best set of variables was determined to be depth, longitude, % mud and rhodolith biomass. There were difficulties in the use of the European Nature Classification System (EUNIS). Data from the otter trawl and beam trawl showed dissimilarities in the total number of species, which was more evident for some taxonomic groups (e.g.: algae, fish, crustaceans). Data from the sidescan sonar demonstrated the same acoustic features of substrate can correspond with more than one benthic habitat type defined from the beam trawl, camera and ROV. Data from the video showed no significant relationships between algal cover (camera and ROV images) and algal biomass (beam trawl).

Kaiser et al. (2000) undertook a benthic marine survey in the Isle of Man, UK, in order to determine how rigorous fishing in the area had affected benthic communities over time. Infaunal samples were collected using an anchor dredge (which is more efficient at infaunal sampling in areas of coarse sediment). The second sampling method used was a 2 m wide beam trawl to collect epifaunal specimens. Data from specimens of both types of equipment were individually analysed using PRIMER software and were clustered by means of the Bray-Curtis similarity index. BIO-ENV was then employed in order to determine the environmental variables that most controlled diversity (sediment size, sediment organic content, depth, weight of stones and weight of broken shell). BIO-ENV revealed that sediment size and depth at both sites was correlated with biomass for both gear types ($R=0.32$, $p<0.001$ for the dredge and $R= 0.49$, $p<0.001$ for the beam trawl). ANOSIM showed that that biomass and abundance were largely correlated with both habitat type and fishing intensity (ANOSIM for the trawl, abundance, $R=0.24$, $p<0.001$ and biomass, $R=0.34$ $p< 0.001$ and for the dredge biomass $R=0.16$, $p<0.5$). However abundance data from the dredge was not correlated with habitat type and fishing intensity ($R=0.09$, $p>0.05$).

Pitcher et al. (2007a) undertook a benthic marine survey of the Torres Strait Island ecosystems. Two main gear types were used, an epibenthic sled and a trawl (high-flying Floria Flyer net). Data collected by sled and trawl showed the same total species richness, but data from the sled was more variable. No statistics or correlations were reported in this study, just general trends. Clear patterns emerged in data from the sled, including an increase in species richness in areas of high density algal seagrass beds and stronger currents. Low species diversity occurred in areas on high mud and in some cases sandier areas. Patterns from trawl data were comparable but less obvious. Modelling and analysis were undertaken with amalgamated data.

Pitcher et al. (2007b) undertook a similar study of the continental shelf of the Great Barrier Reef using towed video and digital cameras, baited underwater video stations, epibenthic sled, and a trawl. They determined correlations between biological parameters (species, assemblage, diversity) correlations and environmental variables (depth, sediment characteristics (% mud, sand, gravel, carbonate), 20 physico-chemical parameters). Data collected by sled showed a larger species richness than that collected by the trawl, but the trawl was a more consistent sampler. High species richness in sled samples included areas of mixed-algal-seagrass beds and strong currents, while low richness was associated with areas of high mud % and inshore areas. Patterns in trawl data were comparable but less obvious. Modelling and analysis were undertaken with amalgamated data.

Przeslawski (unpublished data) collected samples from benthic surveys of Joseph Bonaparte Gulf (SOL4934 & SOL5117) in 2009 and 2010 using a sled, grab and camera. Abiotic variables included depth, latitude, longitude, backscatter and geomorphology (bank, terrace, ridge, plain and valley). The correlation between these abiotic variables and the biotic variables, species richness, H' and abundance, was determined. In general results were inconsistent between gear types (in terms of significant and same-trending correlations or similar pairwise relationships). Congruence between the results of all gear types was only present in geomorphology vs species richness and geomorphology vs abundance. An in-depth analysis of this dataset is presented in Section 3.2.

Guðmundsson (unpublished data) collected amphipods through the Benthic Invertebrates of Icelandic Waters (BIOICE) sampling program which undertook 19 cruises between 1991-2004 around the coast of Iceland (Sigvaldadóttir et al. 2000a, Omarsdottir et al. 2013). The abiotic variables depth, latitude and longitude were correlated with the biotic variables species richness, H' and abundance. Four different gear types were analysed, Agassiz trawl, Sneli sledge, SP-sledge and Triangular dredge. Results between gear types were mainly Consistent as all but two correlations between abiotic and biotic variables were significant. Only the Sneli sledge showed significant correlations in species richness and depth, and H' and depth. Both correlations were negative with R^2=0.07 and R2=0.10 respectively. An in-depth analysis of this dataset is presented in Section 3.3.

3.1.1 Assessment of geographic gaps

The availability of worldwide data from benthic marine biodiversity surveys reporting the results of two or more gear types is generally poor. In particular there are limited studies off the coast of North and South America and off the African coast, and there are no studies based in the east Mediterranean Sea. Studies are also lacking in the deep sea environments of the Pacific, Atlantic and Indian oceans (Figure 3.4). In some cases there are amalgamated data in these areas, but there are no available results reflecting discrete data collected from multiple gear types.

Surveys were concentrated in the coastal regions of UK, Norway and Australia (Figure 3.4). 87% of the studies represented continental coast shelf and 13% represented slope or deep sea regions.

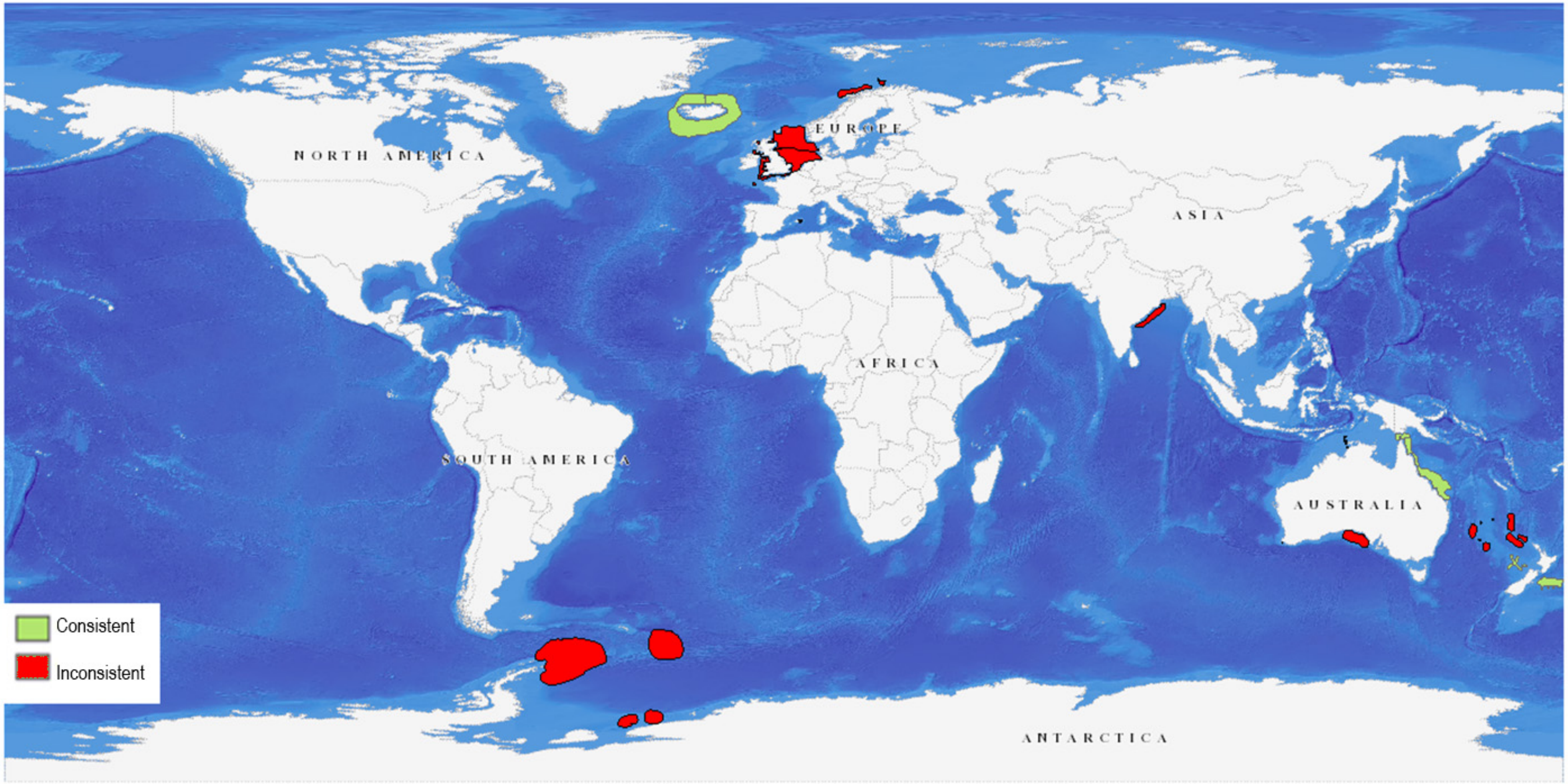


Figure 3.4 Map showing the location of all studies in this review, including colour-coded key of the results of the study in terms of consistent or inconsistent ecological patterns between gear types.

3.1.2 Consistency in ecological patterns

A summary of studies, including whether ecological patterns were consistent among datasets based on different gear types is shown in Table 3.3. Between sampling groups, the only study to yield consistent ecological patterns was between imagery and epifaunal sampling methods (sled, dredge, trawl) (Figure 3.5a). Unfortunately, there were insufficient numbers of studies to determine whether this was due to the actual gear being used or other factors not considered here (e.g. study region, substrate type, target taxa, data characteristics, analyses).

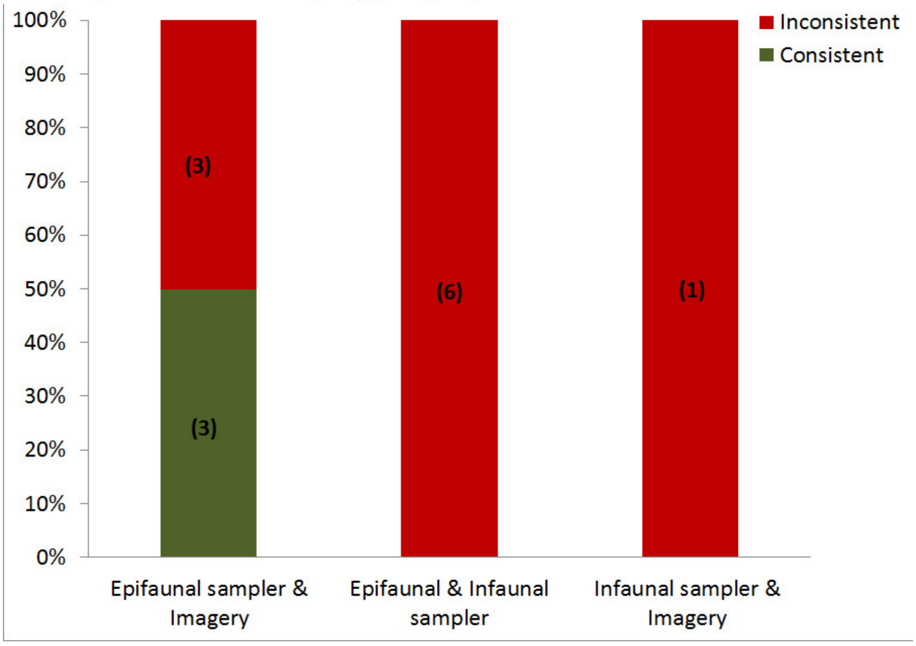
Within a sampling gear group, consistent ecological patterns were detected in 75% of studies using two or more epifaunal samplers (Figure 3.5b). In contrast, inconsistent ecological patterns were observed between grabs and corers, as well as between different imagery systems (Figure 3.5b).

Table 3.3 Summary of studies identified in literature review. 'Inconsistent' refers to different ecological patterns detected among gear types, while 'consistent' means similar ecological patterns were detected among sampling gear types. 'Within' refers to a comparison within a gear group (e.g. sled vs trawl) while 'between' refers to a comparison between gear groups (e.g. sled vs grab).

Study	Region	Biological Variable	Physical Variable	Gear	Comparison	Relationship
Rees et al., 1999	UK coastline	Community structure	Depth, tidal current velocity, temperature, sediment type	Grab, trawl	Between	Inconsistent
Compton et al., 2013	New Zealand	Diversity, community structure	Topography and oceanographic complexity	Sled, video	Between	Consistent
Buhl-Mortensen et al., 2012	Norway	Diversity, species richness, H', evenness, abundance and biomass	Depth and habitat heterogeneity	Video, grab, box corer, beam trawl, sled	Between, within	Inconsistent (between and within)
Basford et al., 1990	Scottish, Norweigan and Danish coasts	Diversity, community structure	Sediment type, depth	Grab, corer, trawl	Between, within	Inconsistent (between) Consistent (within)
Ganesh and Ramen, 2007	Bay of Bengal	Community structure	Depth, temperature, O_2, sediment texture, organic content	Grab, dredge	Between	Inconsistent
Currie et al., 2009 and Ward et al., 2006	Great Australian Bight	Species richness, abundance, biomass, diversity, Community structure?	Depth, upwelling, % mud sediments	Grab, Sled	Between	Inconsistent
Williams et al., 2011	Lord Howe Rise, Norfolk Ridge	Community structure	Depth, temperature salinity, hydrography, O_2, nutrients	Trawl, Sled	Within	Inconsistent
Pitcher et al., 2007a	Torres Strait	Species richness	Depth, sediment characteristics	Trawl, sled	Within	Consistent
Pitcher et al., 2007b	Great Barrier Reef	Assemblages, species richness	Sediment characteristics, dominating flora	Trawl, sled	Within	Consistent
Ellingsen et al., 2007	Southern ocean	Species richness	Depth, longitude and latitude	Sled, box corer	Between	Inconsistent
Kaiser et al., 2000	UK (Isle of Man)	Community structure, biomass, abundance	Sediment size, organic content, depth, stone and broken shell weight	Trawl, dredge	Within	Consistent
Barbera et al., 2012	Mediterranean	Species richness, H', evenness	Latitude, longitude, depth, substrate characteristics	Trawls, video	Between	Inconsistent

Study	Region	Biological Variable	Physical Variable	Gear	Comparison	Relationship
Przeslawski unpublished data	Northern Australia	Species richness, H’ and abundance	Depth, latitude, longitude, backscatter, geomorphology	Sled, camera, grab	Between	Inconsistent
Watson et al., 2005	Hamelin Bay, WA	Species richness, abundance (mean number of individuals)	Relief (high vs low)	Diver Video, Baited Video, Unbaited Video	Within	Inconsistent
BIOICE data	Iceland	Species richness, H’ and abundance	Depth, latitude and longitude	Sled, Trawl and Dredge	Within	Consistent

a) Comparison between sampling gear groups



b) Comparison within sampling gear groups

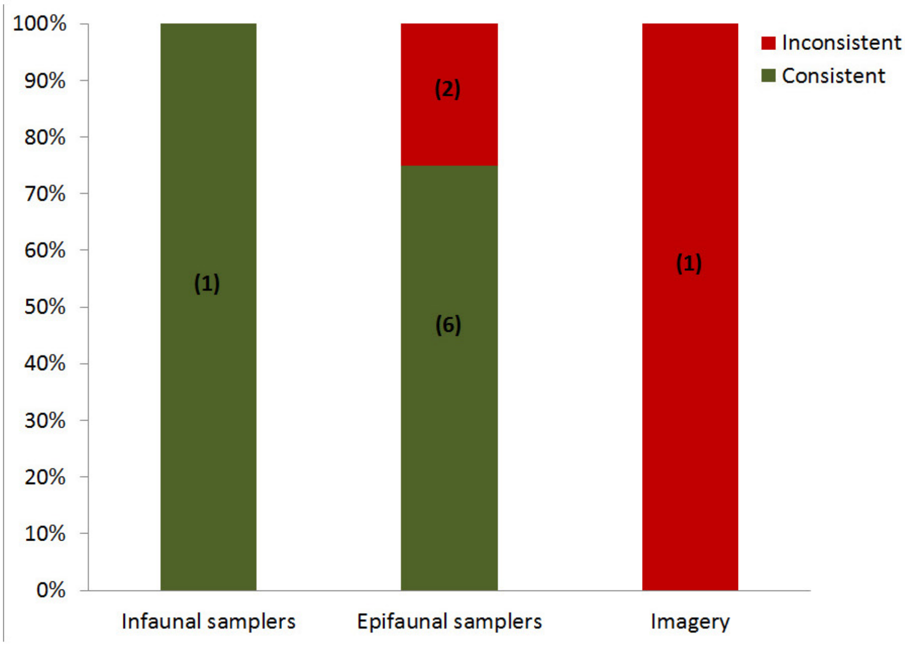


Figure 3.5 The consistency of ecological relationships a) between and b) within sampling gear groups. Epifaunal samplers include sleds, trawls, and dredges. Infaunal samplers include grabs and corers. Numbers in parentheses represent number of studies included.

3.2 Analysis of Dataset 1 (comparison between sampling gear groups)

3.2.1 Univariate analyses (richness, H', abundance)

A summary of the significance test results (including R^2, p value, positive or negative correlation and congruence results) is presented below for depth (Table 3.4), latitude (Table 3.5), longitude (Table 3.6), backcatter (Table 3.7) and geomorphology (Table 3.8). A 'consistent' relationship is one shared by all gear types for a given biological variable, including significance and direction (i.e. positive or negative). An 'inconsistent' relationship is one in which ecological patterns differed among gear types regarding significance or direction.

Table 3.4 Regression results showing relationship between DEPTH and biological variables from multiple gear groups. Bold text denotes significance at α = 0.05. 'Direction' indicates a positive or negative relationship. 'Consistency' indicate consistence (C) or inconsistency (I) among gear groups regarding significance or direction.

Gear Type	Variables	R^2	p	Direction	Consistency
Sled	Depth vs Species Richness	0.0077	0.49	N/A	I
Grab	Depth vs Species Richness	0.029	0.051	N/A	
Video (epifaunal)	Depth vs Species Richness	0.024	0.087	N/A	
Video (Lebensspuren)	Depth vs Species Richness	0.18	**9.2×10^{-7}**	+	
Grab	Depth vs H'	0.155	**3.2×10^{-6}**	-	I
Video (Lebensspuren)	Depth vs H'	0.13	**3.8×10^{-5}**	+	
Grab	Depth vs Abundance	0.10	**0.00018**	-	I
Video (Lebensspuren)	Depth vs Abundance	0.17	**1.9×10^{-6}**	+	

Table 3.5 Regression results showing relationship between LATITUDE and biological variables from multiple gear groups. Bold text denotes significance at α = 0.05. 'Direction' indicates a positive or negative relationship. 'Consistency' indicate consistence (C) or inconsistency (I) among gear groups regarding significance or direction.

Gear Type	Variables	R^2	p	Direction	Consistency
Sled	Latitude vs Species Richness	0.21	**0.00012**	+	I
Grab	Latitude vs Species Richness	0.20	**1.0×10^{-7}**	-	
Video (epifaunal)	Latitude vs Species Richness	0.16	**0.00041**	+	
Video (Lebensspuren)	Latitude vs Species Richness	0.01	0.35	N/A	
Grab	Latitude vs H'	0.10	**0.00020**	-	I
Video (Lebensspuren)	Latitude vs H'	0.02	0.19	N/A	

Gear Type	Variables	R^2	p	Direction	Consistency
Grab	Latitude vs Abundance	0.12	**3.1×10^{-5}**	-	I
Video (Lebensspuren)	Latitude vs Abundance	0.0007	0.94	N/A	

Table 3.6 Regression results showing relationship between LONGITUDE and biological variables from multiple gear groups. Bold text denotes significance at α = 0.05. 'Direction' indicates a positive or negative relationship. 'Consistency' indicate consistence (C) or inconsistency (I) among gear groups regarding significance or direction.

Gear Type	Variables	R2	p	Direction	Consistency
Sled	Longitude vs Species Richness	0.05	**0.00046**	+	I
Grab	Longitude vs Species Richness	0.19	**2.7×10^{-7}**	+	
Video (epifaunal)	Longitude vs Species Richness	0.22	**6.9×10^{-6}**	-	
Video (Lebensspuren)	Longitude vs Species Richness	0.02	0.18	N/A	
Grab	Longitude vs H'	0.19	**3.4×10^{-5}**	+	I
Video	Longitude vs H'	0.04	0.082	N/A	
Grab	Longitude vs Abundance	0.08	**0.0014**	+	I
Video (Lebensspuren)	Longitude vs Abundance	0.002	0.89	N/A	

Table 3.7 Regression results showing relationship between BACKSCATTER and biological variables from multiple gear groups. Bold text denotes significance at α = 0.05. 'Direction' indicates a positive or negative relationship. 'Consistency' indicate consistence (C) or inconsistency (I) among gear groups regarding significance or direction.

Gear Type	Variables	R2	p	Direction	Consistency
Sled	Backscatter vs Species Richness	0.03	0.19	N/A	I
Grab	Backscatter vs Species Richness	0.27	**3.1×10^{-10}**	+	
Video (epifaunal)	Backscatter vs Species Richness	0.05	0.037	N/A	
Video (Lebensspuren)	Backscatter vs Species Richness	0.11	0.0027	N/A	
Grab	Backscatter vs H'	0.20	**1.6×10^{-7}**	+	I
Video (Lebensspuren)	Backscatter vs H'	0.12	**0.0014**	-	
Grab	Backscatter vs Abundance	0.11	**9.9×10^{-5}**	+	I
Video (Lebensspuren)	Backscatter vs Abundance	0.09	0.021	N/A	

*Table 3.8 ANOVA results showing relationship between GEOMORPHOLOGY and biological variables from multiple gear groups. Bold text denotes significance at α = 0.05. 'Consistency' indicate consistence (C) or inconsistency (I) among gear groups regarding significance and pairwise comparisons. B= Bank, T = Terrace, R = Ridge, P = Plain, V = Valley. *Data with heterogeneous variances were transformed prior to ANOVA using square root or log.*

Gear Type	Variables	p	F value	Pairwise Comparisons	Consistency
Sled	Geomorphology vs Species Richness*	**3.3×10^{-6}**	9.9	V&B, V&T, P&B P&R, P&T	C
Video (epifaunal)	Geomorphology vs Species Richness*	**3.7×10^{-8}**	11.9	P&B, P&T, B&R, B&T, V&T	
Grab	Geomorphology vs Species Richness	**1.9×10^{-8}**	12.3	B&R, B&V, P&R, P&V	I
Video (Lebensspuren)	Geomorphology vs Species Richness	**0.00022**	5.9	B&R, V&B	
Grab	Geomorphology vs H'	**1.6×10^{-5}**	7.6	B&V, P&V	I
Video (Lebensspuren)	Geomorphology vs H'	0.0027	4.3	B&R, B&V	
Grab	Geomorphology vs Abundance*	**2.6×10^{-6}**	8.8	B&R, B&V, P&R, P&V	I
Video (Lebensspuren)	Geomorphology vs Abundance*	**1.4×10^{-6}**	9.3	B&R, B&V, P&V, T&V	

The grab and video (*Lebensspuren*) acquired data were the only data available to determine H' and abundance (as data from the sled and video (epifaunal) are presence/absence). Data acquired from all gear types (sled, grab, video (epifaunal) and video (*Lebensspuren*) were available to determine species richness.

Depth

Species richness from sled, grab and video (epifaunal) show consistent patterns, in that there is no correlation with depth (Table 3.4). Only the video (*Lebensspuren*) shows a significant but weak relationship between richness and depth ($R^2 = 0.18$), with increasing richness in deeper waters (Figure 3.6).

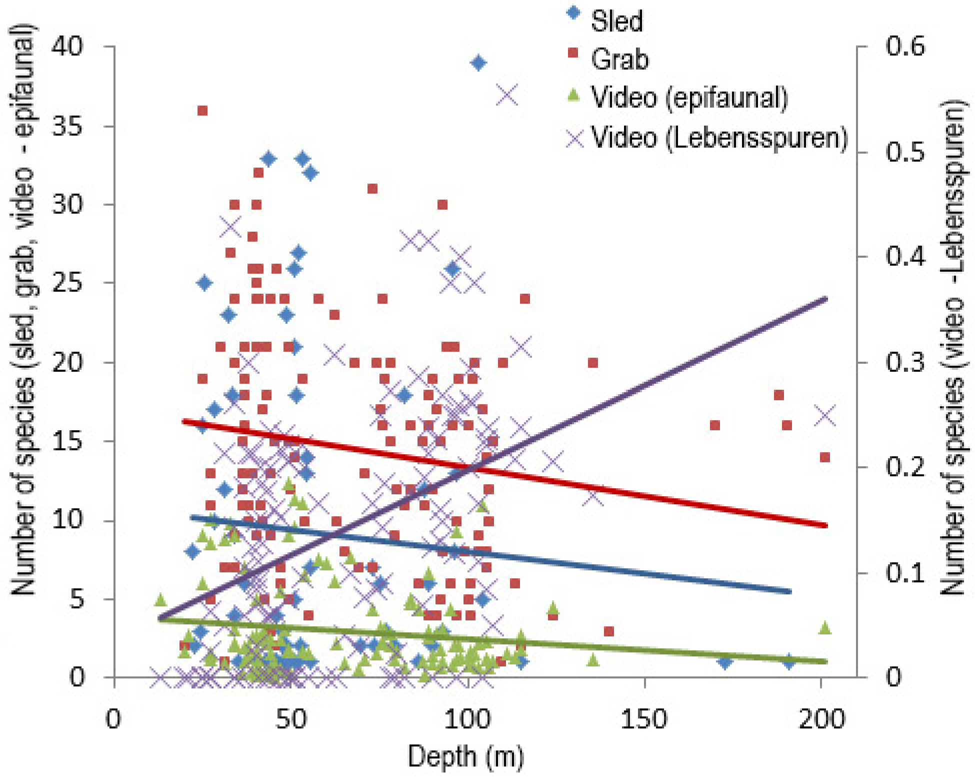


Figure 3.6 The relationship between depth and species richness for sled, grab and video. Lines indicate significant linear best-fit relationships.

H’ and abundance derived from grabs and video (*Lebensspuren*) showed inconsistent relationships with depth. For the grab, diversity and abundance decreased with depth ($R^2 = 0.16$ and 0.10, respectively), while these increased with depth for video (*Lebensspuren*) ($R^2 = 0.13$ and 0.17, respectively) (Figure 3.7).

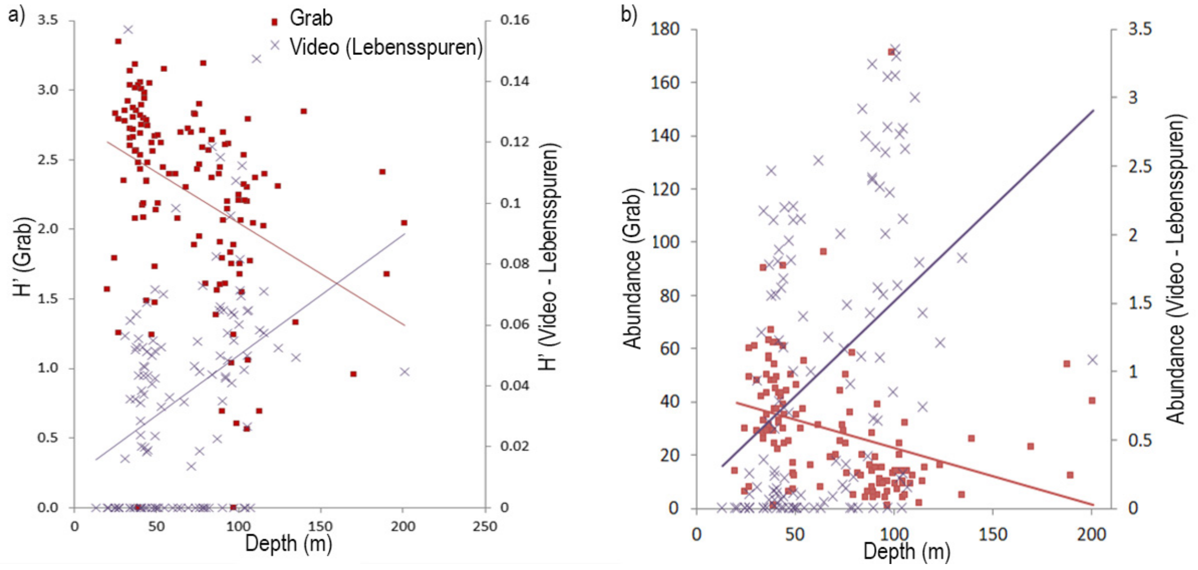


Figure 3.7 The relationship between depth and a) H’ and b) abundance for grab and video (Lebensspuren). Lines indicate significant linear best-fit relationships.

Latitude

As related to latitude, species richness derived from the sled and video (epifaunal) show consistent relationships (R^2 = 0.21 and 0.16, respectively), with richness increasing as distance offshore increases (in an equatorial direction). In contrast, richness derived from grabs increases as distance offshore decreases (in a poleward direction) (R^2 = 0.20), and richness derived from video (*Lebensspuren*) shows no significant correlation with latitude (Figure 3.8).

H' and abundance derived from grabs and video (*Lebensspuren*) showed inconsistent relationships with latitude. H' and abundance derived from grab samples decrease in an equatorial direction (R^2 = 0.10 and 0.12, respectively), while there was no relationship between latitude and H' and abundance derived from video (*Lebensspuren*).

It should be noted, however, that the latitudinal range investigated here only encompassed 2 degrees and latitude (like depth) is simply a proxy for other environmental factors that directly affect organisms. An example in the JBG may include turbidity associated with latitude/distance offshore.

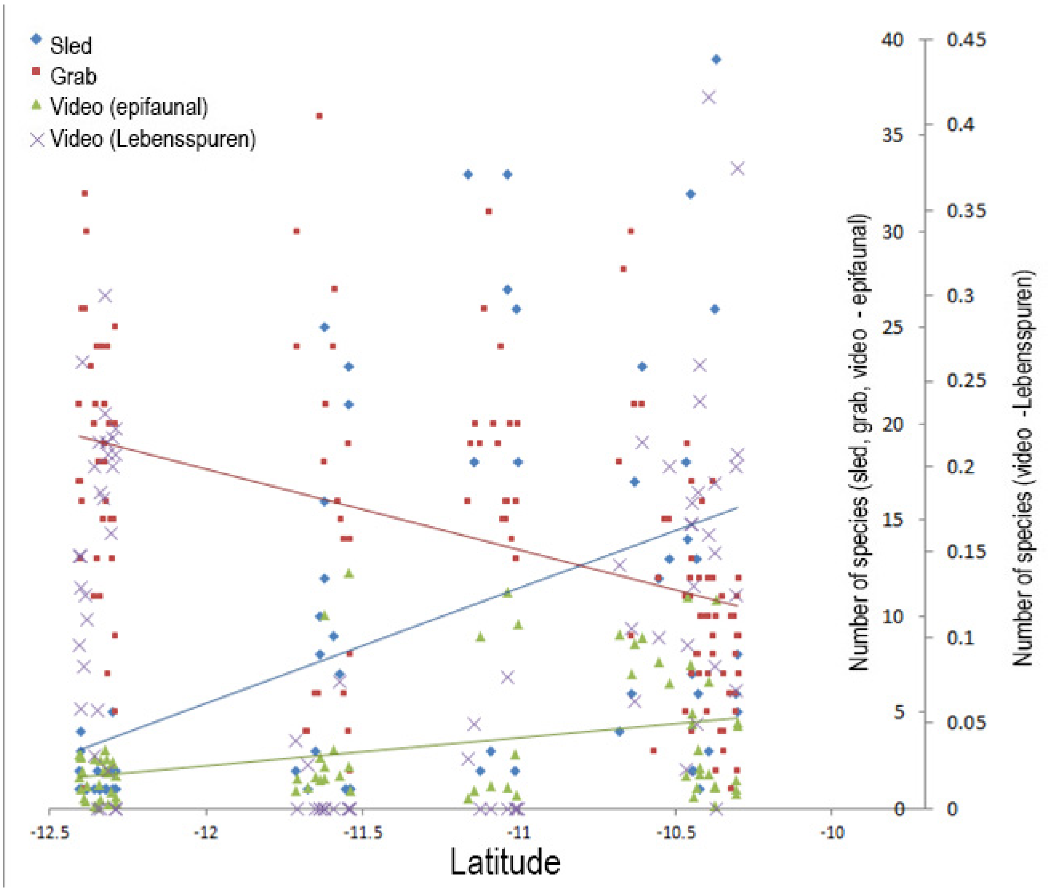


Figure 3.8 The relationship between latitude and species richness for sled, grab and video. Lines indicate significant linear best-fit relationships.

Longitude

As related to longitude, species richness derived from the sled and grab show consistent relationships, with both showing increased richness with increasing longitude ($R^2 = 0.05$ and 0.22, respectively). In contrast, species richness from video (epifaunal) decreases with increasing longitude ($R^2 = 0.22$), and species richness from video (*Lebensspuren)* showed no relationship with longitude (Figure 3.9).

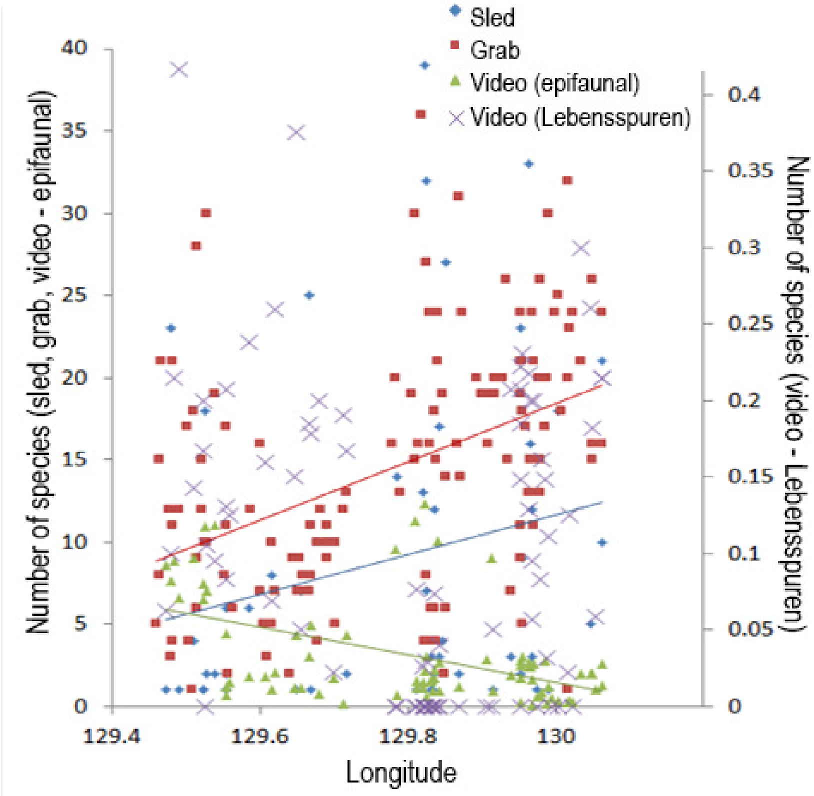


Figure 3.9 The relationship between longitude and species richness for sled, grab and video. Lines indicate significant linear best-fit relationships.

The video (*Lebensspuren*) shows no correlation between both longitude and H' and longitude and abundance. The grab shows positive correlations between both longitude and H' ($R^2 = 0.19$) and longitude and abundance ($R^2 = 0.08$).

It should be noted that the longitudinal range investigated here only encompassed 1 degree.

Backscatter

Richness data from the sled and both video types (epifaunal and *Lebensspuren)* show consistent lack of relationships with backscatter. In contrast, richness from grabs shows a positive correlation with backscatter ($R^2 = 0.27$), indicating an increase in species richness with increasing substrate hardness (Figure 3.10).

There was no consistency in the relationships between H' and abundance between richness from grabs and richness from video (*Lebensspuren*). As backscatter values increase (and substrate gets harder), diversity (H') and abundance from grabs increases ($R^2 = 0.20$ and 0.11, respectively). In contrast, diversity (H') from video (*Lebensspuren*) decreases ($R^2 = 0.12$), while abundance from video (*Lebensspuren*) shows no relationship with backscatter (Figure 3.11).

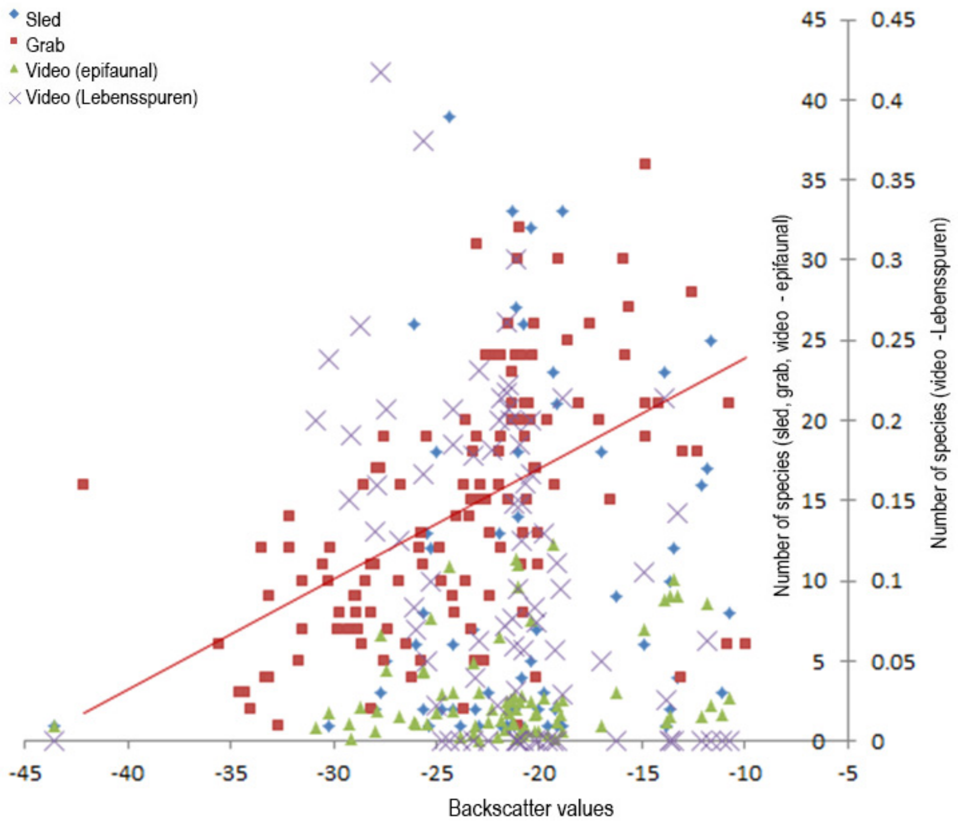


Figure 3.10 The relationship between backscatter and species richness for sled, grab and video. Lines indicate significant linear best-fit relationships.

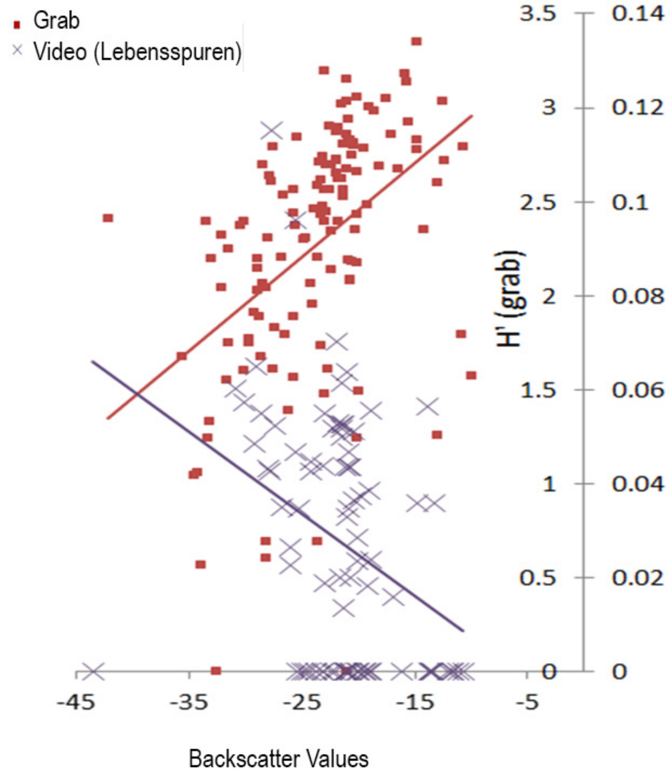


Figure 3.11 The relationship between backscatter and H' for grab and video (Lebensspuren). Lines indicate significant linear best-fit relationships.

Geomorphology

Geomorphology significantly affects species richness across all gear types (Table 3.8), but visual examination and pairwise comparisons suggest that these relationships are not consistent among all gear types. For example, grabs reflect high species richness on plains while sleds and video (epifaunal) show comparatively low richness (Figure 3.12). Sled and video (epifaunal) show the most consistency regarding relationships between species richness and geomorphology, with terrace and bank having the highest species richness, and valley and plain the least (Figure 3.12).

For samples from grab or video (*Lebensspuren*), there were no consistent relationships between geomorphology and H' or abundance. The grab showed a significant relationship between H' and geomorphology, whereas video (*Lebensspuren*) showed no significant relationship (Table 3.8) (Figure 3.13a). Although both grab and video (*Lebensspuren*) were significantly affected by geomorphology, the nature of these relationships were not consistent. For example, abundance from grabs at banks and plains was relatively high while abundance from video (*Lebensspuren*) at these features was relatively low (Figure 3.13b).

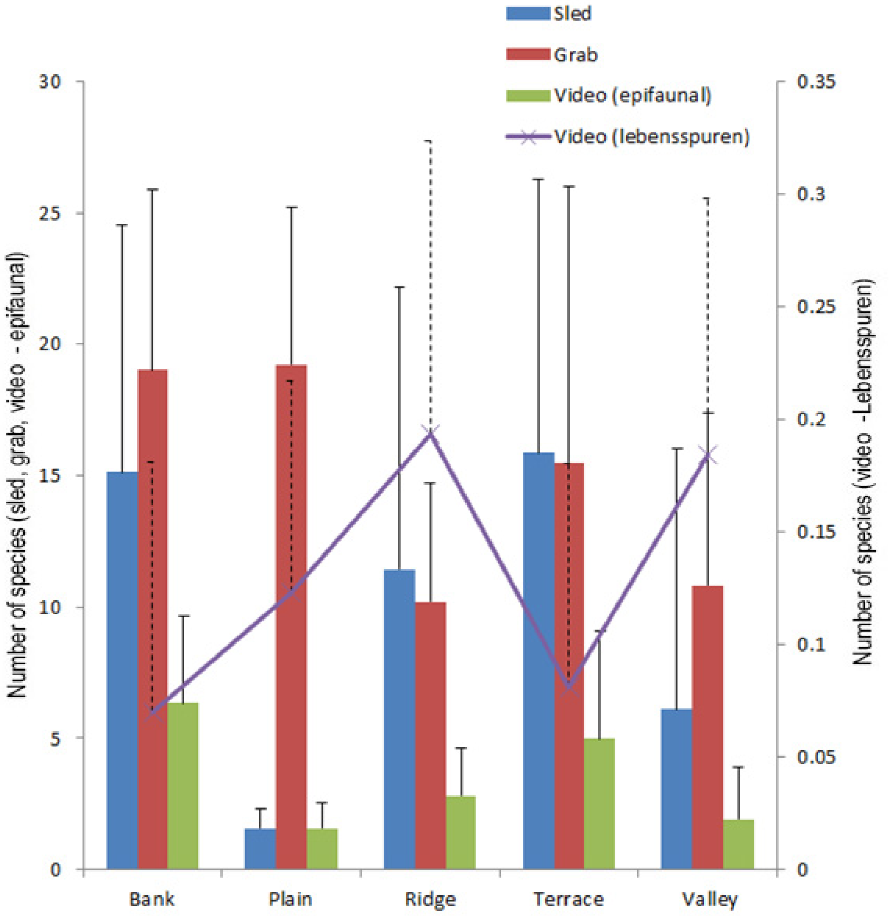


Figure 3.12 Differences in species richness determined from different gear types among geomorphic features. Error bars are standard deviation.

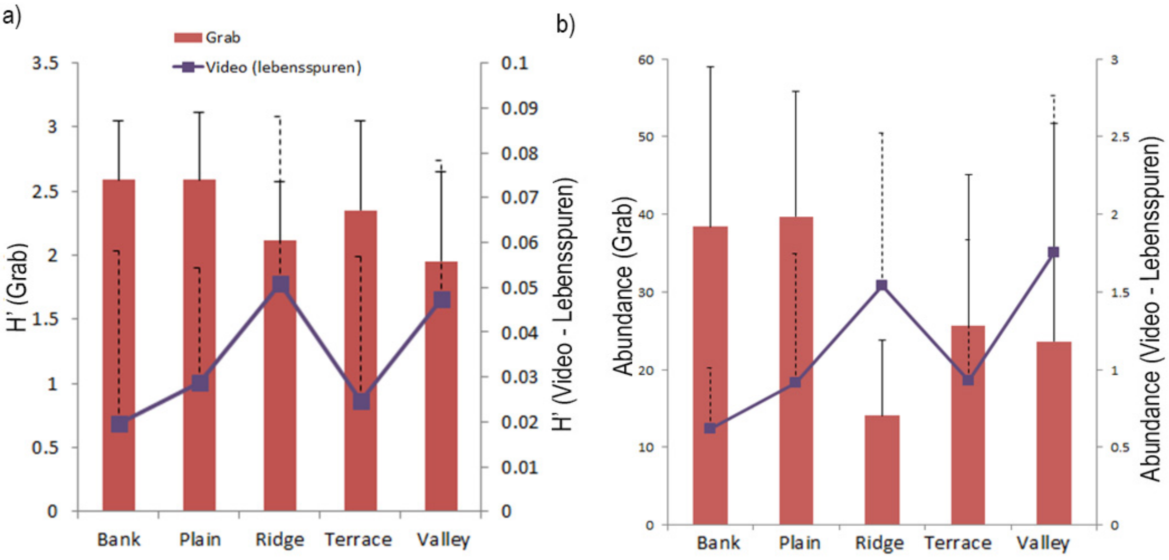


Figure 3.13 Differences in a) H' and b) abundance determined from different gear types among geomorphic features. Error bars are standard deviation.

3.2.2 Multivariate analysis (assemblages)

Assemblages from all gear types were significantly related to geomorphology ($p < 0.001$,Table 3.9a), thus showing broad consistency in the statistical relationships between biological assemblages and geomorphology. Pairwise comparisons showed that all gear types yielded assemblages that were significantly different between banks and deeper geomorphic features (ridges, plains, valleys) but not between banks and terraces (Figure 3.14). There was some variation in the other pairs of geomorphic features (Table 3.10). For example, plains and ridges showed significantly different assemblages collected from grabs and video, but this relationship did not exist among assemblages collected from sleds (Table 3.10). In addition, there was variation among gear types in the distinctiveness of assemblages from a given geomorphic feature. For instance, assemblages collected from grabs over plains were distinctive, as evidenced by the relatively close grouping of points in Figure 3.14. In contrast, assemblages collected from the other gear types over plains widely varied, as shown by the large spread of points (Figure 3.14).

Compared to geomorphology, there was less similarity among different gear types regarding the relationships between biological assemblages and other environmental variables (depth, backscatter, latitude and longitude) (Table 3.9b). Overall, the environmental factors examined were not strong drivers of assemblages recorded from video, but they did show stronger associations with assemblages from sleds and grabs. The strongest relationship was found between latitude/distance offshore and sled assemblage ($\rho = 0.340$), but latitude had much weaker effects on assemblages from other gear types ($\rho = 0.092 – 0.131$). In contrast, depth and backscatter combined to produce the strongest effects on grab assemblages ($\rho = 0.277$), but depth was not a main driver of variation in assemblages from other gear types ($\rho = 0.049 – 0.116$).

Table 3.9 Results from the multivariate statistical tests, including a) PERMANOVAs in which geomorphology was the independent variable, and b) BIO-ENVs in which depth, backscatter, latitude, and longitude were the independent variables.

a) PERMANOVA

Gear	Outlier(s)	Pseudo F	p
Grab	56A	2.5802	<0.001
Sled	4A, 9B, 43A, 19B, 48A, 36B, 42A	1.5004	<0.001
Video1	52A	6.6709	<0.001
Video2	None	5.4619	<0.001

b) BIO-ENV

Gear	Outlier(s)	Best combination (ρ)	p
Grab	56A	Depth & backscatter (0.277)	< 0.01
Sled	4A, 9B, 43A, 19B, 48A, 36B, 42A	Latitude (0.340)	< 0.01
Video1	52A	Backscatter (0.131)	< 0.01
Video2	None	Latitude (0.103)	< 0.01

Table 3.10 Results of pairwise comparisons from PERMANOVA. Geomorphology significantly affected biological assemblages from all gear types (seeTable 3.9). An 'X' denotes significantly different assemblages between two geomorphic features. B = Bank; P = Plain, R =Ridge

Gear	B&P	B&T	B&R	B&V	P&T	P&R	P&V	R&T	R&V	T&V
Grab	X		X	X	X	X	X			
Sled	X		X	X						
Video1	X		X	X	X	X		X	X	X
Video2	X		X	X		X	X	X		X

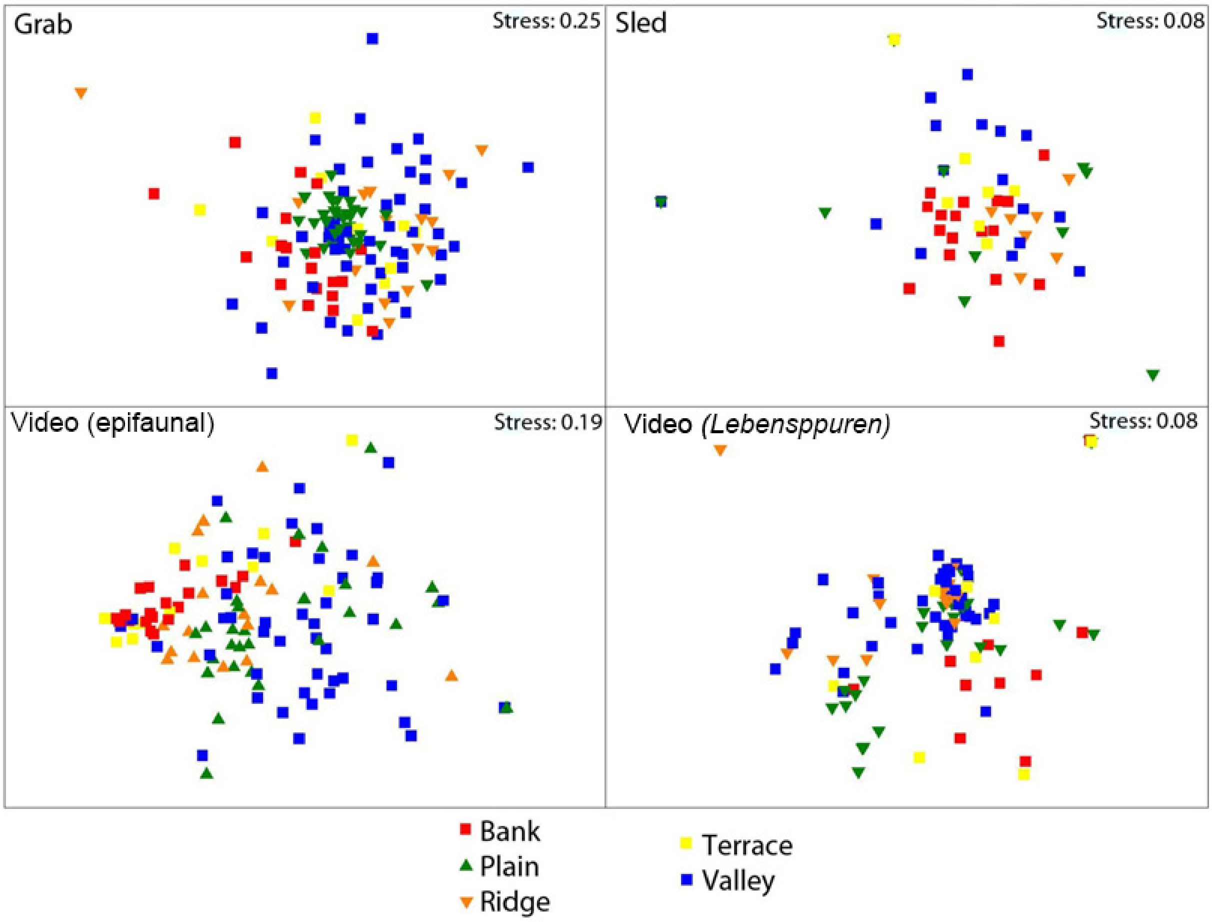


Figure 3.14 Non-metric multidimensional scaling (n-MDS) plot for biological assemblages from different gear types. Each point represents an assemblage from a given location. Colours denote the geomorphic feature from which a sample was taken. The distance between points indicates the similarity in assemblages, with closer points denoting more similar assemblages. Stress values indicate the utility of the n-MDS to visually represent accurate patterns in two dimensions, with stress values above 0.20 considered high.

3.3 Analysis of Dataset 2 (comparison within a sampling gear group)

A summary of the significance test results (including R^2, p value, positive or negative correlation and results) for each physical variable is presented below for depth (Table 3.11), latitude (Table 3.12), and longitude (Table 3.13). Consistent results are defined as ecological relationships similar among all gear types, including significance and correlation direction.

Table 3.11 Gear type, variables, results significance and similarity of results between gear types for data from BIOICE. Abiotic variable: depth.

Gear Type	Variables	R2	P value and significance (bolded) (ANOVA)	Positive (+) or Negative (-) Correlation	Results (Consistent-C or Inconsistent-I)
Agassiz Trawl	Depth vs Species Richness	0.102	0.40	N/A	I
Sneli Sledge	Depth vs Species Richness	0.074	**0.00058**	-	
RP-Sledge	Depth vs Species Richness	0.0091	0.26	N/A	
Triangular Dredge	Depth vs Species Richness	0.018	0.63	N/A	
Agassiz Trawl	Depth vs H’	0.11	0.38	N/A	I
Sneli Sledge	Depth vs H’	0.097	**7.36 x 10^{-5}**	-	
RP-Sledge	Depth vs H’	5 x 10^{-7}	0.99	N/A	C
Triangular Dredge	Depth vs H’	0.026	0.57	N/A	
Agassiz Trawl	Depth vs Abundance	0.045	0.58	N/A	C
Sneli Sledge	Depth vs Abundance	0.023	0.059	N/A	
RP-Sledge	Depth vs Abundance	0.010	0.24	N/A	
Triangular Dredge	Depth vs Abundance	0.11	0.22	N/A	

Table 3.12 Gear type, variables, results significance and similarity of results between gear types for data from BIOICE. Abiotic variable: latitude.

Gear Type	Variables	R2	P value and significance (bolded) (ANOVA)	Positive (+) or Negative (-) Correlation	Results (Consistent-C or Inconsistent-I)
Agassiz Trawl	Latitude vs Species Richness	0.0050	0.86	N/A	C
Sneli Sledge	Latitude vs Species Richness	0.0024	0.55	N/A	
RP-Sledge	Latitude vs Species Richness	0.068	0.0018	N/A	
Triangular Dredge	Latitude vs Species Richness	0.23	0.073	N/A	
Agassiz Trawl	Latitude vs H’	0.00050	0.96	N/A	C

Gear Type	Variables	R2	P value and significance (bolded) (ANOVA)	Positive (+) or Negative (-) Correlation	Results (Consistent-C or Inconsistent-I)
Sneli Sledge	Latitude vs H’	0.00080	0.73	N/A	
RP-Sledge	Latitude vs H’	0.053	0.0064	N/A	C
Triangular Dredge	Latitude vs H’	0.28	0.042	N/A	
Agassiz Trawl	Latitude vs Abundance	0.12	0.35	N/A	C
Sneli Sledge	Latitude vs Abundance	0.00020	0.86	N/A	
RP-Sledge	Latitude vs Abundance	0.018	0.12	N/A	
Triangular Dredge	Latitude vs Abundance	0.13	0.18	N/A	

Table 3.13 Gear type, variables, results significance and similarity of results between gear types for data from BIOICE. Abiotic variable: longitude.

Gear Type	Variables	R2	P value and significance (bolded) (ANOVA)	Positive (+) or Negative (-) Correlation	Results (Consistent-C or Inconsistent-I)
Agassiz Trawl	Longitude vs Species Richness	0.16	0.28	N/A	C
Sneli Sledge	Longitude vs Species Richness	4×10^{-7}	0.99	N/A	
RP-Sledge	Longitude vs Species Richness	0.00070	0.76	N/A	
Triangular Dredge	Longitude vs Species Richness	0.015	0.67	N/A	
Agassiz Trawl	Longitude vs H’	0.090	0.43	N/A	C
Sneli Sledge	Longitude vs H’	0.0019	0.59	N/A	
RP-Sledge	Longitude vs H’	0.0026	0.55	N/A	C
Triangular Dredge	Longitude vs H’	0.0060	0.78	N/A	
Agassiz Trawl	Longitude vs Abundance	0.31	0.12	N/A	C
Sneli Sledge	Longitude vs Abundance	0.00030	0.83	N/A	
RP-Sledge	Longitude vs Abundance	0.035	0.026	N/A	
Triangular Dredge	Longitude vs Abundance	0.020	0.62	N/A	

Due to the high number of insignificant relationships between biological and physical variables across all gear types (Table 3.11, Table 3.12, Table 3.13), most biodiversity relationships were consistent among sampling gear Sneli sledge, RP sledge, Agassiz trawl, Triangular dredge). Only data from the Sneli sledge showed any significant correlations between biological and physical variables: Species richness and diversity (H’) decreased as depth increased (R^2 = 0.07 and 0.10, respectively) (Figure 3.15). Scatterplots of insignificant relationships can be found in Appendix B.

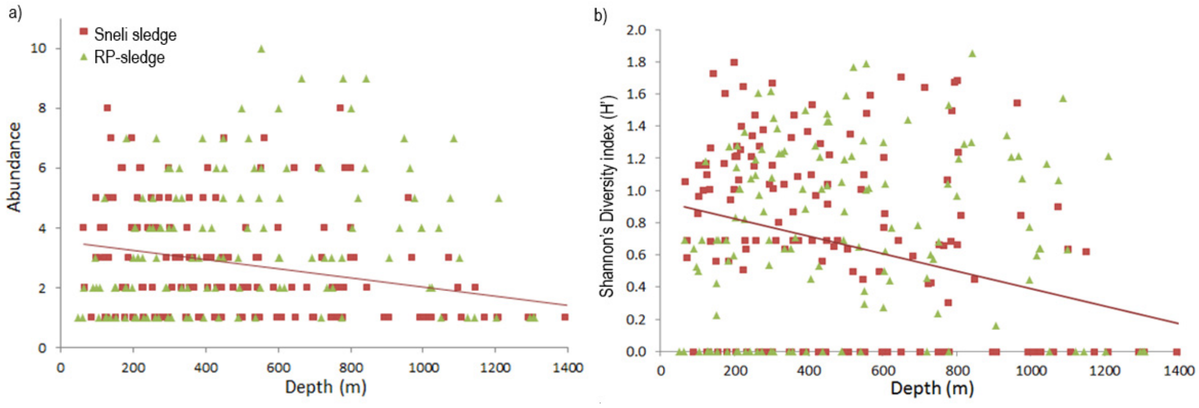


Figure 3.15 Relationships between depth and amphipod species richness for the Sneli sledge and RP-sledge. Lines indicate significant linear best-fit relationship.

3.4 Summary and Discussion

The choice of sampling gear will depend on the aims and hypotheses of a particular study as they relate to quantifying biodiversity. For example, a study focussing solely on habitat-forming epifauna does not need to adequately sample small animals or infauna. As such, a single gear type such as an epibenthic sled may be most appropriate to comprehensively quantify habitat-forming epifauna.

In contrast, a study focused on broad biodiversity patterns across multiple habitats should target as many taxa and environments as possible. In such cases, a combination of epifaunal, infaunal, and imagery sampling systems may be optimal. Gear type combinations that consistently show similar trends are least desirable for studies aiming to broadly quantify biodiversity, and if such combinations can be identified costs and effort can be reduced by using only one gear type. Gear types that show dissimilar trends within a surveyed area are advantageous as they provide a more thorough overview of biodiversity characteristics.

3.4.1 Comparisons between sampling gear groups

Overall, our review and analysis of datasets from two regions (northern Australia and Iceland) demonstrates there is little consistency in marine biodiversity trends between different gear groups, suggesting that ideal gear combinations are not easily able to be generalised among studies and regions. In addition, the lack of consistency between sampling gear groups highlights the need to analyse gear-specific data and avoid amalgamation. If amalgamated, disparate biodiversity trends of taxa from different habitats are at risk of being obscured and overlooked.

In Compton et al. (2013) consistent results were obtained in gear from different groups (sled and video). Our analysis of data from the Joseph Bonaparte Gulf (Dataset 1) also revealed that sled and video yielded univariate and multivariate data with consistent ecological relationships compared to combinations of other gear types (grab and video, grab and sled). Unfortunately, no additional suitable studies that reported gear specific trends of sled and video to augment the dataset were found.

Even among gear that yielded relatively consistent ecological relationships, results varied across biological or environmental factors. For example richness from the sled and video (epifaunal) both showed positive relationships with latitude, but these same gear types showed inconsistent relationships among other abiotic (e.g. backscatter) or biological (abundance) variables.

3.4.2 Comparisons within a sampling gear group

In contrast to ecological relationships between sampling gear groups, there are more consistencies in ecological relationships within a gear group. For example, in Basford et al. (1990) consistent ecological relationships were found in gear types of the same group (grab and corer) but not between groups (grab and trawl, corer and trawl). Similarly, our analysis of data from the BIOICE survey showed consistent non-significant correlations among three epifaunal samplers (sled, trawl, dredge).

Of the eight studies reviewed that examined multiple gear types within a major sampling group (Table 3.3), only two had inconsistent ecological relationships. One study by Williams et al. (2011) revealed mostly inconsistent results for invertebrate community structure using a sled and a trawl. A second study used three different types of video (diver, baited and unbaited) with inconsistent results in species richness and abundance between gear types (Watson et al. 2005). The differences between the three video methods were great enough to produce different biodiversity trends, as diver video and baited video repel and attract vastly dissimilar fish types.

The BIOICE data (Dataset 2) reflected similar consistencies in ecological relationships among data within gear groups. However, only two sets of variables out of 36 showed significant correlations (Figure 3.15), and the consistency of results in the BIOICE data is therefore due to non-significant relationships which is not as strong a justification for consistent ecological relationships as those due to significant and same trending relationships. Nevertheless, all four gear types analysed from the BIOICE data are within the same gear type group (trawl, sledge, dredge), which likely contributes to the consistent results.

3.5 Recommendations

Despite a comprehensive literature review, we were unable to identify enough studies that incorporated multiple gear types to conduct a quantitative analysis (e.g. meta-analysis) on the consistency of ecological relationships between and within sampling gear types. Nevertheless, we were able to combine a qualitative review of the literature with quantitative analyses of datasets from two regions to provide preliminary recommendations and inform further research:

- If general biodiversity or baseline patterns are to be investigated over unspecified habitats or taxaonomic groups, sampling for marine benthic surveys should be carried out using multiple gear types that are concurrently deployed. An ideal scenario is the use of one gear type from each of the major groups, i.e. sled, grab and image system used in tandem to provide the best indication of benthic biodiversity over an unsampled area.
- Target measures of biodiversity need to be decided a priori and appropriate gear used.
- If possible, preliminary data should be acquired to determine the optimal combination of gear types used to sample that region and address a given hypothesis. For example, species richness at each station should be compared between gear types to determine the extent of correlation between the different gear types.
- If only two gear types are able to be deployed, a grab or box corer should be one of them, as this sampling gear type samples a different habitat than epifaunal samplers (sleds, trawls, dredges) and imagery which do not typically provide data on biodiversity related to infauna or small animals. In our analysis of Dataset 1, the sled and imagery data yielded more consistent relationships than grab and imagery or grab and sled, suggesting the grab targeted different taxa or habitats than the sled and imagery system.

3.6 Limitations

The major limitation revealed by this review was the tendency for benthic biodiversity studies to combine their data from multiple gear types to perform analyses and modelling (Branch et al. 1993, Mason 1998, Howell et al. 2002, Schwabe et al. 2007, Kaiser et al. 2010, Schrodl et al. 2011, Zintzen et al. 2011, Barbera et al. 2012, Dauvin et al. 2012, Figuerola et al. 2012). Differences in bio-physical correlations between gear types could therefore not be determined.

Some reasons for this may include

- Only one gear type performed well enough to be deemed suitable for publication
- Results perceived as the highest impact may be associated with a single gear type
- Authors chose to focus on target data and presenting results from alternative gear types may detract from the main focus

In some cases data from different gear types deployed on the same survey are reported in different scientific papers (e.g. Currie et al., 2009 and Ward et al., 2006), creating difficulties identifying parallel datasets for comparison of equipment-specific results.

Additional limitations in the JBG and BIOICE data analyses were largely attributable to the fact that the gear-specific data analysed was not collected for such a purpose. Analyses of gear-specific data therefore had differing spatial coverage, differing types of biological data collected (e.g. presence/absence or abundance) and differing taxonomic resolutions. For example, in Dataset 1, the collection of presence/absence data on the sled and video (epifaunal) resulted in abundance and diversity index being unavailable to compare results between all gear types.

The availability of more gear specific datasets for analysis would be beneficial in future investigations to determine ideal environmentally related gear specific combinations. More beneficial, however, would be datasets collected for the purpose of gear specific comparisons.

4 Conclusions

Management decisions, such as designation of an area as a representative or unique community, can be made as a result of biological data collected from only one sampling method, yet it is unknown how biodiversity patterns from a single method represent those from other methods. Successful marine biodiversity surveys thus require both careful planning of gear type combinations and planned preliminary studies in order to ensure collected data represent accurate trends.

This study indicates that the consistency of biodiversity trends (species richness, diversity indices, abundance and community structure) between gear types show few general trends and is likely highly specific to particular regions, habitats, and taxa. In general, broadscale biodiversity patterns are most consistent among datasets derived from different sampling gear within the same group (i.e. sleds and trawls). A combination of gear types, one from each group (epifaunal, infaunal, imagery), concurrently deployed provides the most reliable results for biodiversity assessments. A lack of gear-specific studies precluded the determination of the optimal combination of gear types for particular regions or environments.

Ultimately, there is a trade-off between multiple sampling methods and spatial coverage and replication. Information about the ideal combination of sampling methods at a given spatial scale, habitat, or region to detect biodiversity patterns will help maximise the number and range of specimens collected, as well as the spatial coverage of the collection.

5 Glossary

Alpha Diversity: Species diversity at a location.

Assemblage: A multivariate measure of the number of species and their abundance/biomass in a given area, often analysed by a species matrix. Often synonymous with ‘species composition’ or ‘community’.

Biodiversity: The variety of life within a population, species, habitat, region or world, often measured as species richness, evenness, diversity, or assemblages (and erroneously confused with abundance and biomass). Biodiversity is often associated with the health or value of a system, such that high biodiversity is considered good. Although it is often not done, an explicit definition of biodiversity in a given study is crucial to clearly define the scope and focus of the study and what is meant by ‘biodiversity’.

Benthic: The bottom of a large body of water, can refer to organisms living on or beneath the seafloor.

Beta diversity: Differences in species richness down environmental gradients, or the degree of dissimilarity in community structure between sites

Diversity Indices: One of a number of univariate values based on mathematical formulas to account for species number, abundance and/or evenness. The most commonly used are Pielou’s evenness (J), Shannon Diversity Index (H) and Simpson Diversity Index (D). As the species richness and evenness increase, the value of a diversity index increases (i.e. higher indices indicate higher biodiversity).

Epifaunal: Organisms living on the seafloor.

Infaunal: Organisms living beneath the seafloor.

Species richness: The number of species in a given area, often referred to as ‘S’.

Multivariate analyses: Statistical analysis in which there are multiple dependent variables (i.e. the variables being measured). This includes analysis of assemblages or numerous environmental factors. Examples of multivariate analyses include ANOSIMs (analysis of similarities), PCA (principal component analysis), and CCA (canonoical correspondence analysis).

Univariate analyses: Statistical analysis in which there is a single dependent variable (i.e. the variable being measured). This includes analysis of species richness, total biomass, and total abundance. Examples of univariate analyses include regressions, correlations, and ANOVAs (analysis of variance).

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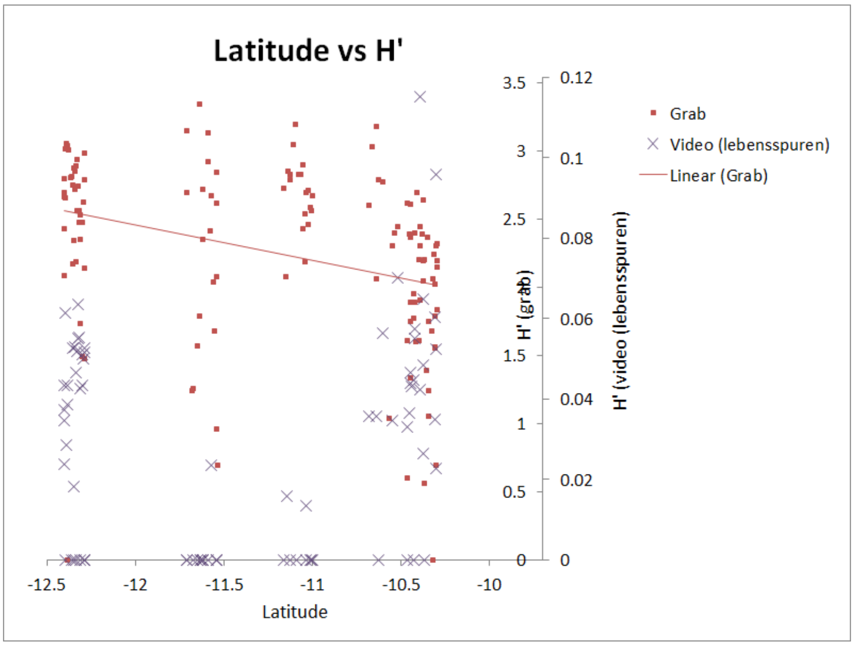
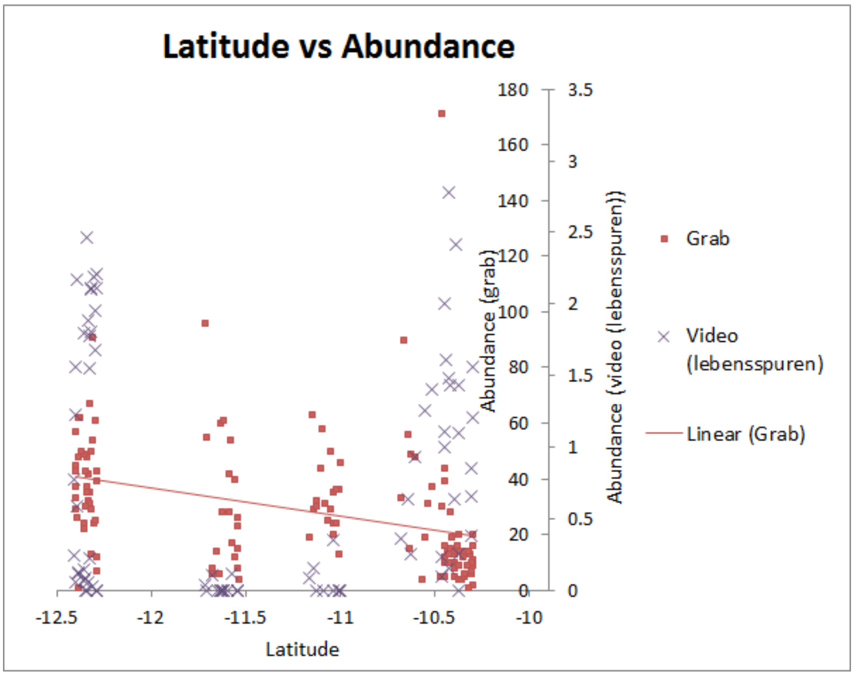
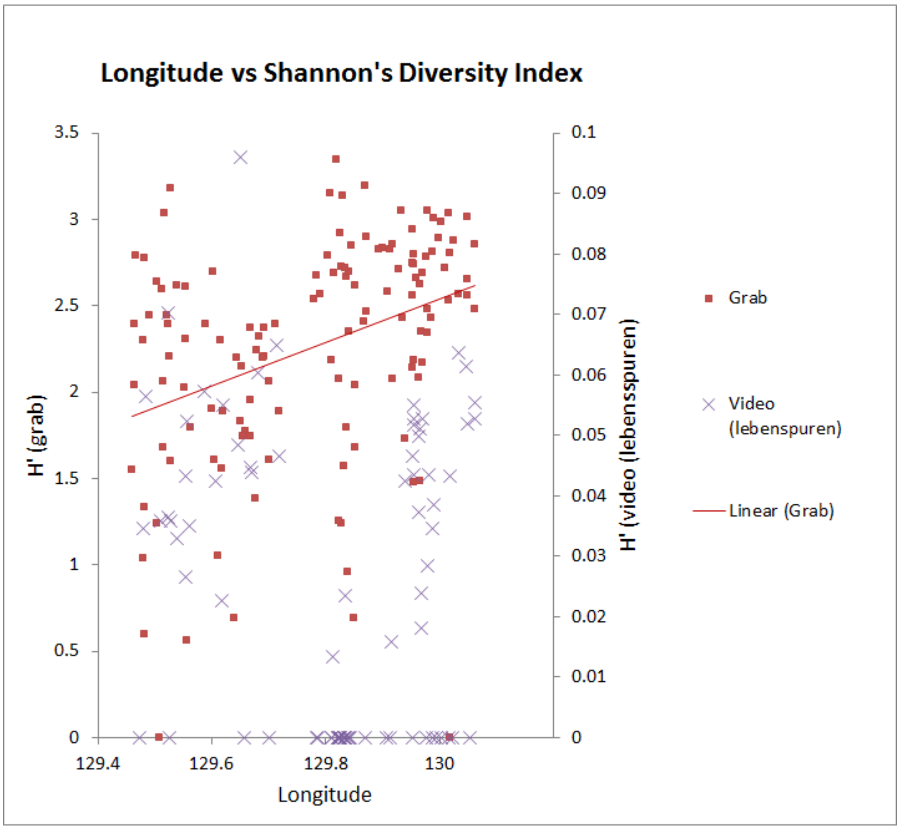
Appendix A Dataset 1 correlation plots (Joseph Bonaparte Gulf)



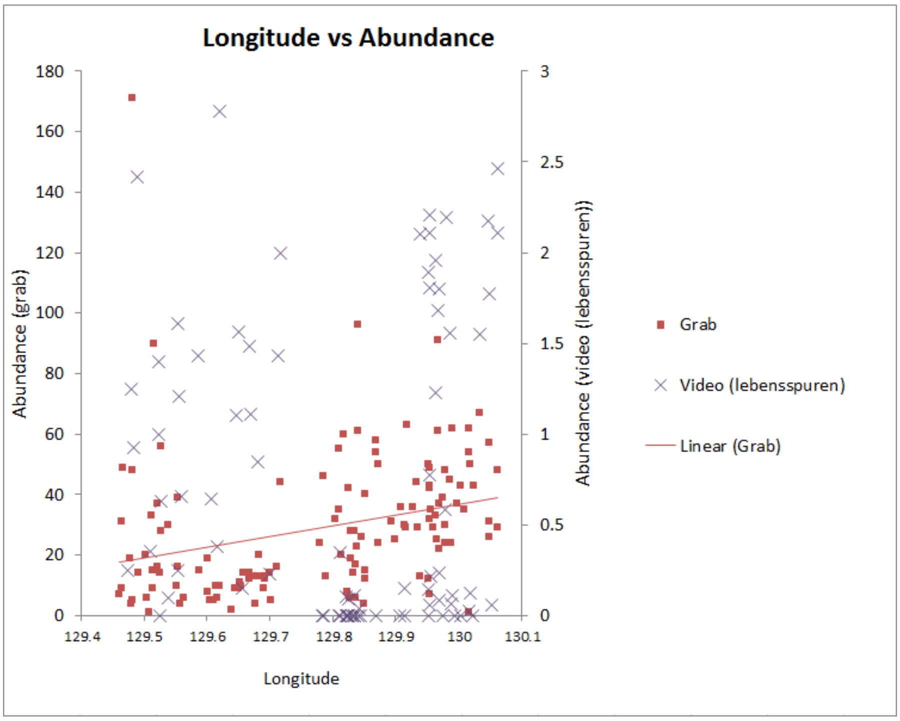
Appendix Figure A.1 Latitude vs H' for the grab and video. Trend lines are shown colour-coded.



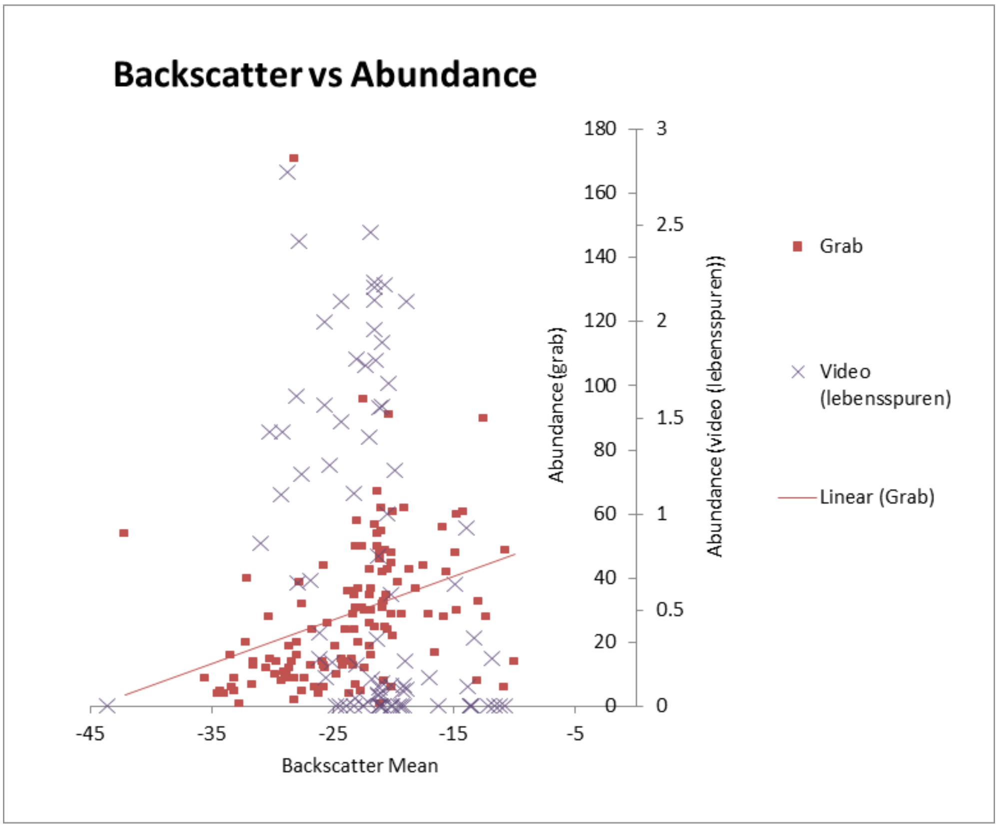
Appendix Figure A.2 Latitude vs abundance for the grab and video. Trend lines are shown colour-coded.



Appendix Figure A.3 Longitude vs H' for the grab and video (Lebensspuren). Trend lines are shown colour-coded.



Appendix Figure A.4 Longitude vs abundance for the grab and video (Lebensspuren). Trend lines are shown colour-coded.

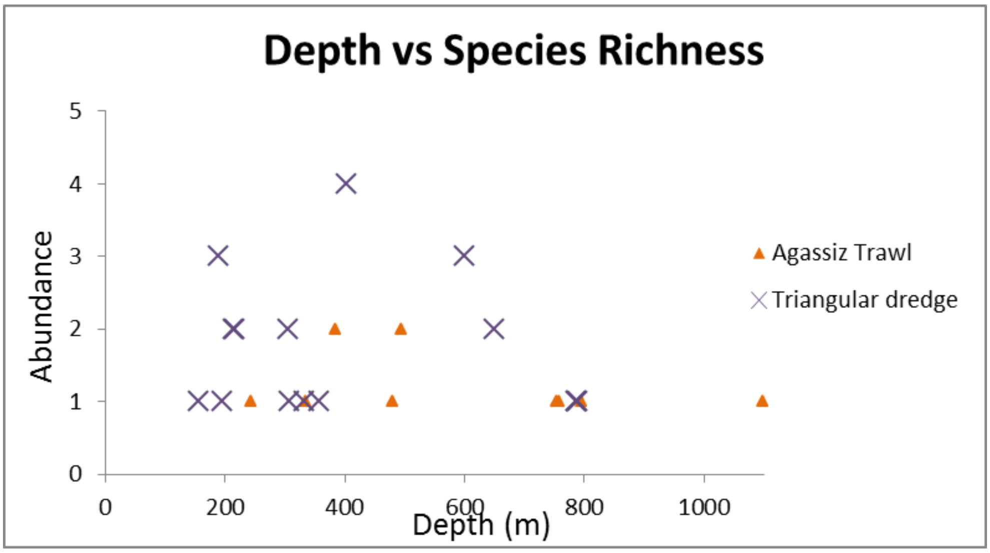


Appendix Figure A.5 Backscatter mean vs abundance for the grab and video (Lebensspuren). Trend lines are shown colour-coded.

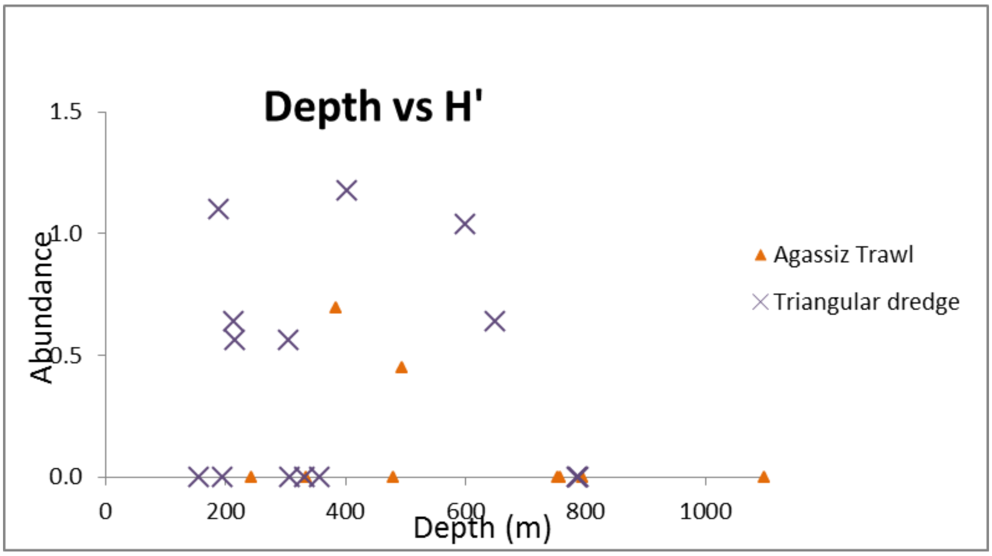
Appendix B Dataset 2 correlation plots (Iceland BIOICE program)

B.1 Depth

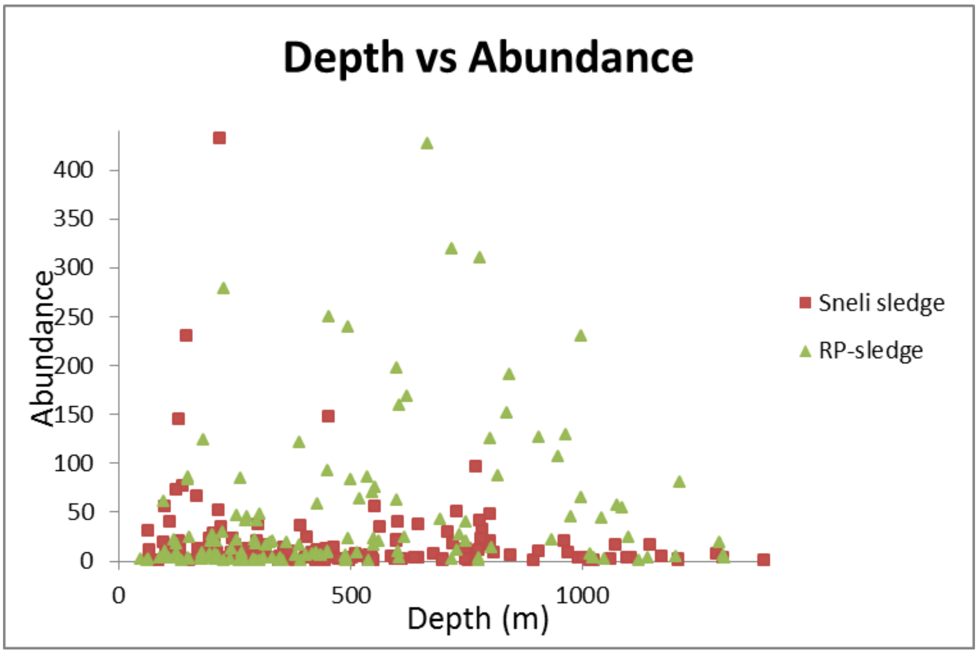
There was no correlation between depth and species richness for the Agassiz trawl and triangular dredge. There was no correlation between Depth and H’ richness for the Agassiz trawl and triangular dredge (Appendix Figure B.1 and B.2). There was no correlation between depth and abundance for the Sneli sledge, SP- sledge, Agassiz trawl and triangular dredge (Appendix Figure B.3 and B.4).



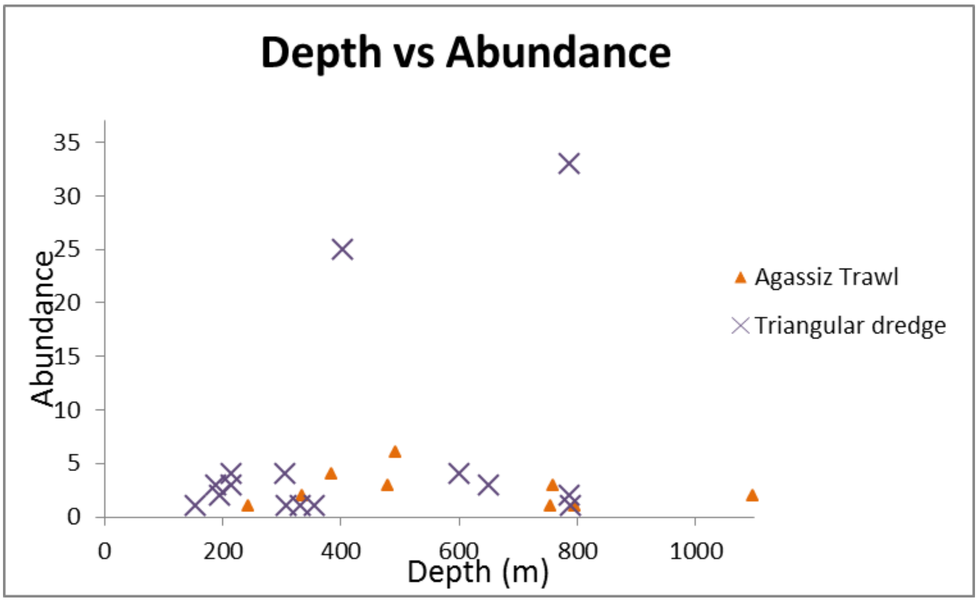
Appendix Figure B.1 Depth vs Species Richness for the Agassiz Trawl and Triangular Dredge.



Appendix Figure B.2 Depth vs H’ for the Agassiz trawl and Triangular dredge.



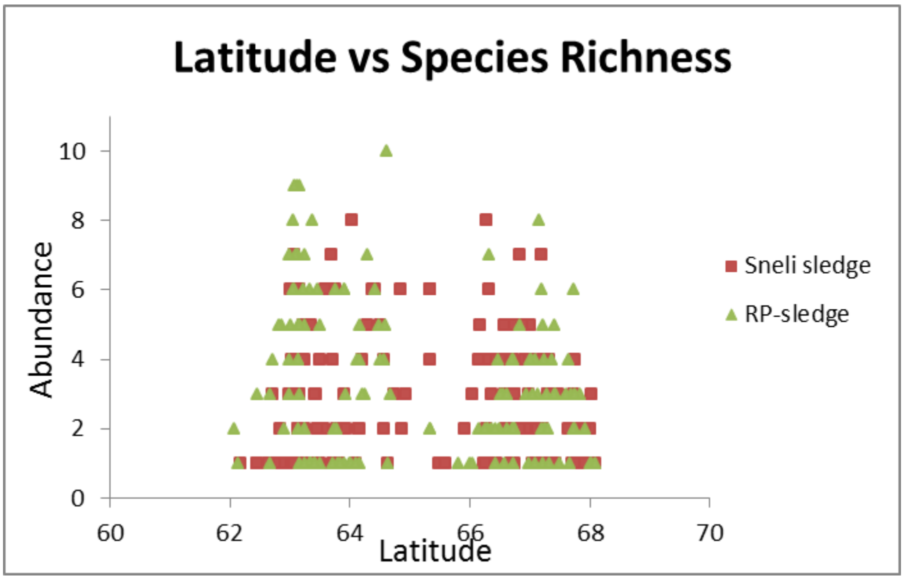
Appendix Figure B.3 Depth vs Abundance for the Sneli sledge and RP-sledge.



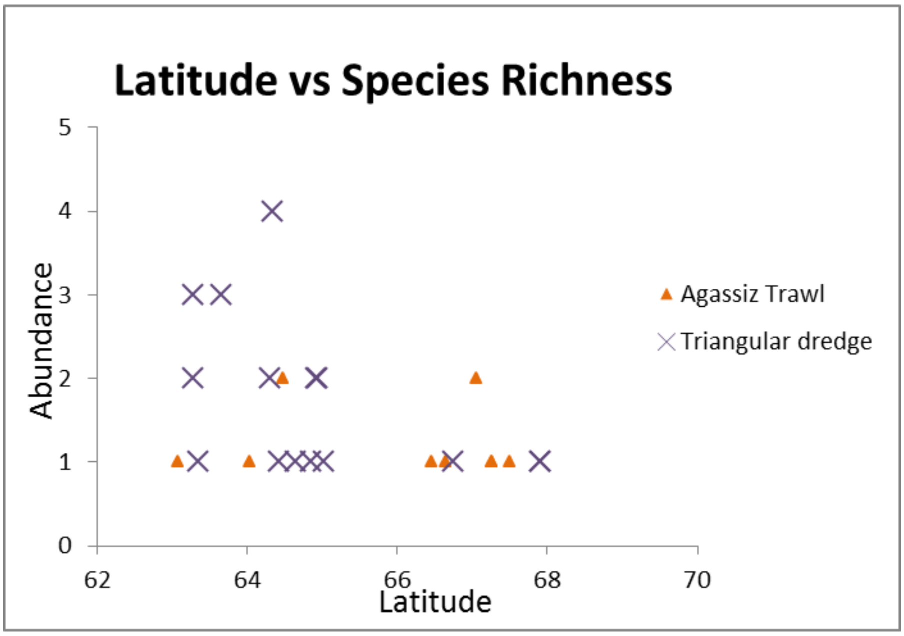
Appendix Figure B.4 Depth vs Abundance for the Agassiz trawl and Triangular dredge.

B.2 Latitude

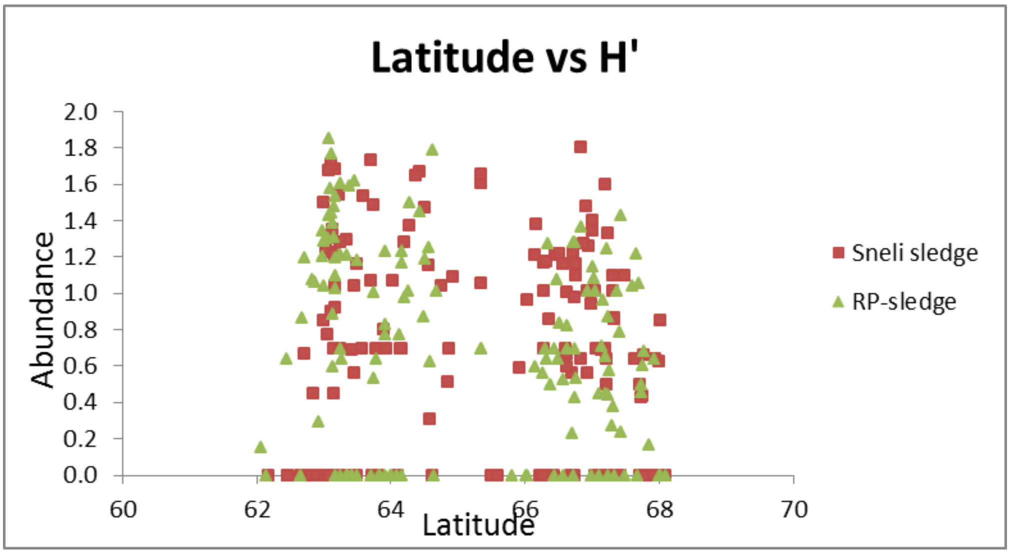
There was no correlation between latitude and species richness, latitude and H’ and latitude and abundance for the all gear types (Appendix Figure B.5-B.10).



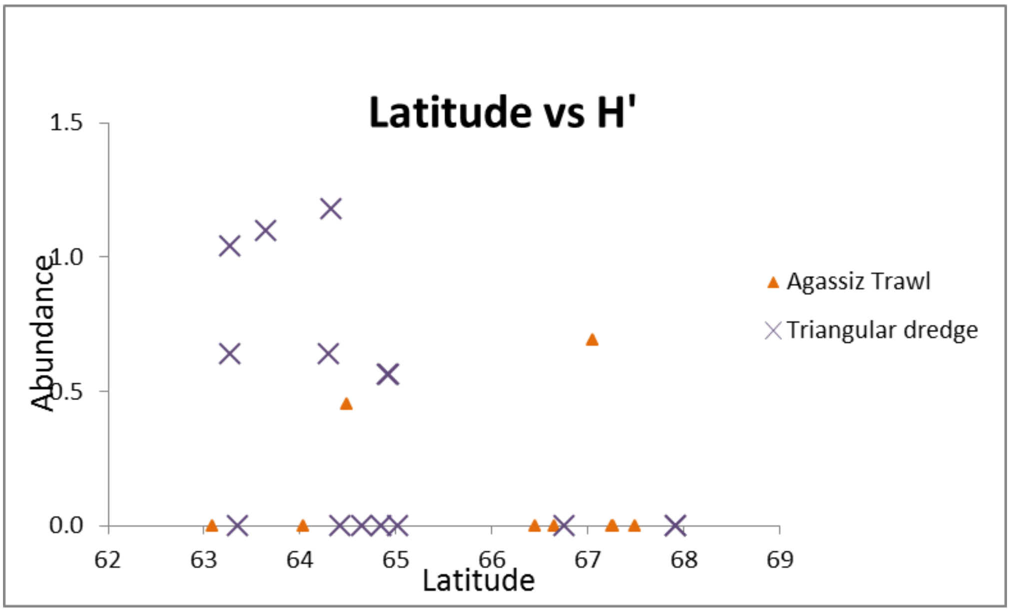
Appendix Figure B.5 Latitude vs species richness for the Sneli sledge and RP-sledge.



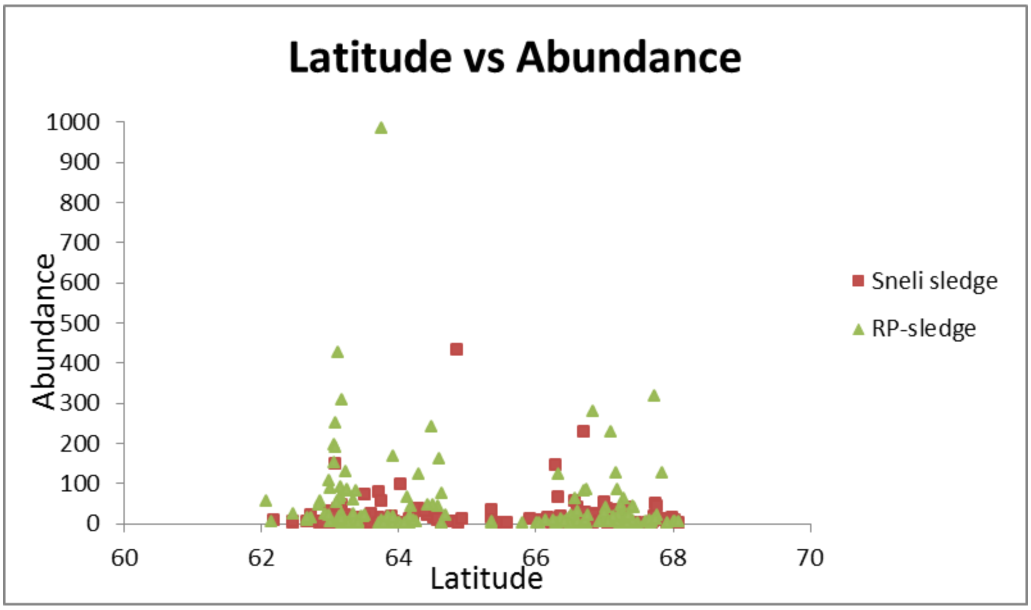
Appendix Figure B.6 Latitude vs species richness for the Agassiz trawl and Triangular dredge.



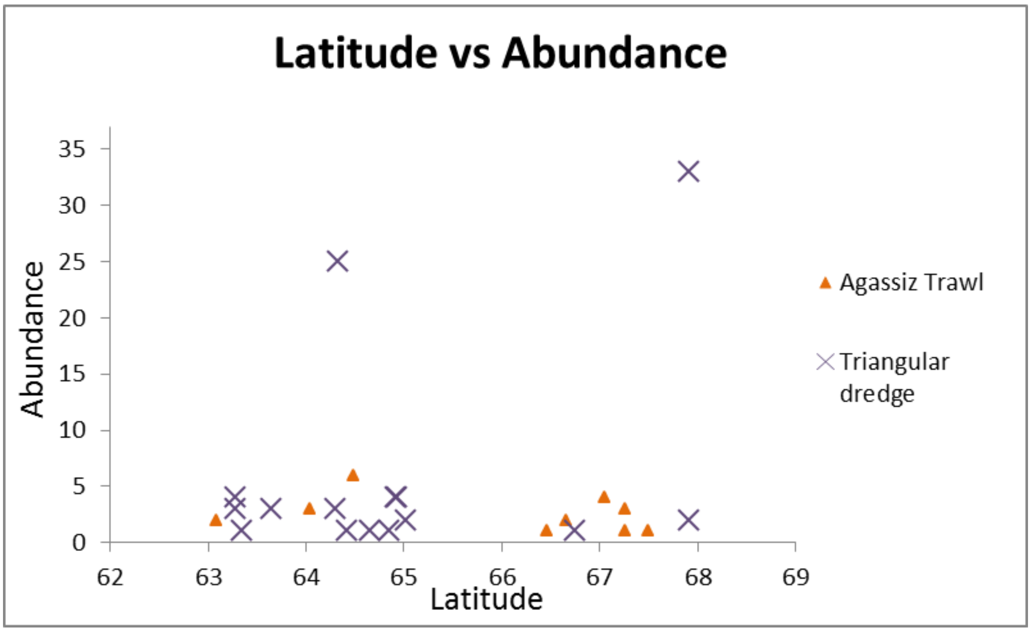
Appendix Figure B.7 Latitude vs H' for the Sneli sledge and RP-sledge.



Appendix Figure B.8 Latitude vs H' for the Agassiz trawl and Triangular dredge.



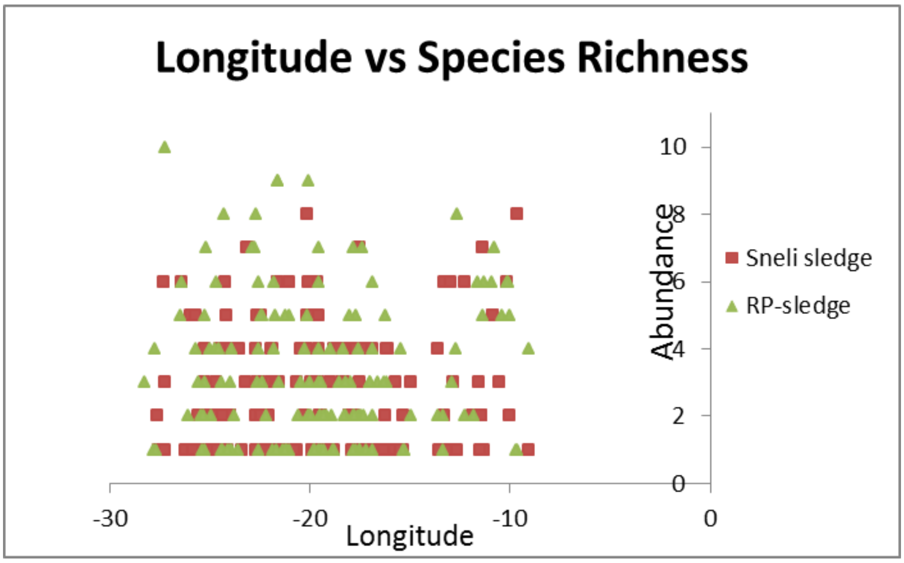
Appendix Figure B.9 Latitude vs H' for the Sneli sledge and RP-sledge.



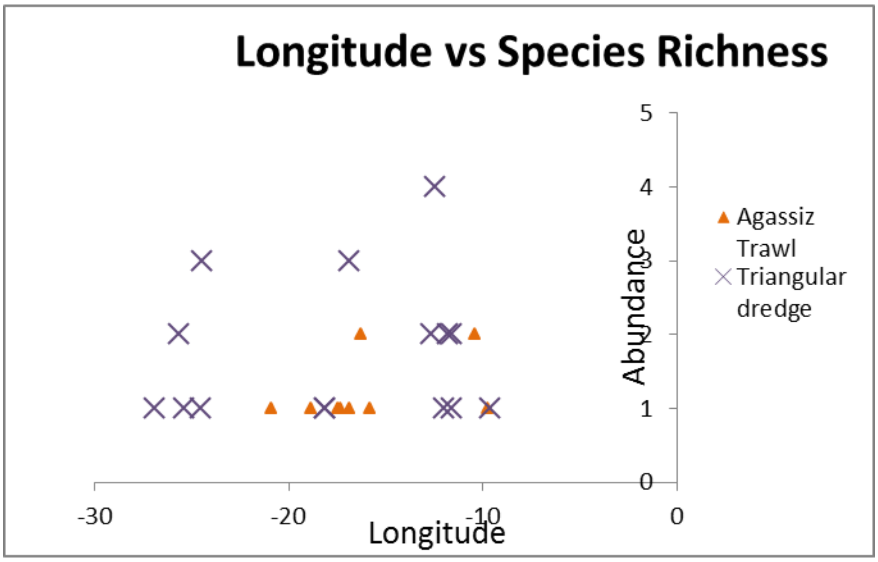
Appendix Figure B.10 Latitude vs H' for the Sneli sledge and RP-sledge.

B.3 Longitude

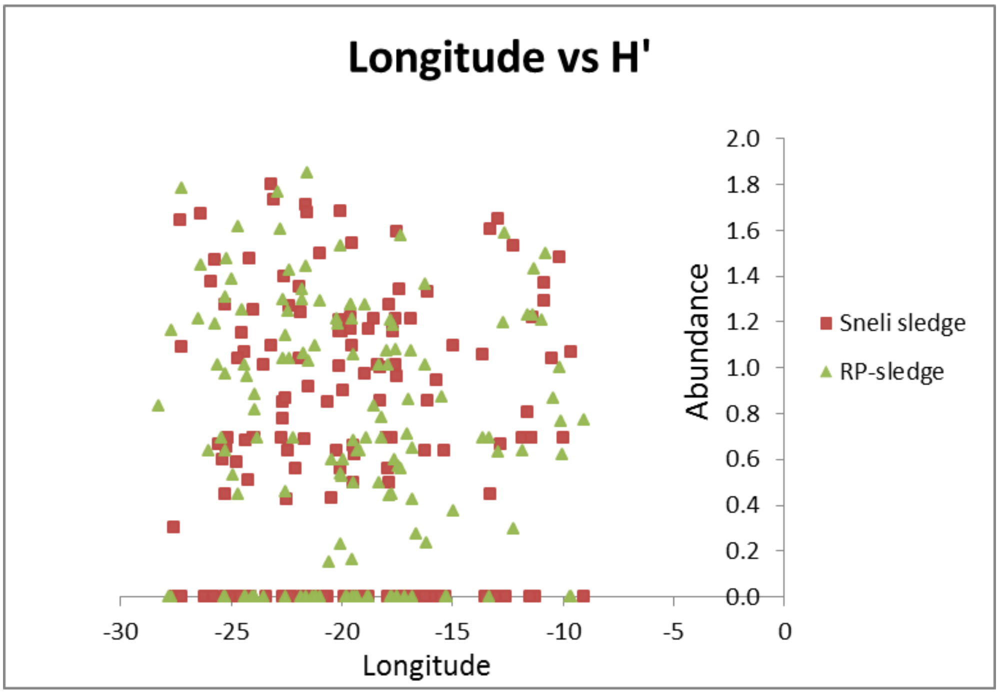
There was no correlation between longitude and species richness, latitude and H’ and latitude and abundance for the all gear types (Appendix Figure B.11-B.16).



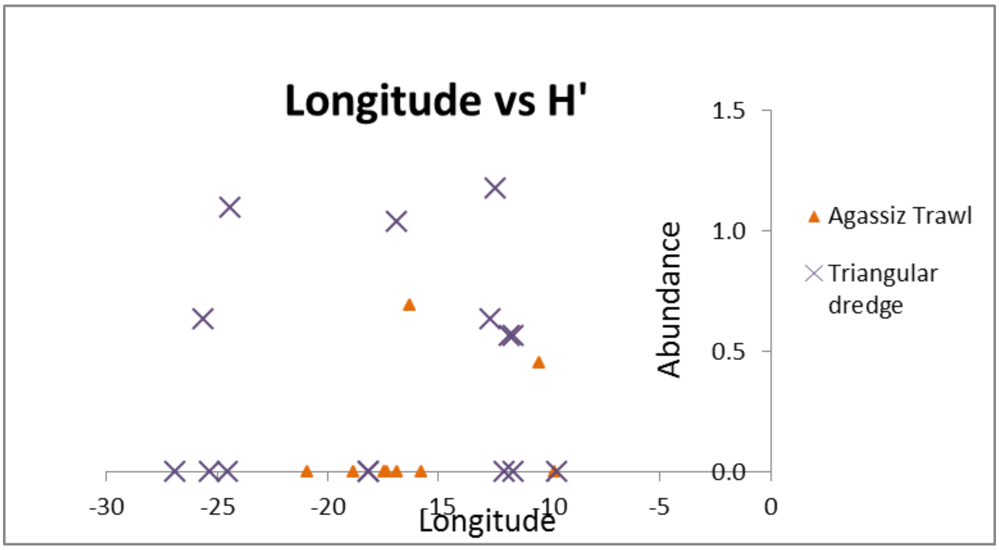
Appendix Figure B.11 Longitude vs species richness for the Sneli sledge and RP-sledge



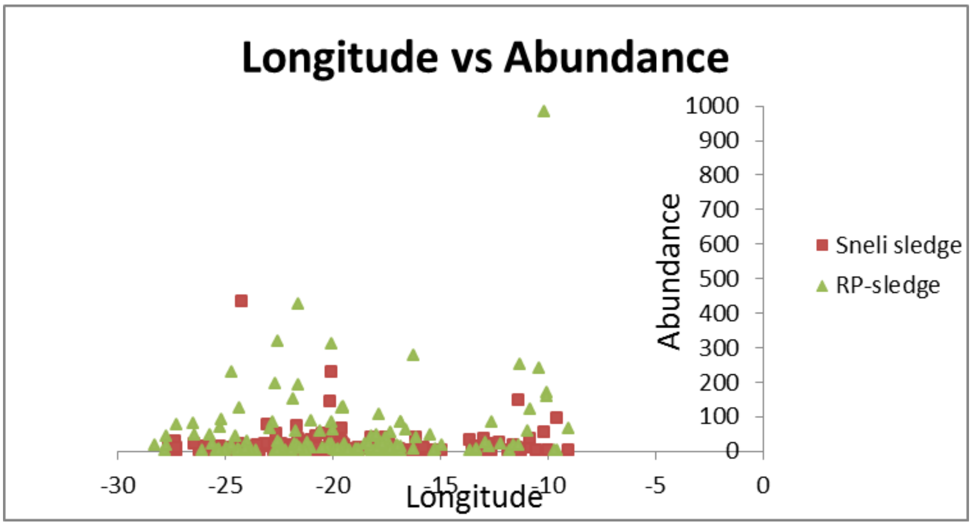
Appendix Figure B.12 Longitude vs species richness for the Agassiz trawl and the Triangular dredge



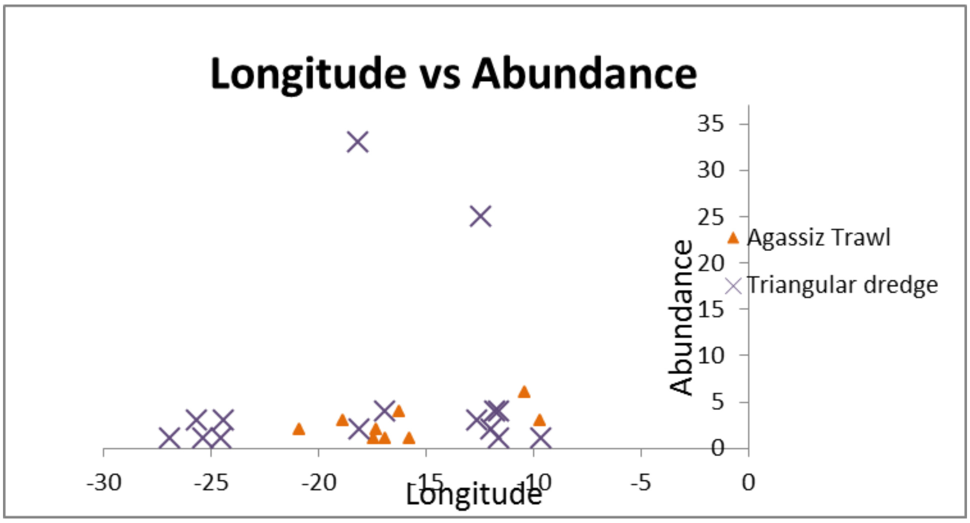
Appendix Figure B.13 Longitude vs H' for the Sneli sledge and RP-sledge



Appendix Figure B.14 Longitude vs H' for the Agassiz trawl and Triangular dredge



Appendix Figure B.15 Longitude vs abundance for the Sneli sledge and RP sledge



Appendix Figure B.16 Longitude vs abundance for the Agassiz trawl and Triangular dredge