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Benthic habitat mapping for the Laxey and Niarbyl Marine Nature Reserves around the Isle of Man

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Abstract

Coastal benthic habitats contain a wide range of habitats and species, but the use of benthic fishing gears threatens to degrade many of these habitats irreversibly. To maintain areas of high biodiversity, 10 Marine Nature Reserves (MNRs) have been designated around the Isle of Man. To aid fine-scale spatial management within 2 MNRs – Laxey and Niarbyl Bay – benthic habitat maps were constructed. Epifaunal species richness was also investigated in relation to substrate hardness to determine what habitats contained the greatest biodiversity. Benthic images were sampled from both MNRs (Laxey n = 377, Niarbyl n = 288), as well as benthic tow videos and BRUVs (Laxey n = 6, Niarbyl n = 8). Habitats were allocated using a statistical (SIMPROF) and qualitative (EUNIS allocation) approach separately, then constructed using extrapolation in ArcGIS. Habitat maps using the statistical approach were less consistent with more habitat types than with the qualitative approach, though extrapolation in both maps makes them unreliable for making fine-scale spatial management decisions. More robust maps could be constructed by incorporating fine-scale bathymetry. In Laxey, eelgrass appeared to be moving northwards outside of the currently established Eelgrass Conservation Zone, while maerl showed few signs of recovery. Niarbyl contained more macroalgae-dominant habitats. Species richness increased with substrate hardness in Laxey, but in Niarbyl habitats with a mix of substrate types had the greatest species richness. Overall, the relationship between species richness and the benthos is more complicated than substrate hardness alone can explain.

Keywords: Habitat Mapping; Benthos; Marine Protected Areas; Species Richness; Substrate; Monitoring; Eelgrass; Maerl; Benthic Images

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List of Abbreviations

ANOSIM	Analysis of Similarity
ANOVA	Analysis of Variance
BRUV	Baited Remote Underwater Video
DEFA	Department for Environment, Food and Agriculture of the Isle of Man Government
EUNIS	European Union Nature Information System
MNR	Marine Nature Reserve
MPA	Marine Protected Area
OSPAR	Convention for the Protection of the Marine Environment of the North-East Atlantic
SE	Standard Error
SIMPER	Similarity Percentage
SIMPROF	Similarity Profile
Tukey HSD	Tukey Honest Significant Difference

1. Introduction

1.1 Coastal Benthic Habitats and their Anthropogenic Threats

Coastal benthic habitats contain a wide variety of habitats and resources, supporting species of both conservational and commercial importance (Henseler *et al.*, 2019). Coastal benthic habitats exhibit a greater concentration of biodiversity than deep-water habitats, as observed by Gray *et al.* (1997) when comparing species richness between habitats between 0-185m with those between 200-5800m. This increased species richness is enabled by the range of environmental conditions and substrate types in shallower waters, leading to heterogeneity in benthic microhabitats (Coleman *et al.*, 2007; Kon *et al.*, 2015). This habitat heterogeneity encourages variation in both floral and faunal assemblages at smaller spatial scales than in deeper waters (Kon *et al.*, 2015). These different microhabitats may also be used by species at specific life stages before moving elsewhere, e.g. as a nursery during larval stages (Kraufvelin *et al.*, 2018; Henseler *et al.*, 2019), contributing to the high species richness observed in these habitats. In this way, coastal marine habitats can also support populations of pelagic and demersal species that primarily inhabit other habitats.

The increased biodiversity of coastal benthos along with its close proximity to land have led to aggregated anthropogenic disturbance in these habitats (Sciberras *et al.*, 2015). The variety of benthic microhabitats in coastal areas promotes greater abundances of epifaunal and infaunal species, hence the primary means of disturbance is benthic trawling. Benthic trawls impact sediment up to a depth of 35cm (Oberle *et al.*, 2016), and can significantly alter substrate properties, including pH and salinity (Das, 2020). On a wide enough spatial and temporal scale, microhabitats that depend upon specific substrate properties may be irreparably degraded by constant benthic trawling (Coleman *et al.*, 2007), in turn significantly reducing biodiversity as a whole. This outcome is particularly likely in coastal benthos due to the aforementioned habitat heterogeneity observed in these regions. Habitat degradation caused by unregulated benthic trawling would also lead to significant economic losses, as stocks of commercial infaunal and epifaunal species would replenish slower due to reduced ecosystem functioning.

Climate change is another anthropogenic factor, which influences marine coastal benthos at a greater scale than benthic trawling. Climate change has led to various changes in environmental conditions, leading to ocean acidification, rising sea level and increased sea surface temperature across the globe (Chust *et al.*, 2022). These impacts have triggered spatial shifts in coastal benthic habitats towards higher latitudes and greater depths (Poloczanska *et al.*, 2016; Chust *et al.*, 2022). Since coastal benthic habitats feature a wide range of species with differing responses to these changes, it is very difficult for conservationists to predict how community compositions and distributions of important microhabitats will be impacted by climate change (Poloczanska *et al.*, 2016).

1.2 Protecting Coastal Benthos

Climate change is difficult to limit via policy measures, but direct disturbances like benthic trawls can have imposed restrictions to prevent irreversible damage. Protection of the various coastal benthic microhabitats can both prevent biodiversity loss and help maintain economic output by encouraging long-term, sustainable use of resources. There are numerous means by which areas containing exploited resources can be protected, the most common of which being by designating Marine Protected Areas (MPAs).

MPAs are designated areas by some form of policy that forces limitations on anthropogenic disturbance, aimed at aiding sustainable use of the species and resources within the area (JNCC, 2019). Establishing these areas can significantly increase biodiversity (Figure 1) (Consoli *et al.*, 2013) while reducing disturbance of vulnerable habitats.

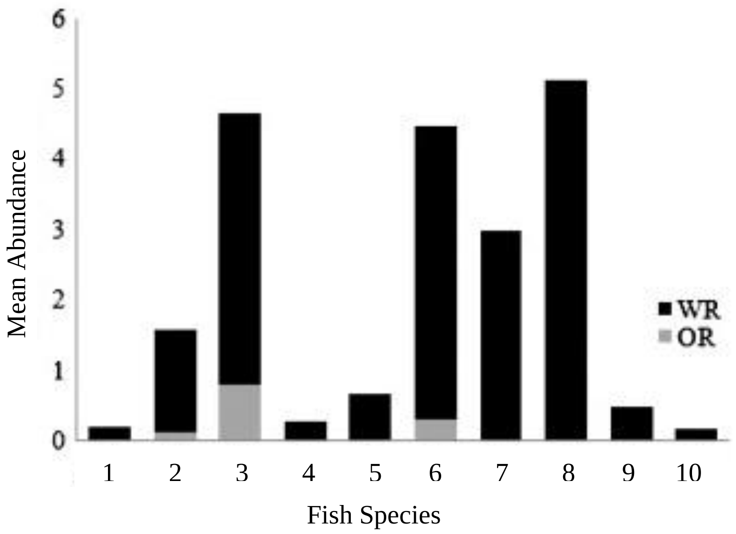


Figure 1. Mean abundances of 10 fish species within (WR) and outside (OR) the Plemmirio MPA, Italy. (Figure from Consoli *et al.*, 2013)

MPAs can vary in restriction levels, with the strictest being No-Take Reserves (NTRs) while others with less severe restrictions are Partially Protected Areas (PPAs) (Sciberras *et al.*, 2015). The most effective MPAs are those which employ a range of restriction levels, allowing stakeholders who make use of the area's resources to continue making use of them, while areas with more vulnerable habitats or that contain species of interest are more strongly protected (Sciberras *et al.*, 2015). Forming these compromises with stakeholders is key, as adherence to MPA restrictions is a major contributing factor towards the overall effectiveness of an MPA (Metcalfe *et al.*, 2013; Dehens and Fanning, 2018). If restrictions are not strongly enforced, they may be completely overlooked, leading to the MPA becoming a paper park – an MPA in which the level of anthropogenic disturbance is the same outside the area as within (Ban *et al.*, 2017).

Even when MPA restrictions are adhered to, MPA effectiveness can still vary depending on the target species or habitat in question. For example, the Gilbert Bay MPA in Labrador, Canada, aimed to conserve populations of the Atlantic cod *Gadus morhua*, but migration of the species outside of the MPA led to an 83% decline in biomass over 14 years (Morris and Green, 2014). After this decline was discovered, fishing limits at certain times of year were suggested to align with migration patterns as a form of adaptive management – a change to restrictive policies to increase MPA effectiveness. This study highlights the importance of MPA monitoring over time to determine whether adaptive measures are needed to meet conservation objectives.

1.3 Important Species and Habitats around the Isle of Man

The primary substrate types around the Isle of Man consist of gravel mixed with varying degrees of sand (Ward *et al.*, 2015). Maximum depth around the coastline varies, with a maximum depth of 20m on the northern and western coastlines, and a 50m maximum on the southern and eastern coasts (Figure 2).

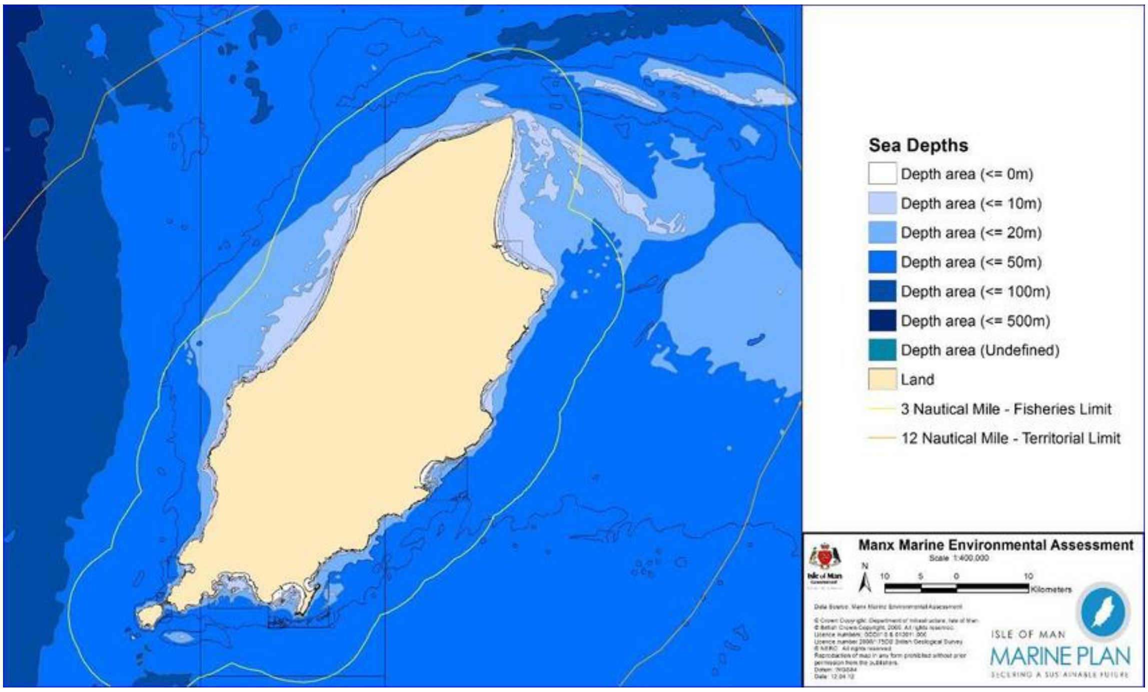


Figure 2. Bathymetry of the Manx Territorial Sea (Figure from Kennington and Hisscott (2013)).

Notable habitats of conservational relevance around the Isle of Man include biogenic reefs, in particular maerl beds. Maerl in itself is a nodular, coralline red algae which forms branch-like structures (Wilson *et al.*, 2004), hence maerl beds are formed when many individual nodules of maerl are situated in close proximity. Maerl beds have been identified as OSPAR priority habitats (Szostek *et al.*, 2017), partially for constituting a cryptic habitat for juvenile fish and scallops (Kamenos, Moore and Hall-Spencer, 2004) during their development. Eelgrass beds have been defined as an important habitat by the DEFA (Duncan, 2018), as they contain a wealth of invertebrate species (Henseler *et al.*, 2019). Both of these habitats are strongly impacted by trawling activity (Duncan, 2018), hence warrant a greater degree of protection where present.

Many commercially relevant species reside within the shallow coastal benthos around the Isle of Man, with the most notable being the king and queen scallops, *Pecten maximus* and *Aquepectin opercularis* respectively. Their combined landings from the Irish Sea generated £8.36 million to the UK economy in 2020 from a catch of 6.298 tonnes (MMO, 2021). Other commercial species include the common whelk *Buccinum undatum*, the langoustine *Nephrops norvegicus* and the brown crab *Cancer pagurus* (Öndes *et al.*, 2019; Emmerson *et al.*, 2020). Since these species are all benthic, coastal water around the Isle of Man have been fished using either crab pots or benthic trawls (Öndes, Kaiser and Murray, 2016; 2018). Benthic trawls contribute significantly towards widespread habitat degradation (Foden, Rogers and Jones, 2011), whereas crab pots cause far less disturbance due to their reduced penetrative depth alongside their use of escape panels for non-target species (Öndes, Kaiser and Murray, 2016). Trawling fisheries have also led to many species being impacted as bycatch (Table 1), which can constitute around 7.42±0.52% of mean catch weight (Boyle *et al.*, 2016).

Table 1. Mean abundances (±SE) per hectare of the fish and invertebrate bycatch species that caused the highest dissimilarity between 4 fishing grounds (colloquial names) taken from SIMPER analysis (Table from Boyle *et al.*, 2016)

	Chickens	Douglas	Ramsey	Targets
Invertebrates				
Alcyonium digitatum	30.47 ± 8.39	112.52 ± 34.8	49.26 ± 17.64	59 ± 21.93
Ophiura	13.37 ± 3.92	3.30 ± 0.89	20.73 ± 5.23	6.97 ± 1.84
Ophiothrix fragilis	9.61 ± 3.75	37.78 ± 24.05	1.35 ± 0.44	0.69 ± 0.34
Psammechinus miliaris	1.21 ± 0.49	19.08 ± 5.14	57.87 ± 25.25	24.74 ± 11.86
Ascidiacea	15.70 ± 3.76	13.47 ± 2.74	3.19 ± 1.50	6.81 ± 1.97
Archidorispse udoargus	8.43 ± 4.21	0.82 ± 0.43	0.94 ± 0.53	5.24 ± 0.96
Diodora graeca	–	10.51 ± 3.28	0.35 ± 0.24	–
Hydroidea	4.69 ± 2.51	0.56 ± 0.45	7.65 ± 2.77	3.61 ± 1.93
Inachus dorsettensis	3.95 ± 1.54	0.11 ± 0.11	6.18 ± 1.49	3.32 ± 1.14
Suberite domuncula	0.48 ± 0.34	2.58 ± 0.86	5.23 ± 1.74	0.29 ± 0.17
Asterias rubens	1.99 ± 0.43	31.38 ± 4.49	19.12 ± 4.26	24.56 ± 2.47
Crossaster papposus	0.17 ± 0.17	8.09 ± 2.27	0.58 ± 0.28	–
Buccinum undatum	–	4.90 ± 1.47	–	0.32 ± 0.24
Elasmobranch and teleost fish				
Scyliorhinus canicula	2.6 ± 0.62	3.26 ± 0.57	2.51 ± 0.47	1.39 ± 0.24
Limanda limanda	2.41 ± 0.88	1.98 ± 0.49	1.18 ± 0.23	1.14 ± 0.25
Eutrigla gurnardus	0.39 ± 0.09	1.22 ± 0.40	0.20 ± 0.09	0.5 ± 0.14
Melanogrammus aeglefinus	3.73 ± 0.72	0.29 ± 0.29	–	1.42 ± 0.40
Microstomus kitt	2.28 ± 0.36	0.26 ± 0.08	–	0.53 ± 0.11
Pleuronectes platessa	0.77 ± 0.15	1.88 ± 0.55	0.30 ± 0.07	0.33 ± 0.06
Aspitrigla cuculus	3.32 ± 0.58	2.73 ± 0.37	1.13 ± 0.33	0.68 ± 0.13
Trigla lucerna	0.15 ± 0.04	0.42 ± 0.08	0.34 ± 0.07	0.13 ± 0.05
Merlangius merlangus	1.53 ± 0.59	0.08 ± 0.04	0.42 ± 0.11	1.80 ± 0.41
Callionymus lyra	0.09 ± 0.06	0.23 ± 0.06	0.07 ± 0.03	0.24 ± 0.08
Liophius piscatorius	0.20 ± 0.04	0.09 ± 0.03	0.02 ± 0.01	0.02 ± 0.01
Trisopterus minutus	0.14 ± 0.08	0.08 ± 0.08	–	0.37 ± 0.22

1.4 Existing Management & Monitoring

Around the Isle of Man, Marine Nature Reserves (MNRs) – a type of MPA exclusive to Manx waters (JNCC, 2019) – have been established to manage anthropogenic disturbance. Ten MNRs have been designated around the Isle of Man (Figure 3), encompassing 51.8% of its territorial waters (0-3 nautical miles) (DEFA, 2021a). In these areas, mobile fishing gears are strictly prohibited, while static gears like crab pots can be used in most areas where priority habitats are not present (Duncan, 2018). These MNRs have previously proven to be successful at increasing abundances of commercial species. For instance, catchments of *P. maximus* in Ramsey Bay after 4 years of MPA establishment exhibited a ninefold increase in capture rate compared to catchments during the same year outside of the MPA (Dignan *et al.*, 2014). However, many of these MNRs do not have fully established management plans due to their relative recency of establishment (Schéré, Dawson and Schreckenberg, 2020).

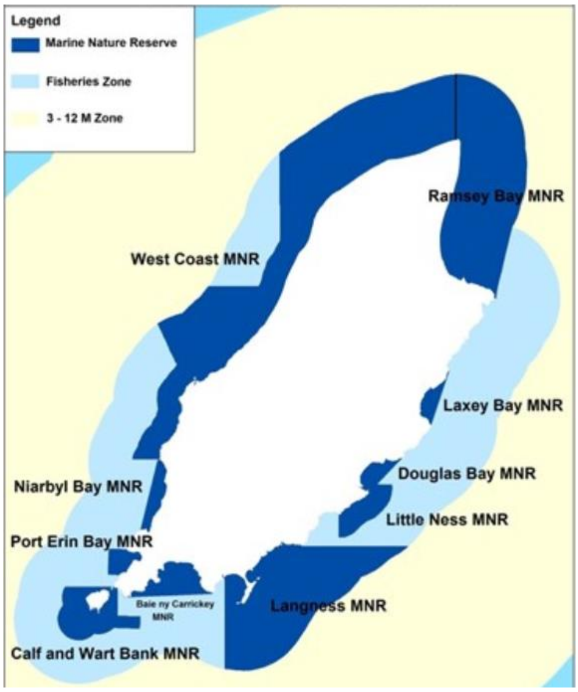


Figure 3. The distribution of MNRs around the Isle of Man as of 2018. Light yellow indicates territorial waters between 3 and 12 nautical miles from shore, while dark blue areas indicate designated MNRs alongside respective labels denoting their location (Image from DEFA (2021))

Spatial management plans can be informed by benthic habitat mapping, which can help determine the extent of priority habitats to allow a mix of restriction levels in a spatial management plan. Since many of the important commercial species around the Isle of Man are benthic, information on community composition and habitat distribution provided by benthic habitat mapping allows an insight into how restricting anthropogenic disturbance could benefit both biodiversity and stakeholders who target those species in the long-term. Information on species richness between different habitats can also help inform what habitats may be of higher priority to conserve, which can also be discerned by benthic surveys as part of habitat mapping.

1.5 Aim, Objectives, and Hypothesis

Benthic surveys of the MNRs are essential to inform robust and effective spatial management planning, though both the Laxey and Niarbyl Bay MNRs have yet to be mapped. This analysis aims to aid in the monitoring and spatial management for both of these MNRs by constructing habitat maps. To meet this aim, 3 main objectives have been set:

- Objective 1 – Constructing fine-scale benthic biotope maps using benthic survey data alongside EUNIS habitat classification, both for the Laxey and Niarbyl MNRs.
- Objective 2 – Identify organisms recorded by BRUV footage and seabed images to the lowest taxonomic level, reporting the presence of species of particular commercial/conservational interest.
- Objective 3 – Provide recommendations for spatial zoning and possible adaptive measures using said benthic biotope maps and species identification.

To further inform recommendations for spatial zoning, species richness between different habitats will also be investigated. It is predicted that soft substrates will be dominated by burrowing species within the benthos, whereas habitats with hard substrates will allow a more diverse macroalgal community, in turn supporting a wider range of species, or a more cryptic environment for juveniles of various species to evade predation. As such, the tested hypothesis is that benthic habitats with a harder substrate will have a greater epibenthic species richness than habitats with a softer substrate in both the Laxey and Niarbyl MNRs.

2. Methods

2.1 Study Area

Benthic survey data was taken from both the Laxey and Niarbyl MNRs off the coast of the Isle of Man (Figure 4a&b), encompassing 3.97km² and 5.66km² respectively. Within these MNRs, the use of mobile fishing gears like benthic trawls are prohibited. Furthermore, the Laxey Bay MNR contains an Eelgrass Conservation Zone (Figure 4c) within which static fishing gears are additionally prohibited (DEFA, 2021a).

Figure 4. The area designated as (a) the Niarbyl Bay MNR, (b) the Laxey Bay MNR and (c) the Eelgrass Conservation Zone within Laxey Bay MNR (Figures from DEFA (2021))

2.2 Data Collection

Benthic trawl videos and still images were recorded using an underwater video sledge – a metal framework on skis, towed over the seabed by a vessel. As surveying took place in a protected area, the sledge was designed to minimise contact with the seabed. Two cameras were used on the sledge: a Canon EOS 400D to capture still images every 10 seconds (FOV 44×29cm), and a GoPro HERO3 to record continuous video footage (FOX ~62×35cm). Two underwater lights were fitted to the sledge to brighten the video footage and still images of the benthos.

Surveying of Laxey Bay took place on the 14th and 15th June 2016. Six transects were sampled to collect an even distribution of data (Figure 5a) over the course of 60 minutes, at a speed of ~1 knot. This led to 360 photographs being taken from each tow. To allow photographs to be geo-referenced, GPS data (including time and vessel speed) were recorded every 30 seconds throughout the survey, and the start and end times of each tow documented.

Niarbyl surveys took place on the 20th of June, with 27 transects sampled (Figure 5b) each for 10 minutes at ~1 knot, to collect an even distribution of data throughout the area. This resulted in 60 photographs recorded per transect. GPS data was recorded every 30 seconds during surveying to allow geo-referencing, as well as the start and end times of each tow documented.

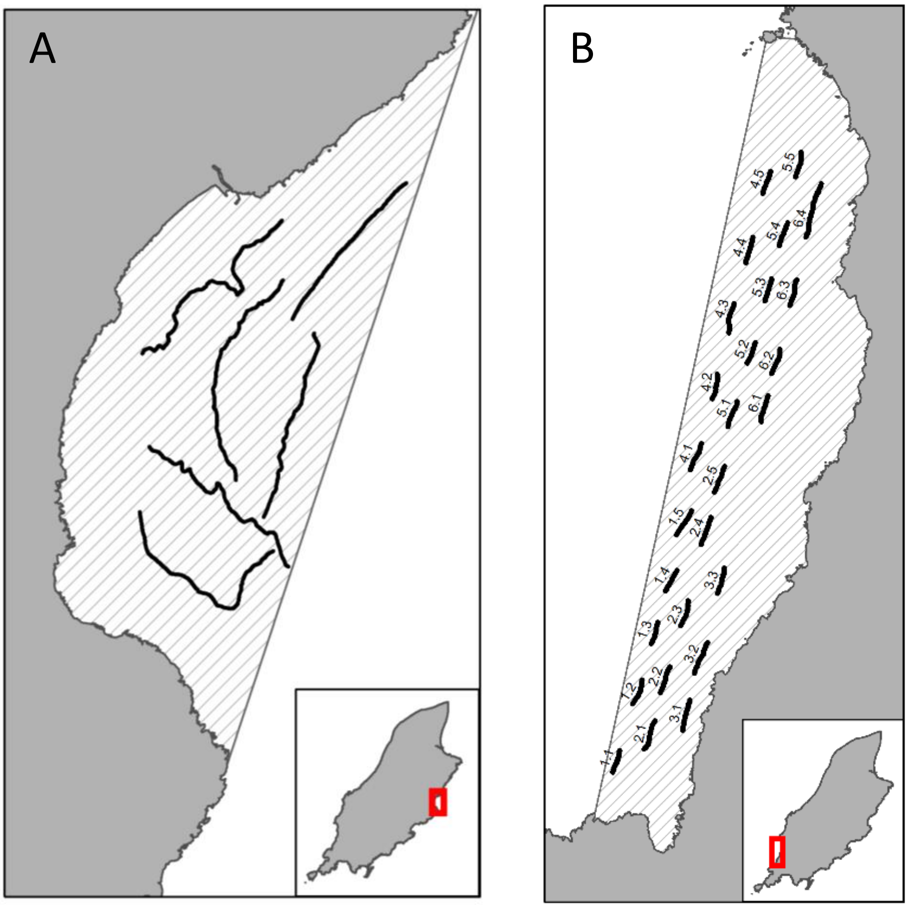


Figure 5. Maps illustrating the locations of transects recorded from the (a) Laxey and (b) Niarbyl Bay MNRs. Niarbyl transects are labelled by tow number, then transect number. For example, 2.3 indicates the third transect of the second tow.

BRUVs were deployed randomly between the 14th and 20th June 2016 for varying amounts of time, between 40-120 minutes. These were sampled at 6 locations in Laxey and 8 locations in Niarbyl (Figure 6). The BRUV consisted of a de-meshed lobster pot with bait, a GoPro Hero 3 camera and an underwater light attached to the frame.

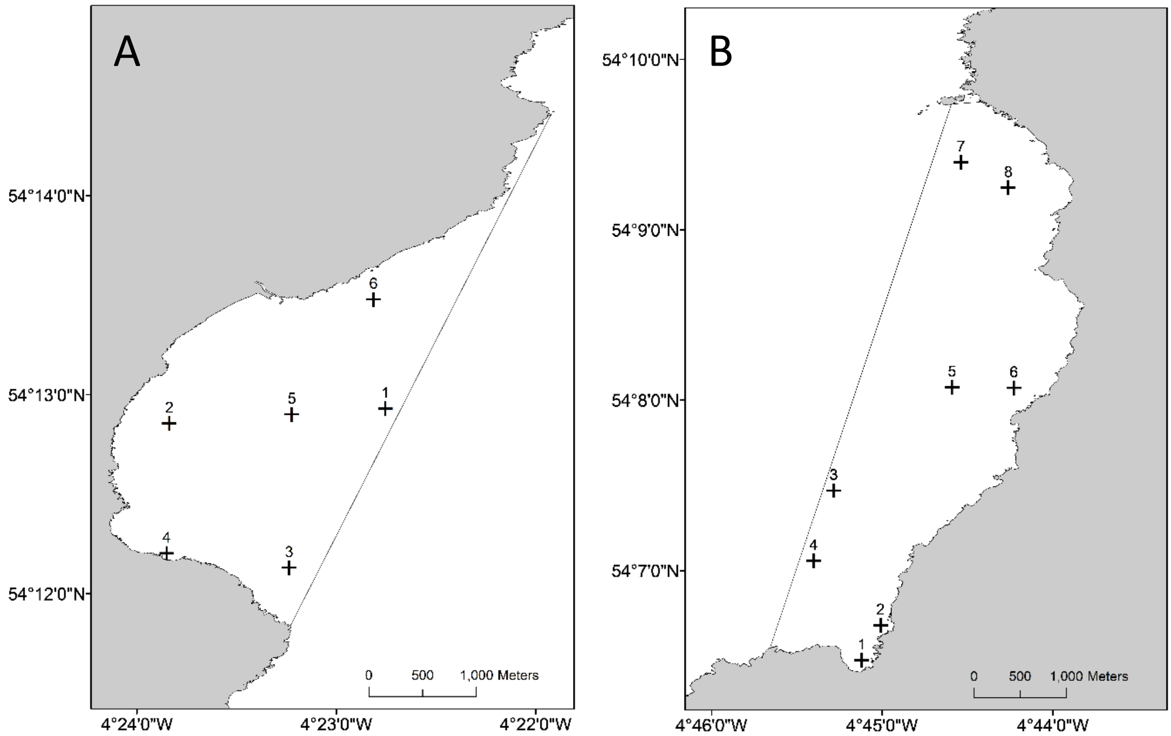


Figure 6. Maps illustrating the locations of BRUVs deployed in (a) Laxey and (b) Niarbyl.

2.3 Image & BRUV Analysis

Still images were analysed rather than frames of video footage to eliminate the possibility of blurry frames and reduced resolution affecting the analysis. To account for the high quantity of images and for time constraints, every 6th photograph was analysed (1 per minute of tow). These images were then assessed using a standardised scoring technique (Table 2) adapted from Hannah and Blume (2012).

Table 2. Scoring system used to determine the visibility and quality of images taken during benthic surveys of Laxey and Niarbyl Bay MNRs (Adapted from Hannah and Blume (2012)).

Score	Visibility	Quality
0	0% visibility	Photograph completely blurred, major issue with lighting or camera angle
1	<50% visibility, e.g. if obscured by suspended sediment	Photograph largely blurred, obscuring benthos
2	>50% visibility, view partly obscured	Photograph partly blurry, benthos mainly discernible
3	100% visibility	Clear photo

Images which scored 0 or 1 in either category were replaced by either the subsequent or previous image (randomly), given that the new image did not score 0 or 1 in either category. If these criteria were not met, the first image that scored the highest was selected instead.

Images were then analysed using point sampling (as illustrated by Figure 7) using the software ImageJ (Schneider, Rasband and Eliceiri, 2012). To estimate percentage cover, 5×8 grid was overlain over each image, then the substrate or organism beneath each point was counted and recorded, with each point representing 2.5% cover. Sediment cover was split into 5 main categories – sand/mud, gravel, pebble, boulder, and shell. Gravel, pebble, and boulder were distinguished by the size of stones that points fell on, though no strict parameters were set for distinguishing between gravel and pebble; distinctions between these groups were largely subjective.

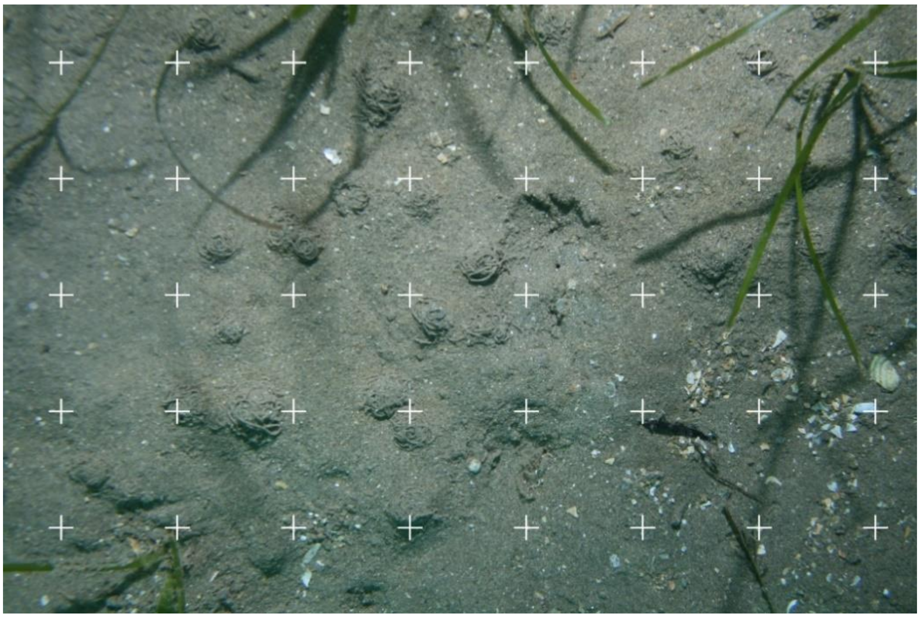


Figure 7. Image demonstrating the standardised point sampling grid used to extract percentage cover data, with each point representing 2.5% of the image. In this example, 36 points fell on sand, equating to 90% cover.

The presence of any flora or fauna was recorded, with species identified to the lowest possible taxonomic level, or with a suitable physical description when necessary – e.g. for organisms too small to identify, or that could not be seen clearly in the image. Abundance data was recorded for epifaunal species whose frequencies could be feasibly counted, e.g. crustaceans or fish, otherwise only presence or absence was recorded.

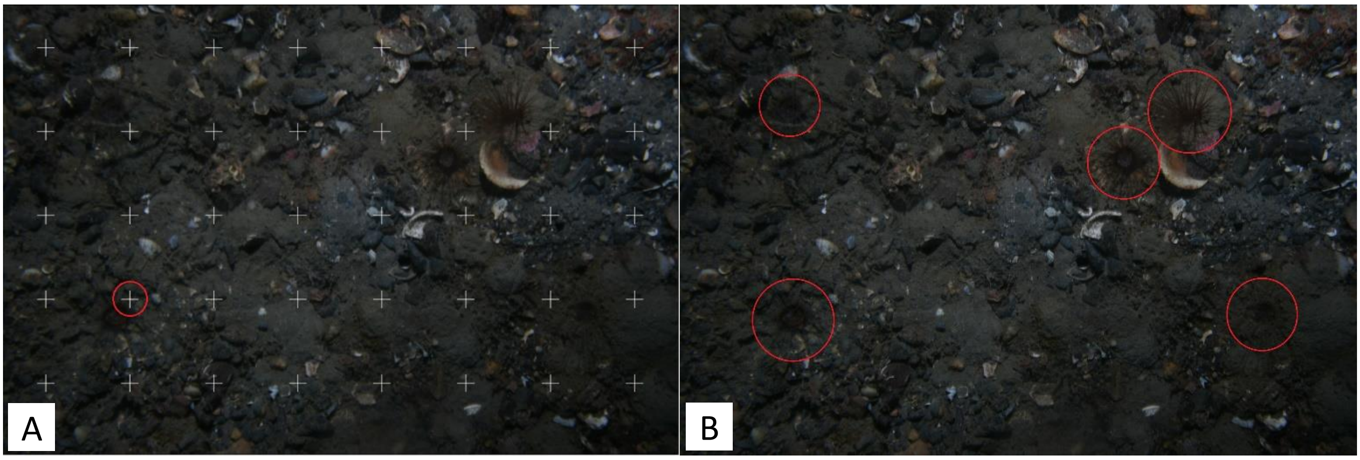


Figure 8. Image demonstrating how a species was recorded in terms of (a) percentage cover versus (b) total abundance. In this example, percentage cover of the anemone *Cerianthus lloydii* was counted as 2.5% as denoted by the red circle around the cross in Image A. Total abundance of *C. lloydii* was counted as 5, with each individual circled in red in Image B.

BRUV analysis primarily involved reporting species to the lowest taxonomic level and their abundance in terms of 'max*N*' – the maximum abundance of each species visible in the video. Previous studies of benthic assemblages have deployed BRUVs throughout a wider timeframe (Herbert *et al.*, 2017) or in conjunction with other static benthic survey gears (Switzer *et al.*, 2020) to allow quantitative analysis of mobile species' abundances. Due to the inconsistencies in BRUV deployment and the single type of gear deployed, these max*N* abundances were only analysed qualitatively. BRUV analysis also involved discerning species of interest to meet Objective 2, using mobile species' abundances as evidence towards suggested MNR management as per Objective 3.

2.4 Statistical Analysis & Habitat Allocation

Percentage cover data for both MNRs was square root transformed to reduce the influence of higher values throughout statistical analysis. A dissimilarity matrix of square root transformed percentage cover was constructed using Euclidean distance dissimilarity, then hierarchical clustering was applied using Ward's minimum variance. Benthic habitats were then distinguished from this dataset via SIMPROF analysis ($\alpha = 0.01$) using the vegan package in R version 1.3.1093. The resulting significantly differing groupings of images were treated as different habitat types. Initially Bray-Curtis dissimilarity was to be used instead of Euclidean distance, but errors within the vegan package prevented Bray-Curtis dissimilarity from being applied.

ANOSIMs helped determine whether other concurrent data showed greater similarity when assorted into SIMPROF groups rather than as a random assortment. Within-group similarity of 4 data types was investigated using ANOSIMs: percentage cover, species presence-absence data, species richness and epifaunal abundances.

SIMPER analysis of SIMPROF clusters was also used to identify which species contributed to the clustering arrangement. SIMPER analysis was carried out using PRIMER 7 Version 7.0.21.

After SIMPROF analysis, each image was separately assigned a EUNIS habitat type both using images and video footage of each tow, according to the EUNIS habitat classification system. EUNIS habitats are categorised in a hierarchical system, increasing in complexity as levels increase (EEA, 2019) (Table 3). This system was selected as it has undergone revision as of 2016 to increase its suitability in describing marine benthic habitats in the Atlantic (Montefalcone, Tunesi and Ouerghi, 2021). ANOSIMs and SIMPER tests were then conducted using the EUNIS groupings, to allow comparison between the suitability of both clustering methods.

Table 3. Example of EUNIS hierarchical approach to habitat classification. Level signifies the tier of classification, while category describes what factor(s) are considered for that level of classification. EUNIS and JNCC codes are 2 different naming schemes used for EUNIS habitat types.

Level	**Category**	**Example**	**EUNIS Code**	**JNCC Code**
1	Environment	Marine	A	--
2	Broad habitat type	Sublittoral sediment	A5	SS
3	Complex habitat type	Sublittoral mud	A5.3	SS.SMu
4	Biotope Complex	Circalittoral sandy mud	A5.35	SS.SMU.CSaMu
5	Biotope & Sub-biotope	*Amphiura filiformis* and *Nuculoma tenuis* in circalittoral and offshore sandy mud	A5.353	SS.SMU.CSaMu. AfilNten

2.5 Benthic Habitat Map Construction

The aforementioned recordings of GPS co-ordinates taken approximately every 30 seconds were then associated with their respective images. Two benthic habitat maps were constructed per marine reserve – one that present habitats distinguished solely by SIMPROF analysis, followed by another that employs EUNIS habitat classification informed by sample images and tow video footage. Both of these types of habitat designations were also associated with their respective images. Benthic habitat maps were then constructed using the Euclidean Allocation function in ArcGIS Version 10.8.1. Euclidean allocation analysis used the positions and habitat designations to extrapolate habitat types of the surrounding, non-sampled area to construct habitat maps that encompassed the entire MNR. The resulting fine-scale habitat maps met Objective 1.

2.6 Species Richness Analysis

Once EUNIS assignments were completed, ANOVAs were performed along with Tukey HSD post hoc tests (α = 0.05) to determine which habitats significantly differed from one another in terms of species richness. Each habitat was also assigned a substrate category based on whether it was 'hard,' 'soft,' or 'mixed,' with any significant differences between habitats then compared with their respective substrate categories to address the hypothesis.

After BRUVs were associated with their respective EUNIS habitat type, qualitative assessment of the hypothesis also involved comparing species richness between these videos to incorporate larger, more mobile demersal species as well as mobile benthic predators in this analysis.

3. Results

3.1 Distribution of sampled images

The raw dataset was subset to every 6th image, then image quality and visibility was assessed as per the methodology. A total of 377 still images from Laxey (Figure 8a) and 288 from Niarbyl (Figure 8b) constituted the dataset for further analysis. Areas that are far from a sampled datapoint (e.g. the northernmost extent of the Laxey MNR) are less reliable due to extrapolation.

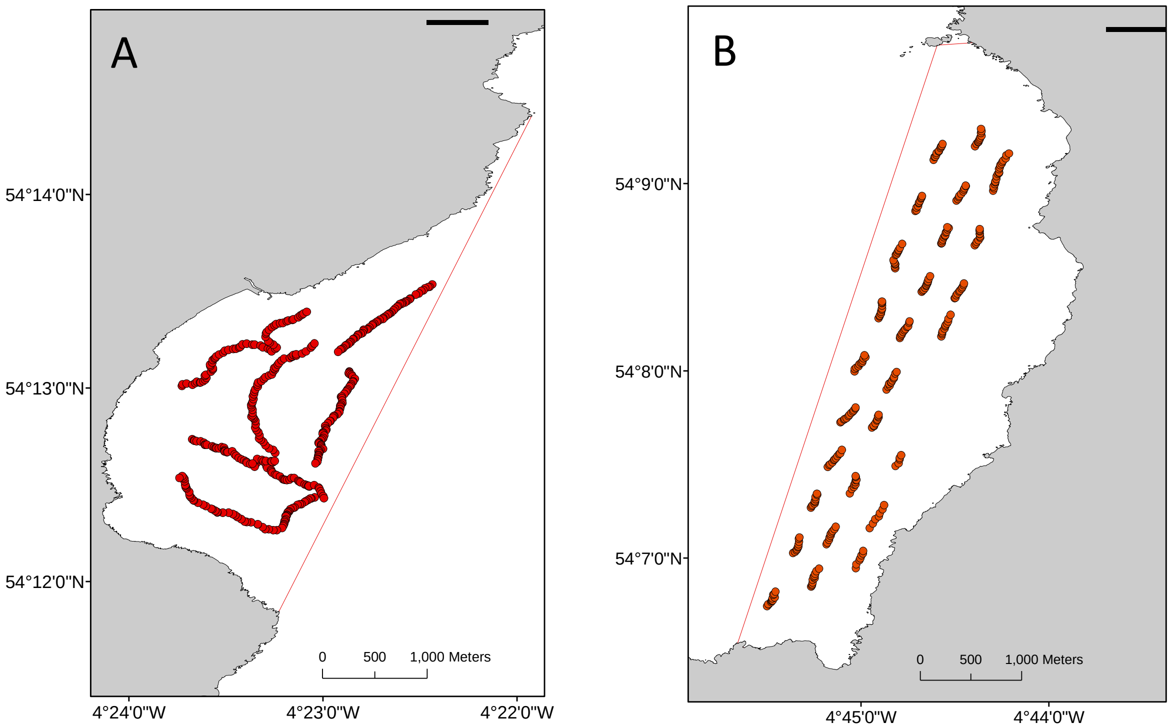


Figure 9. Distribution of sampled images from (a) Laxey (n = 377) and (b) Niarbyl (n = 288). Red circles represent the location of each still image, red lines indicate the extent of the MNR.

3.2 Benthic Image Analysis, Statistical Analysis & Habitat Maps

3.2.1 Laxey Image Overview

The majority of benthic images from the Laxey MNR contained sand/mud at percentage covers upwards of 80%. Those that didn't contain sand/mud were instead covered by dead maerl and/or shell fragments, indicative of damage from previous benthic trawling. In total, 62 taxa were identified from 12 different phyla (see Appendix I). Living maerl *Phymatolithon calcareum* was identified in 13 sampled images, with percentage covers between 2.5 and 15%. Worm casts were observed in numerous images containing sand/mud and were generally similar in appearance (Figure 9), indicative of the lugworm *Arenicola marina*.

Figure 10. Image of 3 lugworm (*Arenicola marina*) casts from a benthic image taken from the Laxey MNR.

In terms of epifauna, the main observed species were hermit crabs *Pagurus prideaux*, which was identified in 10 images. Eight of these individuals also carried the cloak anemone *Adamsia palliata* on their shells. Epifaunal species appeared to be sparsely distributed, though this may have been due to the towed apparatus scaring away some species. In total, 64 species were identified/ described from the Laxey dataset.

3.2.2 Laxey SIMPROF

Cluster analysis using the SIMPROF function was performed on square root transformed percentage cover data, leading to 17 significant clusters being designated. ANOSIM identified significantly greater within-group similarity within SIMPROF clusters when applied to percentage cover (R = 0.65, $p < 0.001$), species composition (R = 0.43, $p < 0.001$), species richness (R = 0.41, $p < 0.001$) and epifaunal abundances (0.064, $p < 0.001$), with the strongest within-group similarities observed when looking at percentage cover.

Table 4. Benthic habitat types determined by SIMPROF analysis of percentage cover in Laxey Bay MNR, alongside the number of images comprising these clusters. Habitat descriptions derived after observing the images constituting each habitat type and comparing to other outgroups. The average similarity alongside the taxa contributing >25% of the within-group similarity from SIMPER analysis are also reported.

Habitat number and description	**Images**	**Average similarity (%)**	**Characterising taxa**
1 – Dead maerl with hydroids & bryozoans	19	33.7	Maerl, Unidentified Hydroid/Bryozoan spp.
2 – Sand with some dead maerl	18	33.2	Maerl, Brown Algae Film
3 – Dead maerl/Gravel	6	17.4	Maerl, Fine Phoaeophyceae spp.
4 – Sand with occasional worm casts, slight algal film	18	59.7	Brown Algae Film
5 – Sand with algal film	49	70.0	Brown Algae Film
6 – Sand with worm casts, minimal algal film	26	80.1	Worm Casts
7 – Sand with abundant worm casts	66	81.5	Worm Casts
8 – Sand with many shell fragments and occasional worm casts	7	14.7	Worm Casts
9 – Sand with shell fragments and sparse worm casts	35	52.4	Worm Casts
10 – Sand with shell fragments and frequent worm casts	21	77.4	Worm Casts
11 – *Zostera marina* on sand	8	82.6	Worm Casts, *Zostera marina*
12 – Sand with many shell fragments with hydroids & bryozoans	3	9.5	Unidentified Hydroid/Bryozoan spp.
13 – Sand with many shell fragments and some worm casts	27	70.8	Worm Casts
14 – *Zostera marina* & Rhodophyta sp.	1	100.0	NA
15 – Sand with shell fragments and *Laminaria digitata* debris	2	33.3	*Laminaria digitata*
16 – Sand with occasional worm casts	68	51.2	Worm Casts
17 – Sand with some shell fragments inhabited by *Pagurus prideaux*	3	16.7	*Adamsia palliata*, *Pagurus prideaux*

SIMPER analysis (summarised in Appendix II) led to the identification of 17 clusters as shown in Table 4, though 15 of these habitats contained some degree of sandy substrate. 7 of these clusters were also distinguished by variable percentage covers of worm casts, while another 3 were primarily characterised by brown algae film. Both worm casts and algal film were primarily found on soft substrate, therefore recording these separately to sand/mud is likely have conflated the number of SIMPROF clusters identified.

Mean species richness significantly varied between the SIMPROF clusters ($F_{(16,360)}$=12.3, p < 0.001). Habitats containing dead maerl – habitats 1 and 2 – appeared to contain greater species richness than numerous soft substrate habitats, including habitats 6, 7, 9, 10, and 16 (Figure 11). Greater variance in species richness mainly came from habitats containing shell fragments (12, 15 and 17).

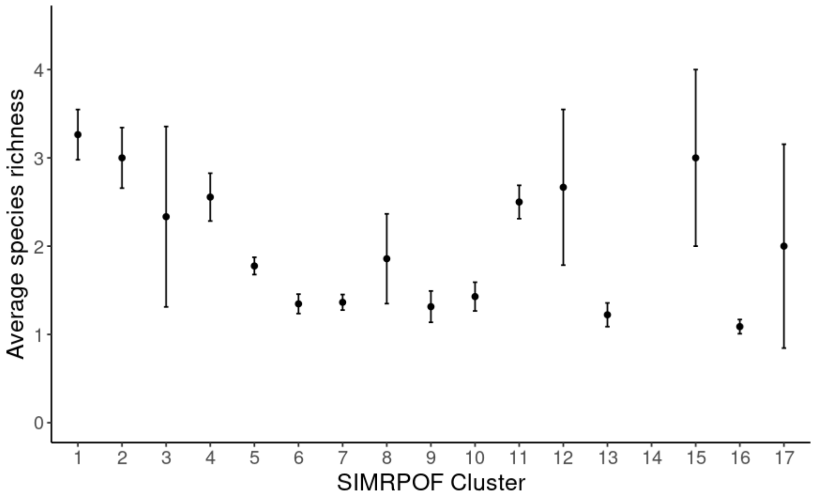


Figure 11. Mean (±SE) species richness per image (n = 1-68) for each Laxey SIMPROF cluster.

3.2.3 Laxey EUNIS

Using the EUNIS classification system, 6 unique biotopes were identified in the Laxey MNR (See Appendix III). Both Maerl on Hard Substrate and Maerl and Echinoderms on Hard Substrate were very similar habitats in appearance, differing more in community composition, as some areas contained significantly more *Nemertesia* spp. and *Cerianthus lloydii*. ANOSIMs confirmed significant within-group similarities in percentage cover (R = 0.79, $p < 0.001$), species composition (R = 0.68, $p < 0.001$), species richness (R = 0.65, $p < 0.001$) and epifaunal abundance (R = 0.095, $p < 0.001$); all with stronger within-group similarities (i.e. greater R values) than the SIMPROF clusters.

Table 5. Benthic habitat types determined by EUNIS classification in Laxey Bay MNR, substrate category for comparisons (soft, mixed, or hard), and the number of images comprising these biotopes. The average similarity alongside the taxa contributing >25% of the within-group similarity from SIMPER analysis are also reported.

Habitat Number, JNCC Code and EUNIS Habitat Name	**In-text Habitat Name**	**Substrate category**	**Images**	**Average similarity (%)**	**Characterising taxa**
1 – SS.SMu.CSaMu Circalittoral Sandy Mud	Circalittoral Sandy Mud	Soft	259	59.9	Worm Casts
2 – SS.SMp.SSgr.Zmar *Zostera marina/angustifolia* beds on lower shore or infralittoral clean or muddy sand	Zostera Sand	Soft	18	58.2	Worm Casts
3 – SS.SSa.IMuSa Infralittoral Muddy Sand	Infralittoral Muddy Sand	Soft	53	63.6	Brown Algae Film
4 – SS.SMp.Mrl.PCal *Phymatolithon calcareum* maerl beds in infralittoral clean gravel or coarse sand	Maerl on Hard Substrate	Hard	8	48.4	Unidentified Hydroid/Bryozoan spp.

5 – SS.SCS.ICS Infralittoral Coarse Sediment	Infralittoral Coarse Sediment	Mixed	20	34.1	Brown Algae Film, Maerl
6 – SS.SMp.Mrl.PCal.Nmix *Phymatolithon calcareum* maerl beds with *Neopentadactyla mixta* and other echinoderms in deeper infralittoral clean gravel or coarse sand	Maerl and Echinoderms on Hard Substrate	Hard	19	28.5	Maerl, Unidentified Hydroid/Bryozoan spp.

SIMPER analysis (summarised in Appendix IV) showed that the main characterising taxa of these habitats were worm casts, brown algal film, and unidentified hydrozoan/bryozoan spp. (Table 5). The vast majority of images – 259 total – were designated as circalittoral muddy sand.

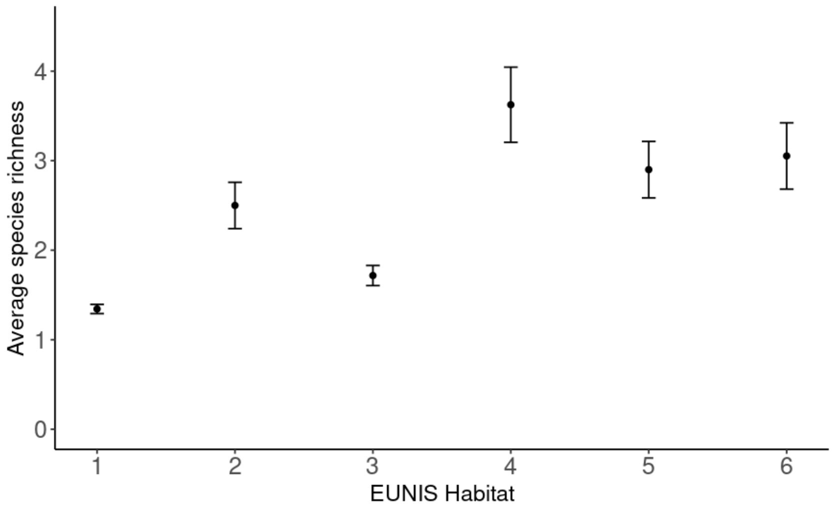


Figure 12. Mean (±SE) species richness per image (*n* = 8-259) for each Laxey EUNIS biotope.

Mean species richness significantly varied between EUNIS biotopes ($F_{(5,371)}$=31.2, p < 0.001) (Figure 12), with species richness apparently greatest in hard and mixed substrates (Habitats 4, 5, and 6).

Tukey HSD post hoc found that average species richness was significantly lower in Circalittoral Sandy Mud than every other habitat at a 95% confidence level – apart from Infralittoral Muddy Sand (Table 6). However, the adjusted *p* value between Circalittoral Muddy Sand and Infralittoral Sandy Mud was < 0.1, suggesting a greater dataset could also make this difference significant. Infralittoral Muddy Sand, another soft substrate habitat, also featured significantly lower species richness compared to the other hard/mixed substrates identified. An increased dataset could additionally lead to a significant difference being identified between mean species richness in Zostera Sand and Maerl on Hard Substrate. In summation, analysis of species richness between EUNIS habitat types supports the hypothesis of species richness being greater in habitats with harder substrates than softer substrates.

Table 6. Table showing Tukey HSD outputs at a 95% confidence level from ANOVA of species richness between Laxey EUNIS habitats. Within each pairwise comparison, the habitat with the lower mean species richness is listed on the left side, while the habitat with greater species richness is listed above. Substrate categories are also listed adjacent to each habitat label. Only results for which $p \leq 0.1$ are included. Adjusted p reported to 3 decimal places.

			Habitat with greater Species Richness				
			Soft		Mixed	Hard	
			Zostera Sand	Infralittoral Muddy Sand	Infralittoral Coarse Sediment	Maerl on Hard Substrate	Maerl and Echinoderms on Hard Substrate
Habitat with lower Species Richness	**Soft**	Circalittoral Sandy Mud	<0.001	0.090	<0.001	<0.001	<0.001
		Zostera Sand	-	0.028	-	0.056	-
		Infralittoral Muddy Sand	-	-	<0.001	<0.001	<0.001

3.2.4 Laxey Benthic Habitat Maps

Benthic habitat maps both for SIMPROF (Figure 11a) and EUNIS (Figure 11b) habitat types were constructed using Euclidean Allocation in ArcGIS 10.8.1.

The SIMPROF map appears largely inconsistent, with habitats arranged sporadically throughout the MNR. Habitats 5, 6, and 16 occupied the greatest allocated area, all of which being sandy habitats with varying degrees of algal film and worm casts. Habitats 1-4 were arranged close to one another at around 54°13’0’’N, 4°23’0’’W, all of which contained dead or living maerl. This same area was later designated as 3 different EUNIS habitats: Maerl on Hard Substrate, Infralittoral Coarse Sediment, and Maerl and Echinoderms on Hard Substrate.

The EUNIS map poses that the majority of the MNR is Circalittoral Sandy Mud, with lesser instances of Infralittoral Muddy Sand, with habitats arranged much less sporadically. Since some Circalittoral Sandy Mud was allocated close to the coastline, it is likely that some of this habitat blends with an infralittoral counterpart, with the transects being too far to detect this change. A blend of hard and mixed substrate habitats made up the area of the MNR around 4°23’W, between latitudes of 54°12’N and 54°13’N.

The Laxey Eelgrass Conservation Zone did not fully align with the designated Zostera Sand determined by Euclidean Allocation. This could be in part due to the patchiness of the sampling methodology leading to instances of *Zostera marina* not being recorded, as isolated clumps were what primarily determined their designations. *Z. marina* was located on circalittoral sandy mud, hence according to the produced habitat map, the species may expand into the surrounding space over a longer timeframe. The current habitat map suggests *Z. marina* may be expanding northwards, with an apparently isolated extent north of 54°13’N.

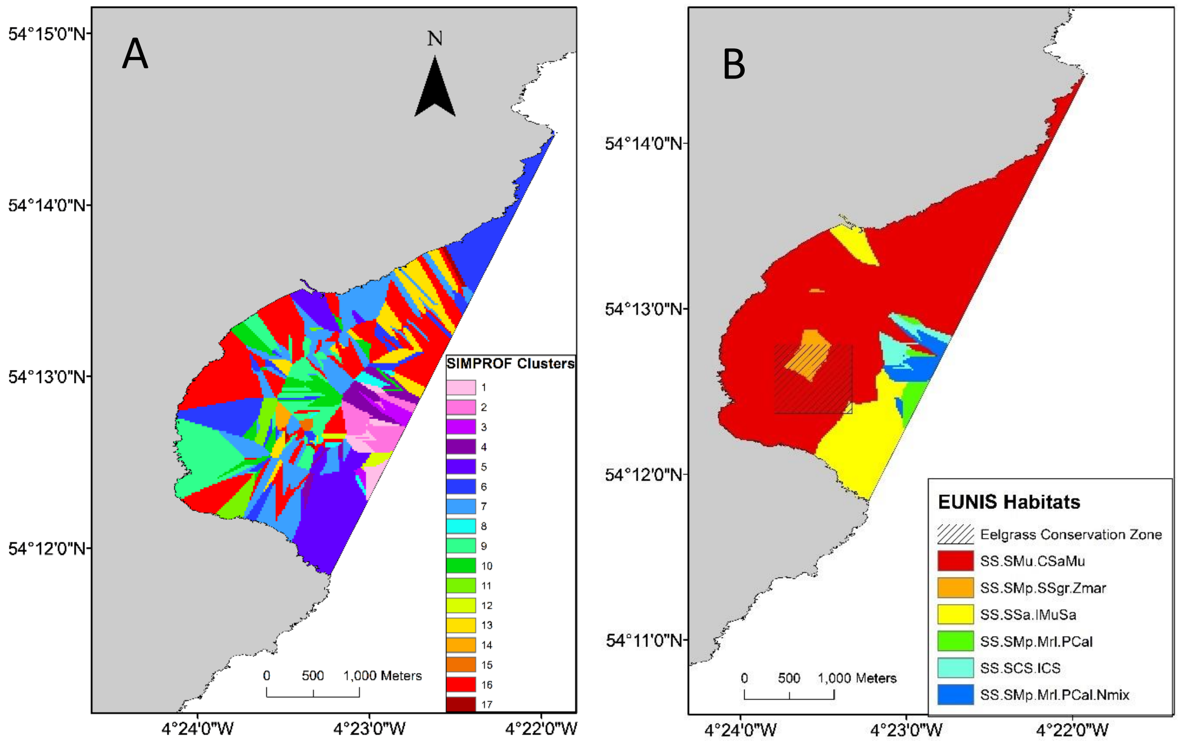


Figure 13. Benthic habitat maps of Laxey produced by Euclidean allocation of (a) SIMPROF clusters and (b) EUNIS habitat types.

3.2.5 Niarbyl Image Overview

Niarbyl appeared to show greater diversity in habitat types, with the substrates sand/mud, gravel, pebble, and shell appearing frequently, in a wide range of percentage covers. Sand/mud was the most frequent substrate, recorded in 213 of the 288 images, though its percentage cover varied widely, between 2.5% and 97.5%. Gravel was similarly common and variable; observed in 208 images in percentage covers between 2.5% and 100%.

In total, 56 taxa were identified from 11 different phyla (See Appendix V). In many of the sand/mud dominated images, brittlestar arms were also observed (Figure 13). These were identified as the species *Amphiura filiformis*, which is known to inhabit the Northeast Atlantic and burrow under the sediment, stretching its arms above to feed (Trannum, 2017).

Figure 14. Image of sandy/muddy seabed with buried brittlestars (*Amphiura filiformis*) from the Nairbyl MNR.

3.2.6 Niarbyl SIMPROF

SIMPROF analysis of square root transformed percentage cover for Niarbyl led to 13 significant clusters being identified. ANOSIMs confirmed that these clusters had significant within-group similarities in terms of percentage cover (R = 0.81, $p < 0.001$), species composition (R = 0.46, $p < 0.001$), species richness (R = 0.46, $p < 0.001$) and epifaunal abundances (0.11, $p < 0.001$).

Table 7. Benthic habitat types determined by SIMPROF analysis of percentage cover in Laxey Bay MNR, alongside the number of images comprising these clusters. Habitat descriptions derived after observing the images constituting each habitat type and comparing to other outgroups. The average similarity alongside the taxa contributing >25% of the within-group similarity from SIMPER analysis are also reported.

Habitat Number and Description	Images	Average similarity (%)	Characterising taxa
1 – Gravel with some sand	10	42.5	Brown Algae Film
2 – Gravel & sand with some algae film	12	29.9	Brown Algae Film
3 – Gravel & sand with *Cerianthus lloydii*	23	15.4	*Pomatoceros triqueter* tubes, *Cerianthus lloydii*
4 – Fine gravel with brown algae film	15	57.7	Brown Algae Film
5 – Gravel and shell fragments with brown algae film	39	52.5	Brown Algae Film
6 – Fine gravel, dead maerl and shell fragments with occasional red algae	50	12.3	Fine Rhodophyta spp.
7 – Sand with algal film and brittlestars	47	69.3	Fine Rhodophyta spp., Brittlestar Arms
8 – Sand & shell fragments, with algal film and brittlestars	27	34.5	Brown Algae Film
9 – Coarse gravel/stone with bryozoans and hydroids	9	20.5	Hydrozoan/Bryozoan Turf
10 – Fine red and/or brown algae on gravel/stone	24	36.8	Fine Rhodophyta spp., Fine Phoaeophyceae spp.
11 – Fine red algae and *Pomatoceros triqueter* tubes on gravel/stones	13	29.3	-

12 – Dense red algae	17	51.8	Fine Rhodophyta spp.
13 – Dense brown algae	12	65.4	Fine Rhodophyta spp., *Laminaria digitata*

Within-group similarities and characterising taxa were determined using SIMPER analysis (Table 7)(See Appendix VI). Most habitats were characterised by brown algae film and fine Rhodophyta spp., with the number of images constituting each group ranging from 9 to 47. 5 habitats had gravel as their sole substrate type, while just 1 of the clusters solely contained sand, suggesting low habitat diversity in terms of soft substrates in Niarbyl.

Mean species richness was significantly different between SIMPROF clusters ($F_{(12,285)}$=13.1, $p <$ 0.001), with the greatest species richness observed in habitats 10 and 11 – 2 habitats on gravel/stones – while the lowest species richness was observed in habitats 3, 6, and 8, all habitats with finer substrate sizes (Figure 12). Aside from habitats 10 and 11, mean species richness of every SIMPROF habitat was lower than 4.

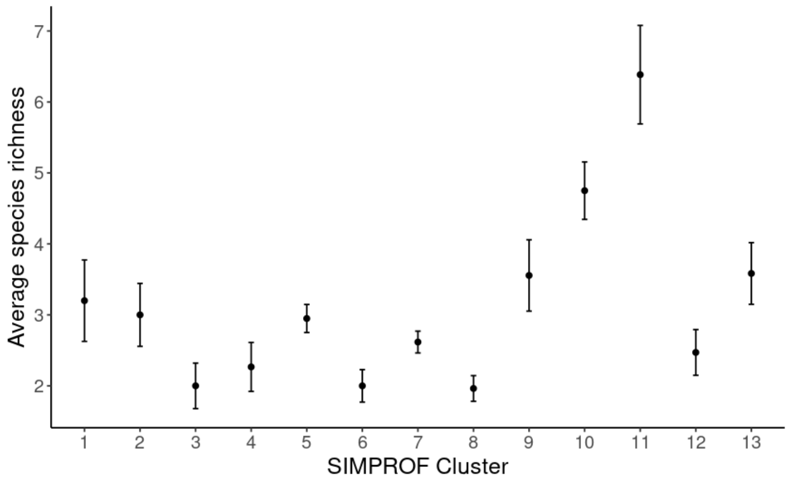


Figure 15. Mean (±SE) species richness per image (n = 9-50) for each Niarbyl SIMPROF cluster.

3.2.7 Niarbyl EUNIS

The EUNIS classification system led to the identification of 8 distinct biotopes in Niarbyl Bay MNR (See Appendix VII). ANOSIMs found significant within-group similarities in percentage cover ($R = 0.72$, $p < 0.001$), species composition ($R = 0.47$, $p < 0.001$), species richness ($R = 0.48$, $p < 0.001$) and epifaunal abundances (0.15, $p < 0.001$). The only within-group similarity that was weaker using the EUNIS system rather than the SIMPROF clusters was that of percentage cover.

Table 8. Benthic habitat types determined by EUNIS classification in Niarbyl Bay MNR, substrate category (soft, mixed, or hard), and the number of images comprising these biotopes. The average similarity alongside the taxa contributing >25% of the within-group similarity from SIMPER analysis are also reported.

Habitat Number, JNCC Code and EUNIS Habitat Name	**In-text Habitat Name**	**Substrate category**	**Images**	**Average similarity (%)**	**Characterising taxa**
1 – SS.SMp.KSwSS.LsacR.CbPb Red seaweeds and kelps on tide-swept mobile infralittoral cobbles and pebbles	Kelp on Cobbles and Pebbles	Hard	32	36.3	Fine Rhodophyta spp., Fine Phaeophyceae spp.
2 – SS.SSa.CMuSa Circalittoral muddy sand	Circalittoral Muddy Sand	Soft	73	55.2	Brown Algae Film, Brittlestar Arms
3 – SS.SMx.CMx.ClloMx.Nem *Cerianthus lloydii* with *Nemertesia* spp. and other hydroids in circalittoral muddy mixed sediment	Cerianthus Mixed Sediment	Mixed	47	21.1	*Cerianthus lloydii*
4 – SS.SMp.KSwSS.LsacR.Mu *Saccharina latissima* with red and brown seaweeds on lower infralittoral muddy mixed sediment	Kelp on Mixed Sediment	Mixed	4	53.9	*Pomatoceros triqueter* tubes, Fine Rhodophyta spp.
5 – SS.SMx.CMx.OphMx *Ophiothrix fragilis* and/or *Ophiocomina nigra* brittlestar beds on sublittoral mixed sediment	Brittlestars on Mixed Substrate	Mixed	12	32.7	*Clavelina lepadiformis*
6 – SS.SCS.CCS Circalittoral Coarse Sediment	Circalittoral Coarse Sediment	Hard	77	34.0	Brown Algae Film
7 – SS.SMp.KSwSS.LsacR.Gv *Saccharina latissima* and robust red algae on infralittoral gravel and pebbles	Saccharina on Gravel and Pebbles	Hard	49	35.8	Fine Rhodophyta spp.
8 – SS.SMp.KSwSS.Tra Mats of *Trailliella* on infralittoral muddy gravel	Trailliella on Muddy Gravel	Hard	4	48.3	Fine Rhodophyta spp.

Summarised results of SIMPER analysis of EUNIS habitats are shown in Table 8 (full results in Appendix VIII), which showed a greater range of characterising taxa than with SIMPROF habitats. Both Kelp on Mixed Sediment and Trailliella on Muddy Gravel were made up of 4 images, suggesting these habitats were more sparse than other habitats like Circalittoral Coarse Sediment and Circalittoral Muddy Sand (which both were consisted of over 70 images). The low sample size of these habitats makes conclusions drawn about species richness in these habitats less robust.

Mean species richness significantly varied between EUNIS biotopes ($F_{(7,290)}$=13.7, p < 0.001). The greatest species richness, upwards of 5 per image, were observed from Kelp on Mixed Sediment and Brittlestars on Mixed Substrate (Figure 13). Every other habitat aside from Kelp on Cobbles and Pebbles contained markedly lower species richness, with averages between 2 and 3.

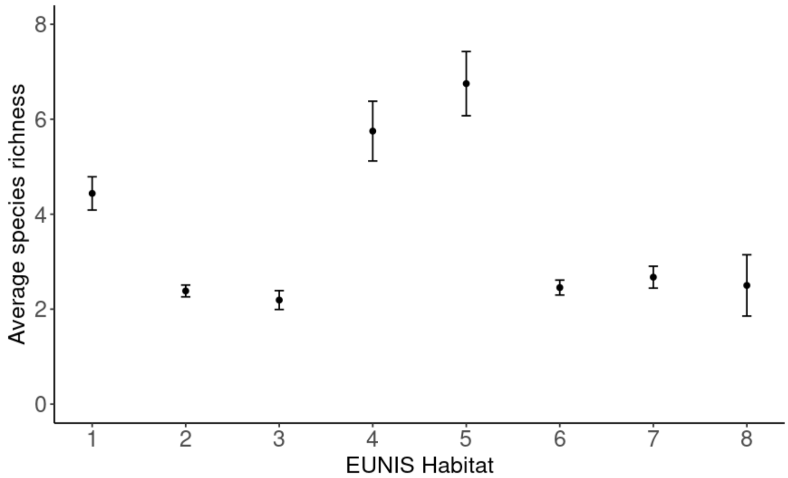


Figure 16. Mean (±SE) species richness per image (n = 4-77) for each Niarbyl EUNIS biotope.

Tukey HSD post hoc identified significant differences between means of different pairs of EUNIS habitats, as detailed in Table 9. The difference between mean species richness of Kelp on Cobbles and Pebbles and Brittlestars on Mixed Substrate was close to the 5% significance level, therefore an increased sample size could change this result. Conversely, the difference between mean species richness of Kelp on Mixed Sediment and Saccharina on Gravel and Pebbles was close to 5% significance, hence greater sample size could make the different non-significant. Overall, Niarbyl only features 1 habitat with soft substrate, which had a significantly lower mean than 2 mixed and 1 hard substrate habitat. Most of the significant differences came from species richness in either Kelp on Mixed Sediment or Brittlestars on Mixed Substrate being greater than another habitat.

Table 9. Table showing Tukey HSD outputs at a 95% confidence level from ANOVA of species richness between Niarbyl EUNIS habitats. Within each pairwise comparison, the habitat with the lower mean species richness is listed on the left side, while the habitat with greater species richness is listed above. Substrate categories are also listed adjacent to each habitat label. Only results for which $p \leq 0.1$ are included. Adjusted p reported to 3 decimal places.

			Habitat with greater Species Richness		
			Mixed		**Hard**
			Kelp on Mixed Sediment	Brittlestars on Mixed Substrate	Kelp on Cobbles and Pebbles
Habitat with lower Species Richness	**Soft**	Circalittoral Muddy Sand	0.019	<0.001	<0.001
	Mixed	Cerianthus Mixed Sediment	0.004	<0.001	<0.001
	Hard	Kelp on Cobbles and Pebbles	<0.001	0.071	-
		Circalittoral Coarse Sediment	0.013	<0.001	<0.001
		Saccharina on Gravel and Pebbles	0.027	<0.001	<0.001
		Trailliella on Muddy Gravel	-	0.014	-

This dataset gives contrasting arguments towards the hypothesis – while mixed substrate v. soft substrate supported it, mixed substrate v. hard substrate opposed it. Comparing between BRUV mean species richness of soft and hard substrates provides evidence towards rejecting the hypothesis, as mean species richness was greater by 2.17 in soft substrates than hard substrates. Arguments could be made for species richness being underestimated in Saccharina on Gravel and Pebbles and Trailliella on Muddy Gravel as these habitats were dominated by macroalgae, therefore benthic species may have been obscured both in BRUVs and benthic images. No such argument could be made for Circalittoral Coarse Sediment however, as this habitat was not cryptic and features very little macroalgae – though this habitat was not part of BRUV surveys. The main issue with this analysis was that only 1 soft substrate habitat occurred in Niarbyl, therefore the case could be that circalittoral muddy sand features an abnormally high species richness compared to other soft substrate habitats. Comparisons between SIMPROF cluster species richness also suggested areas dominated by Rhodophyta on hard substrate had greater species richness than other habitats, somewhat supporting the hypothesis. Overall, the Niarbyl dataset gave contrasting arguments about the validity of the hypothesis, instead suggesting that mixed substrate habitats may support the greatest species richness.

3.2.8 Niarbyl Benthic Habitat Maps

Benthic habitat maps both for SIMPROF (Figure 14a) and EUNIS (Figure 14b) habitat types were constructed using Euclidean Allocation in ArcGIS 10.8.1.

The SIMPROF habitat map shows relative consistency in the locations of habitat types, with certain habitats generally associated with one another. For example, habitats 10 and 11 were allocated at the southern extent of the MNR around 4°45'W, interspersed with one another, whereas habitats 4, 5, and 6 were all associated in close proximity to one another further north. In this way, SIMPROF analysis appeared to show a more coherent view of how habitats may be situated in comparison to the SIMPROF map constructed for Laxey.

Niarbyl Bay was composed of a greater range of EUNIS habitats than Laxey, with further possibility of infralittoral counterparts for circalittoral habitats that were associated by the coastline, e.g. Circalittoral Coarse Sediment at around 54°8'N, 4°44'W. The habitat with the least distribution was Trailliella on Muddy Gravel, which was a difficult habitat to assign due to the patchy nature of the data and the area itself surveyed within its transect. The difficulty in identifying these habitats came from its patchy nature and macroalgal community composition – the substrate itself was coarse gravel with some sand/mud, turf macroalgae was primarily fine, bushy Rhodophyta spp. resembling *Trailliella*, and covering macroalgal species including *Laminaria digitata* and *Saccharina latissima* then sometimes obscured the substrate and turf algae even further. There were some cases of Rhodophyta appearing without covering algae altogether – hence defined as mats of *Trailliella*. These habitats also contained large boulders which would feature their own communities of small, robust algae, which added to the difficulty of identifying EUNIS habitat types from image analysis alone – making the benthic tow videos vital in identifying when this occurred, avoiding false habitat identification. Using the tow video to assist with habitat identification also revealed that instances of *Laminaria digitata* and Rhodophyta spp. were inconsistent across the area, therefore designations between Circalittoral Coarse Sediment and Saccharina on Gravel and Pebbles should be treated tentatively.

Furthermore, Circalittoral Muddy Sand may be composed of 2 different habitats based on community composition, as some of the allocated area only featured substrate with some shell fragments, while other areas contained burrowing brittlestars (likely *Amphiura filiformis*) at high concentrations. SIMPROF habitats 7 and 8 may describe some of this difference, though the nature of point sampling also made percentage covers of brittlestar arms inconsistent, therefore these 2 clusters do not offer a robust alternative arrangement of 2 circalittoral muddy sand habitats.

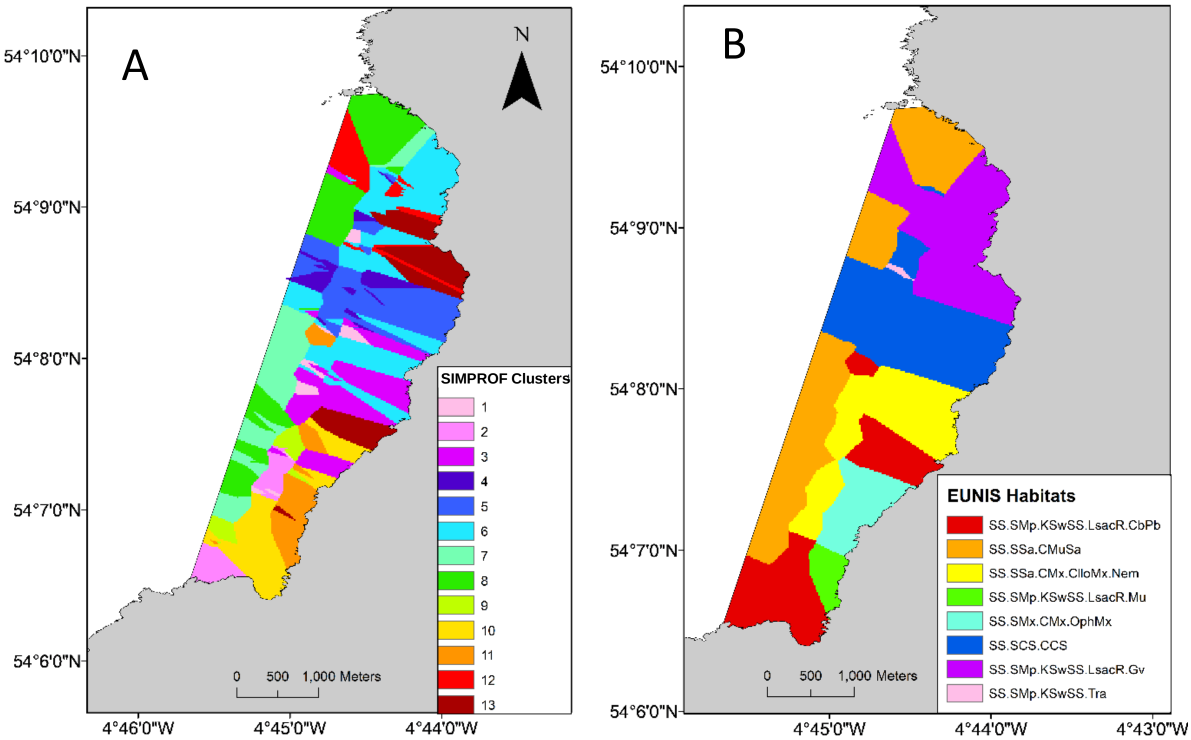


Figure 17. Benthic habitat maps of Niarbyl produced by Euclidean allocation of (a) SIMPROF clusters and (b) EUNIS habitat types.

3.3 BRUV Footage Analysis

Species abundances/presence was recorded for each BRUV (see Appendix IX). BRUV positions were overlayed with EUNIS habitat maps to determine which habitat each BRUV was placed in, then compared with species richness data, as seen in Table 10. Since every BRUV in Laxey was recorded in a soft substrate habitat, no comparisons could be made regarding substrate category to test the hypothesis. In contrast, 5 different EUNIS habitats were recorded from Niarbyl, with the greatest species richness observed in Kelp on Mixed Sediment, a mixed substrate category habitat. The mean species richnesses of the soft, mixed, and hard substrate category habitats were 5.67, 7.33 and 3.50 respectively. Comparing between soft and mixed substrate categories supports the hypothesis of harder substrate habitats supporting a greater species richness, though the hard category having the lowest richness overall provides evidence against this prediction.

Table 10. EUNIS habitat associated with each BRUV position, alongside species richness observed in each recording (n = 14).

Location	BRUV Number	EUNIS Habitat	Species Richness
Laxey	1	Circalittoral Sandy Mud	8
	2	Circalittoral Sandy Mud	8
	3	Infralittoral Muddy Sand	5
	4	Circalittoral Sandy Mud	6
	5	Circalittoral Sandy Mud	5
	6	Circalittoral Sandy Mud	4
Niarbyl	1	Kelp on Cobbles and Pebbles	2
	2	Kelp on Mixed Sediment	12
	3	Circalittoral Muddy Sand	4
	4	Circalittoral Muddy Sand	9
	5	Cerianthus Mixed Sediment	5
	6	Kelp on Mixed Sediment	5
	7	Saccharina on Gravel and Pebbles	5
	8	Circalittoral Muddy Sand	4

In Laxey, BRUV positioning unfortunately missed the 2 hard substrate habitats, with the vast majority being recorded in Circalittoral Sandy Mud. As such, this dataset cannot be used as evidence for or against the hypothesis set in this analysis. Within this habitat, the main species observed was overwhelmingly hermit crabs (*Pagurus bernhardus*), being observed in every BRUV with an average maxN of 12.4, in contrast to the 11 specimens observed throughout the entire Laxey dataset. This suggests underestimates of epifaunal abundance in Laxey's circalittoral sandy mud, which may have been due to the sampling equipment scaring away the species as it was towed. Catsharks *Scyliorhinus canicula* were also observed in every BRUV, with an average maxN of 2.67. Most BRUVs also captured footage of whelks *Buccinum undatum*, particularly in BRUV 6 where a maxN of 14 was recorded for the species.

In Niarbyl, comparing between BRUV mean species richness of soft and hard substrates provides evidence towards rejecting the hypothesis, as mean species richness was greater in soft substrates by 2.17. However, arguments could be made for species richness being underestimated in every habitat containing some form of large macroalgae as epifaunal species may have been obscured from view. As such, this data does not hold robust opposition against the study hypothesis. Many epifaunal species were observed across the sampled BRUVs, with the main observed species being the crab *Liocarcinus duperator*, seen in 5 of the 8 BRUVs with an average maxN of 2.8. *L. duperator* was only absent from habitats containing kelp *Laminaria digitata*. These habitats instead featured different crustacean species, like lobsters (*Homarus gammarus*), and velvet crabs (*Necora puber*). Kelp-dominated habitats also contained more fish species, like pollock (*Pollachius pollachius*), and corkwing wrasse (*Symphodus melops*).

3.4 Species of Interest from Benthic Images and BRUVs

No species of solely conservational interest were recorded in Laxey, though BRUV footage did detect a variety of commercially significant species, including dab *Limanda limanda*, whelk *Buccinum undatum* and sand eels *Ammodytes tobianus*. The most notable case was BRUV 6, where *B. undatum* was observed at a maxN of 14, suggesting a greater population at this point. Image data similarly did not feature any species of strict conservational interest. The scallop *Aquepectin* *opercularis* was observed 3 times across both hard substrate habitats, though the individuals were all relatively small compared to surrounding substrata.

No species of particular conservational or commercial importance were identified from benthic images of Niarbyl, though a wide variety of macroalgae were observed throughout many of the hard and mixed substrate habitats. Kelps (*Laminaria digitata* and *Saccharina latissima*) are of particular importance in these areas by acting as a canopy, allowing turf algae to grow underneath. In contrast, BRUV footage of Niarbyl showcased a wide diversity of commercial species, both benthic and demersal. In terms of benthic species, an Atlantic lobster *Homarus gammarus*, was observed within the Kelp on Cobbles and Pebbles habitat of BRUV 1, while brown crabs *Cancer pagurus* were also observed in BRUVs 4,5 and 8 (Habitats Circalittoral Muddy Sand and Cerianthus Mixed Sediment). These species are also of some conservational relevance, to the extent that minimum catch sizes have been put in place to prevent overfishing of immature individuals (DEFA, 2021b). In terms of demersal fish species, a whiting *Merlangius merlangus* was observed in BRUV 3, while numerous pollock *Pollachius pollachius* were observed in BRUVs 2, 6 and 7 (Kelp on Mixed Sediment and Saccharina on Gravel and Pebbles), likely in larger groupings than the maxN implies due to the angle of the BRUVs. An aggregation of juvenile fish that appeared to resemble pollock were also observed in BRUV 5 (Cerianthus Mixed Sediment), suggesting there may be a viable stock within the MPA.

3.5 Future Spatial Management Suggestions

The Laxey Bay MNR mostly consists of non-speciose circalittoral sandy mud, though there is potential for eelgrass to continue expanding into this available area. Current mapping of *Z. marina* beds suggest that the species is shifting northwards, therefore the Conservation Zone could benefit from being expanded northwards, possibly being reduced in latitudinal extent to account for this change. However, since most of this area was extrapolated when constructing the habitat map, more accurate recording of eelgrass bed cover should be taken to better inform the extent of the habitat to ensure that the Eelgrass Conservation Zone encapsulates its full extent.

Maerl beds within Laxey have mostly been damaged from previous dredging activity, with possible slight signs of recovery observed in this study – though without a baseline, this assumption is mostly uncertain. This slow recovery is attributed to maerl being a slow growing species with poor recruitment rates (Hall-Spencer and Moore, 2000). These habitats still require strict restrictions on dredging to allow further recovery and may benefit from measures like maerl relocation from elsewhere to help re-establish the habitat.

There may be some potential to relax restrictions on benthic fishing at around the positions of BRUV 6, as this area is circalittoral sandy mud – hence not a priority habitat – with a potentially significant *B. undatum* population. If this potential stock is to be utilised, measures should be made to ensure a limited catch, with careful assessment to ensure the species is not overexploited. This should also involve minimum catch sizes that consider variations induced by spawning seasons as posed by Emmerson *et al.* (2020) to avoid local overexploitation.

The Niarbyl MNR featured the greatest epifaunal species richness in the EUNIS habitat Kelp on Mixed Sediment. Since this habitat's diversity is largely attributed to *Laminaria digitata* and *Saccharina latissima* (2 kelp species), arguments could be made to restrict static fishing gears in these areas to prevent damage to these species, hence the habitat as a whole – though a preliminary investigation of how static gears impact kelp would be needed to inform whether these restrictions are necessary.

Future investigations into pollock populations within this MNR could allow fishers to use pelagic trawls/non-benthic fishing gears to reduce benthic disturbance, while still generating income. Uses of different mesh sizes, along with fishing in Kelp on Mixed Sediment areas could allow trawls of these species to avoid removing juveniles while making use of the stock. Assessments of whiting stock could be another avenue for generating income – though from this dataset, pollock appears more abundant.

These suggestions together create a possible conflict, with Kelp on Mixed Sediment being having the greatest epibenthic species richness while also containing a possible exploitable stock of pollock. As such, careful investigation into the relationships between pollock and the other species in Niarbyl should also be carried out to avoid an instance of demersal stock changes influencing community compositions, as was previously observed by Gjøsæter, Bogstad and Tjelmeland (2009) after capelin *Mallotus villosus* stock collapses.

All of these suggestions are based on data from 2016, therefore any actions taken based on these findings should be informed by more recent investigation beforehand. This dataset allows a baseline to compare to future surveys of these MNRs, both in habitat distribution and community compositions.

In terms of monitoring, future habitat mapping could incorporate fine-scale bathymetry (using equipment like multibeam echosounders, for example) alongside ground truthing surveys similar to the methodology used for this analysis. This data can be used alongside machine learning approaches like Random Forests, which have seen increased usage in recent years to produce fine-scale benthic habitat maps (Porskamp *et al.*, 2018; Buhl-Mortensen *et al.*, 2020), better informing spatial management plans. This methodology would also reduce extrapolation, producing more reliable habitat maps.

Future surveys can also use habitat designations from previous maps to inform BRUV placements, ensuring a wide range of habitats are sampled to better ascertain the breadth of biological diversity within the MNRs.

4. Discussion

4.1 Epifaunal Diversity relative to Habitat Substrate Hardness

The results of this analysis gave contrasting views about how substrate hardness relates to species richness of a habitat – data from Laxey suggests species richness increases with substrate hardness, whereas data from Niarbyl suggests species richness is greatest where there are a mix of substrate types. The main issue with using solely substrate hardness to predict levels of benthic diversity is that the relationship between a biological community and the benthos it occupies is more complex than a single, unspecific factor can accurately describe consistently. Numerous studies have found apparent positive correlations between substrate hardness and species richness, though further review has indicated that substrate hardness is one factor contributing towards overall seabed stability, which is a better predictor for species richness of a benthic habitat that incorporates a range of other factors (McArthur *et al.*, 2010). Other abiotic factors relating to seabed stability include slope, particle size, and degree of water motion (McArthur *et al.*, 2010), hence data on these factors should be included to better determine the spatial arrangement of benthic diversity from substrate properties. Other substrate properties like %mud and %gravel can also serve as good predictors of benthic community structures (McArthur *et al.*, 2010; Roland Pitcher *et al.*, 2012), while being more quantifiable values than substrate hardness.

The results of the Niarbyl dataset further exemplify how complex relationships between biota and benthos can lead to differences in the distribution of benthic diversity which substrate hardness alone can not explain. In the case of Niarbyl, habitats which had a mix of both gravel/pebble and sand/mud substrates featured the greatest epifaunal biodiversity, contrary to the prediction of the hypothesis. Similar observations have been attributed to the occurrence of interstitial spaces – areas of soft sediment between areas of harder substrate (Marshall, Bucher and Smith, 2018). These interstitial spaces can ameliorate potentially harsh conditions for various species, increasing the number of ecological niches within the habitat, allowing a greater species diversity to occupy said habitat. In addition, the habitat Kelp on Mixed Sediment also contained the kelp *Saccharina latissima*, which can ameliorate conditions for understory algae species (Teagle *et al.*, 2017), again providing a wider diversity of ecological niches for increased epifaunal diversity. This may explain why, of Niarbyl's hard substrate habitats, Kelp on Cobbles and Pebbles had the greatest epifaunal species richness. This amelioration can also explain why the greatest species richness between BRUVs was observed in Kelp on Mixed Sediment. However, this does not explain why the greatest average species richness was observed in Brittlestars on Mixed Substrate.

In summation, there is little correlation between epifaunal diversity and habitat substrate type, with species richness generally being dependent on a range of other abiotic and biotic factors. As such, habitat substrate type alone is not a robust indicator of the level of benthic diversity within a habitat.

4.2 Important Species and Habitats in both MNRs

In both MNRs, no species solely relevant to conservation were recorded, while some species of commercial relevance were identified. This may in part be due to most of the MNR consisting of sandy/muddy sediment, supporting a greater infaunal diversity that benthic images and BRUVs could not detect. In addition, heavy metal runoff from disused mines around Laxey (Daka, 2006) may also be influencing biological community structure in Laxey Bay. With no baseline to compare to, it is difficult to conclude whether any observed abundances of *B. undatum* were significantly greater than before the MNR was designated. However, since many fisheries of *B. undatum* are threatened by local overexploitation (Emmerson *et al.*, 2020), it is important that areas within the MNR containing this species are carefully managed to maintain a stable population around the Manx coastline.

The lack of species of conservational relevance may also have been due to the condition of important habitats in Laxey. The Laxey MNR featured both eelgrass (*Zostera marina*) and maerl (*Phymatolithon calcareum*) beds, though in differing states of health.

The eelgrass beds appeared to show signs of recovery, with an apparent northward extent outside of the range of the currently designated Eelgrass Conservation Zone. Limitations pertaining to the methodology make it unclear whether eelgrass has shifted or grown northwards, since mapping of the Eelgrass Conservation Zone was extrapolated from other datapoints. Eelgrass beds did not appear in high densities, instead appearing in occasional patches with regions of sand/mud between them. Previous efforts towards gauging the health of eelgrass beds have surmised that eelgrass beds are dynamic and can have varying recovery timescales depending on a range of abiotic factors; and that no meaningful indicators for eelgrass bed recovery have yet been identified (Duarte *et al.*, 2013; O'Brien *et al.*, 2018). Since no factors have been defined, currently it may be best to use area cover, eelgrass density, and species richness of biological communities as proxies for eelgrass bed health until more robust indicators are defined. It may be possible to encourage *Z. marina* recovery further by introducing seeds to areas with suitable substrate and water quality for *Z. marina*, as replanting efforts for this species have been able to significantly increase eelgrass bed cover over the course of 3 years (Orth *et al.*, 2006).

In contrast, maerl beds within Laxey were mostly dead with few signs of recovery. Recovery speeds of maerl beds differ between species, with the species *Lithothamnion corallioides* and *Spongites fruticulosus* proliferating faster than species like *Phymatolithon calcareum* (Barberá *et al.*, 2017; Qui-Minet *et al.*, 2021)– the main species observed in this area. Past observations of *P. calcareum* beds after dredging bans have found no signs of recovery after 4 years (Hall-Spencer and Moore, 2000), which has primarily been attributed to their slow growth rate, between 0.5-1.5mm per year (Wilson *et al.*, 2004). The degraded state of this habitat likely led to decreased species diversity, particularly in the juvenile species that usually use maerl to evade predation (Szostek *et al.*, 2017). To speed up the recovery of this habitat, live *P. calcareum* could be relocated from elsewhere similar to the methodology used by Sheehan *et al.* (2015), since the biological community associated with maerl beds can recover much faster than the maerl itself. If maerl beds can be re-established in this way, living maerl may go on to spawn and increase the rate of maerl recruitment in the surrounding area, overall leading to faster habitat recovery.

As for Niarbyl Bay, the main species of commercial relevance observed were benthic crustaceans – namely *Homarus gammarus* and *Cancer pagurus*. It is important that catch limitations are upheld on these species, especially since future climate change will exert further pressure on them as the prevalence of crustacean shell disease increases (King *et al.*, 2014; Rowley *et al.*, 2014). Some commercial fish species were also observed, including *Merlangius merlangus* and *Pollachius pollachius*, with juvenile *Pollachius pollachius* also identified within the habitat. Pollock are of some commercial importance, valued at around £2,706 per tonne (MMO, 2021) with the potential for further profits by incorporating their roe (Furey, Hoeche and Noci, 2020).

The highest species richness was observed in 2 mixed substrate habitats in Niarbyl – Kelp on Mixed Sediment and Brittlestars on Mixed Substrate. Temperate kelp habitats often showcase high biodiversity whilst providing ecosystem services like CO_2 sequestration and nutrient cycling (Casado-Amezúa *et al.*, 2019), which in the past have justified MPA designations elsewhere (Caselle *et al.*, 2015). On the other hand, few habitats like Brittlestars on Mixed Substrate have been cited as significant enough to warrant protection, nor have any similar habitats identified as OSPAR priority habitats (OSPAR, 2022). Since this habitat had the highest epifaunal diversity overall in Niarbyl despite the lack of kelp, further investigation into the functioning of this habitat may be crucial for maintaining biodiversity within the MNR and informing whether additional restrictions are needed to uphold the high diversity observed in this dataset.

4.3 Mapping Methodologies

Two methods were used for allocating habitat types for each benthic image – SIMPROF clustering as a statistical approach, and allocation using EUNIS classification as a qualitative approach. Overall, benthic habitat maps constructed from SIMPROF clusters followed less consistent arrangements (especially for Laxey Bay) and resulted in more biotopes being identified than when using EUNIS classification. Taking a qualitative approach also allowed benthic video and BRUV footage to be incorporated into habitat classification. However, the final benthic habitat maps constructed relied heavily on extrapolation by using Euclidean Allocation.

Other mapping methodologies can reduce levels of extrapolation by incorporating fine-scale bathymetry and fine-scale changes in substrate types to produce robust benthic habitat maps (Proudfoot *et al.*, 2020). Fine-scale bathymetry data can be collected remotely using equipment like multibeam echosounders (Porskamp *et al.*, 2018; Proudfoot *et al.*, 2020), then compared with biological communities observed in benthic surveys similar to the methodology used in this study. Once this data is collected, statistical methods like the increasingly used 'Random Forest,' approach can be used to model habitat distributions (Roland Pitcher *et al.*, 2012; Porskamp *et al.*, 2018; Misiuk *et al.*, 2019). Though this methodology benefits from reduced extrapolation, its accuracy decreases when more biotic classes are identified within a given region (Porskamp *et al.*, 2018) – therefore in this case, it would likely be less suitable for mapping Niarbyl than Laxey.

Fine-scale mapping of habitats bordering the coastline is especially important since these habitats are in the closest proximity to terrestrial human activity. The methodology of this study meant habitats that habitats further offshore were extrapolated up to the coastline, making these maps unreliable for informing coastal management. Particularly fine-scale coastal habitat maps can be constructed by using drone images alongside ground truthing surveys (Nababan *et al.*, 2021) to better inform decisions about coastal and inshore management bordering these MNRs, further helping to maintain their biodiversity.

4.4 Methodology Limitations & Suggestions for Future Analyses

Statistical analysis was limited to using Euclidean distance rather than Bray-Curtis dissimilarity. The main flaw of Euclidean distance is that it can lead to areas with no species in common being more similar than areas with the same species (Ricotta and Pavoine, 2022) when used in an ecological context. This may have led to SIMPROF clusters being constructed containing images that were dissimilar in species composition, which could partially explain the inconsistent distribution of habitats seen in the Laxey SIMPROF habitat map. Were this methodology repeated, fixing the error in the vegan package preventing the use of Bray-Curtis dissimilarity would be strongly recommended.

Euclidean Allocation uses a large amount of extrapolation; therefore these maps are not fully representative of habitat diversity in these MNRs. This extrapolation could explain the apparent reduced distribution of eelgrass beds in comparison to the Eelgrass Conservation Zone governmentally designated. Patchiness of instances of eelgrass along with the sub-sampling of images could also explain this difference. One of the benthic images at the start of the fourth tow, at the southern end of the Eelgrass Conservation Zone, featured *Z. marina* but was still identified as Circalittoral Sandy Mud due to the other images in the tow not containing any eelgrass. Were this methodology repeated, designations of eelgrass beds may be different.

Many of the EUNIS designations were based on vague descriptions that could fit what was observed. For example, 'coarse sediment' used for areas of dead maerl even though the description implied large, non-calcareous stones. The aforementioned Niarbyl circalittoral muddy sand was another example of how EUNIS classifications could not account for the perceived differences between clusters of images, hence they had to be grouped together. Furthermore, some sediment types could not be fully identified, since identifying between, for example, 'muddy sand,' and 'sandy mud,' required samples of benthic substrate to be analysed.

This research was restricted to investigating epibenthic fauna, since infaunal species were not visible in benthic images. This was particularly relevant for eelgrass beds, which are highly speciose in infaunal invertebrates (Henseler *et al.*, 2019). As such, the suggestion made for *B. undatum* stock assessment could change depending on infaunal species richness.

Epibenthic species richness using this methodology was likely underestimated overall, since the towed sledge likely evoked evasive responses from surveyed species, either hiding or escaping. This is likely the reason why high abundances of *Pagurus bernhardus* were observed during BRUV recordings, but not from still image analysis. To prevent this factor leading to habitat misidentifications based on community compositions in future surveys, it is important to continue recording video data of benthic tows. Future surveys could also employ BRUVs in a variety of habitat types within each MNR based off of previous benthic habitat mapping, allowing more comparison between observed species abundances in different habitats.

References

Ban, N. C., Davies, T. E., Aguilera, S. E., Brooks, C., Cox, M., Epstein, G., Evans, L. S., Maxwell, S. M. and Nenadovic, M. (2017) 'Social and ecological effectiveness of large marine protected areas', *Global Environmental Change*, 43, pp. 82–91. doi: 10.1016/J.GLOENVCHA.2017.01.003.

Barberá, C., Mallol, S., Vergés, A., Cabanellas-Reboredo, M., Díaz, D. and Goñi, R. (2017) 'Maerl beds inside and outside a 25-year-old no-take area', *Marine Ecology Progress Series*, 572, pp. 77–90. doi: 10.3354/MEPS12110.

Boyle, K., Kaiser, M. J., Thompson, S., Murray, L. G. and Duncan, P. F. (2016) 'Spatial Variation in Fish and Invertebrate Bycatches in a Scallop Trawl Fishery', *Journal of Shellfish Research*, 35(1), pp. 7–15. doi: 10.2983/035.035.0102.

Buhl-Mortensen, P., Dolan, M. F. J., Ross, R. E., Gonzalez-Mirelis, G., Buhl-Mortensen, L., Bjarnadóttir, L. R. and Albretsen, J. (2020) 'Classification and Mapping of Benthic Biotopes in Arctic and Sub-Arctic Norwegian Waters', *Frontiers in Marine Science*, 7. doi: 10.3389/FMARS.2020.00271.

Casado-Amezúa, P., Araújo, R., Bárbara, I., Bermejo, R., Borja, Díez, I., Fernández, C., Gorostiaga, J. M., Guinda, X., Hernández, I., Juanes, J. A., Peña, V., Peteiro, C., Puente, A., Quintana, I., Tuya, F., Viejo, R. M., Altamirano, M., Gallardo, T. *et al.* (2019) 'Distributional shifts of canopy-forming seaweeds from the Atlantic coast of Southern Europe', *Biodiversity and Conservation*, 28(5), pp. 1151–1172. doi: 10.1007/S10531-019-01716-9.

Caselle, J. E., Rassweiler, A., Hamilton, S. L. and Warner, R. R. (2015) 'Recovery trajectories of kelp forest animals are rapid yet spatially variable across a network of temperate marine protected areas', *Scientific Reports*, 5. doi: 10.1038/SREP14102.

Chust, G., González, M., Fontán, A., Revilla, M., Alvarez, P., Santos, M., Cotano, U., Chifflet, M., Borja, A., Muxika, I., Sagarminaga, Y., Caballero, A., de Santiago, I., Epelde, I., Liria, P., Ibaibarriaga, L., Garnier, R., Franco, J., Villarino, E. *et al.* (2022) 'Climate regime shifts and biodiversity redistribution in the Bay of Biscay', *Science of The Total Environment*, 803, p. 149622. doi: 10.1016/J.SCITOTENV.2021.149622.

Coleman, N., Cuff, W., Moverley, J., Gason, A. S. H. and Heislers, S. (2007) 'Depth, sediment type, biogeography and high species richness in shallow-water benthos', *Marine and Freshwater Research*, 58(3), pp. 293–305. doi: 10.1071/MF06098.

Consoli, P., Sarà, G., Mazza, G., Battaglia, P., Romeo, T., Incontro, V. and Andaloro, F. (2013) 'The effects of protection measures on fish assemblage in the Plemmirio marine reserve (Central Mediterranean Sea, Italy): A first assessment 5 years after its establishment', *Journal of Sea Research*, 79, pp. 20–26. doi: 10.1016/J.SEARES.2013.01.004.

Daka, E. R. (2006) 'Population differences in susceptibility to stress in Littorina saxatilis from metal contaminated and uncontaminated sites in the Isle of Man', *Journal of Environmental Sciences*, 18(2), pp. 364–368. Available at: https://www.webofscience.com/wos/woscc/full-record/WOS:000236120700029 (Accessed: 4 May 2022).

Das, M. (2020) 'Trawl-induced biological and chemical degradation in Bengal Offshore', *Sustainable Water Resources Management*, 6(4). doi: 10.1007/S40899-020-00412-9.

DEFA (2021a) *Isle of Man Government - Marine Nature Reserves*. Available at: https://www.gov.im/about-the-government/departments/environment-food-and-agriculture/environment-directorate/ecosystem-policy/wildlife-biodiversity-and-protected-sites/protected-sites/marine-nature-reserves/ (Accessed: 11 November 2021).

DEFA (2021b) *Sea-Fisheries (Technical Measures) (Amendment) Regulations SEA-FISHERIES*

(TECHNICAL MEASURES) (AMENDMENT) REGULATIONS 2021.

Dehens, L. A. and Fanning, L. M. (2018) ‘What counts in making marine protected areas (MPAs) count? The role of legitimacy in MPA success in Canada’, *Ecological Indicators*, 86, pp. 45–57. doi: 10.1016/J.ECOLIND.2017.12.026.

Dignan, S., Bloor, I., Duncan, P., Kaiser, M., Murray, L., Kennington, K. and Gell, F. (2014) ‘Ramsey Marine Nature Reserve Fisheries Management Zone: A novel approach to mitigating the socioeconomic impacts of an MPA. ICES CM 2014/B:18’.

Duarte, C. M., Kennedy, H., Marbà, N. and Hendriks, I. (2013) ‘Assessing the capacity of seagrass meadows for carbon burial: Current limitations and future strategies’, *Ocean and Coastal Management*, 83, pp. 32–38. doi: 10.1016/J.OCECOAMAN.2011.09.001.

Duncan, P. F. (2018) *The New Isle of Man 0-3 nm Marine Nature Reserves What You Need to Know: Questions and Answers Background*. Available at: http://ec.europa.eu/environment/nature/natura2000/marine/docs/Socio - (Accessed: 11 November 2021).

EEA (2019) *EUNIS -EUNIS habitat type hierarchical view*. Available at: https://eunis.eea.europa.eu/habitats-code-browser.jsp?expand=1#level_423 (Accessed: 6 December 2021).

Emmerson, J. A., Hollyman, P. R., Bloor, I. S. M. and Jenkins, S. R. (2020) ‘Effect of temperature on the growth of the commercially fished common whelk (Buccinum undatum, L.): A regional analysis within the Irish Sea’, *Fisheries Research*, 223. doi: 10.1016/J.FISHRES.2019.105437.

Foden, J., Rogers, S. I. and Jones, A. P. (2011) ‘Human pressures on UK seabed habitats: A cumulative impact assessment’, *Marine Ecology Progress Series*, 428, pp. 33–47. doi: 10.3354/MEPS09064.

Furey, A. E., Hoeche, U. and Noci, F. (2020) ‘Adding value to under-utilised Irish fish roe: a physico-chemical and sensory comparison of cured Irish pollock (Pollachius pollachius) roe with commercial mullet (Mugil cephalus) and cod (Gadus morhua) products’, *Irish Journal of Agricultural and Food Research*, 59(1). doi: 10.15212/IJAFR-2020-0114.

Gjøsæter, H., Bogstad, B. and Tjelmeland, S. (2009) ‘Ecosystem effects of the three capelin stock collapses in the Barents Sea’, *Marine Biology Research*, 5(1), pp. 40–53. doi: 10.1080/17451000802454866.

Gray, J. S., Poore, G. C. B., Ugland, K. I., Wilson, R. S., Olsgard, F. and Johannessen (1997) ‘Coastal and deep-sea benthic diversities compared’, *Marine Ecology Progress Series*, 159, pp. 97–103. doi: 10.3354/MEPS159097.

Hall-Spencer, J. M. and Moore, P. G. (2000) ‘Scallop dredging has profound, long-term impacts on maerl habitats’, *ICES Journal of Marine Science*, 57(5), pp. 1407–1415. doi: 10.1006/JMSC.2000.0918.

Hannah, R. W. and Blume, M. T. O. (2012) ‘Tests of an experimental unbaited video lander as a marine fish survey tool for high-relief deepwater rocky reefs’, *Journal of Experimental Marine Biology and Ecology*, 430–431, pp. 1–9. doi: 10.1016/J.JEMBE.2012.06.021.

Henseler, C., Nordström, M. C., Törnroos, A., Snickars, M., Pecuchet, L., Lindegren, M. and Bonsdorff, E. (2019) ‘Coastal habitats and their importance for the diversity of benthic communities: A species- and trait-based approach’, *Estuarine, Coastal and Shelf Science*, 226, p. 106272. doi: 10.1016/J.ECSS.2019.106272.

Herbert, R. J. H., Collins, K., Mallinson, J., Hall, A. E., Pegg, J., Ross, K., Clarke, L. and Clements, T. (2017) ‘Epibenthic and mobile species colonisation of a geotextile artificial surf reef on the south coast of England', *PLoS ONE*, 12(9). doi: 10.1371/JOURNAL.PONE.0184100.

JNCC (2019) *About Marine Protected Areas | JNCC - Adviser to Government on Nature Conservation*. Available at: https://jncc.gov.uk/our-work/about-marine-protected-areas/#what-are-mpas (Accessed: 10 November 2021).

Kamenos, N. A., Moore, P. G. and Hall-Spencer, J. M. (2004) 'Maerl grounds provide both refuge and high growth potential for juvenile queen scallops (Aequipecten opercularis L.)', *Journal of Experimental Marine Biology and Ecology*, 313(2), pp. 241–254. doi: 10.1016/J.JEMBE.2004.08.007.

Kennington, K. and Hisscott, A. (2013) 'Hydrology, Weather and Climate, Climatology', in *Manx Marine Environmental Assessment. Isle of Man Marine Plan. Isle of Man Government*, p. 45. Available at: https://www.researchgate.net/publication/283356339_Chapter_21_Hydrology_Weather_and_Climate_Climatology (Accessed: 13 April 2022).

King, N. G., Duncan, P. F., Kennington, K., Wootton, E. C. and Jenkins, S. R. (2014) 'Characterisation of shell disease syndrome in the brown crab, Cancer pagurus, in a discrete Irish Sea fishery', *Journal of Crustacean Biology*, 34(1), pp. 40–46. doi: 10.1163/1937240X-00002208.

Kon, K., Tsuchiya, Y., Sato, T., Shinagawa, H. and Yamada, Y. (2015) 'Role of microhabitat heterogeneity in benthic faunal communities in sandy bottom sediments of Oura Bay, Shimoda, Japan', *Regional Studies in Marine Science*, 2, pp. 71–76. doi: 10.1016/J.RSMA.2015.05.007.

Kraufvelin, P., Pekcan-Hekim, Z., Bergström, U., Florin, A. B., Lehikoinen, A., Mattila, J., Arula, T., Briekmane, L., Brown, E. J., Celmer, Z., Dainys, J., Jokinen, H., Kääriä, P., Kallasvuo, M., Lappalainen, A., Lozys, L., Möller, P., Orio, A., Rohtla, M. *et al.* (2018) 'Essential coastal habitats for fish in the Baltic Sea', *Estuarine, Coastal and Shelf Science*, 204, pp. 14–30. doi: 10.1016/J.ECSS.2018.02.014.

Marshall, J. E., Bucher, D. J. and Smith, S. D. A. (2018) 'Patterns of infaunal macromollusc assemblages in a subtropical marine park: Implications for management', *Marine and Freshwater Research*, 69(4), pp. 502–513. doi: 10.1071/MF17122.

McArthur, M. A., Brooke, B. P., Przeslawski, R., Ryan, D. A., Lucieer, V. L., Nichol, S., McCallum, A. W., Mellin, C., Cresswell, I. D. and Radke, L. C. (2010) 'On the use of abiotic surrogates to describe marine benthic biodiversity', *Estuarine, Coastal and Shelf Science*, 88(1), pp. 21–32. doi: 10.1016/J.ECSS.2010.03.003.

Metcalfe, K., Roberts, T., Smith, R. J. and Harrop, S. R. (2013) 'Marine conservation science and governance in North-West Europe: Conservation planning and international law and policy', *Marine Policy*, 39(1), pp. 289–295. doi: 10.1016/J.MARPOL.2012.12.002.

Misiuk, B., Diesing, M., Aitken, A., Brown, C. J., Edinger, E. N. and Bell, T. (2019) 'A spatially explicit comparison of quantitative and categorical modelling approaches for mapping seabed sediments using random forest', *Geosciences (Switzerland)*, 9(6). doi: 10.3390/GEOSCIENCES9060254.

MMO (2021) 'UK Sea Fisheries Statistics 2020 2'. Available at: https://www.gov.uk/government/statistics/uk-sea-fisheries-annual-statistics-report-2020. (Accessed: 11 November 2021).

Montefalcone, M., Tunesi, L. and Ouerghi, A. (2021) 'A review of the classification systems for marine benthic habitats and the new updated Barcelona Convention classification for the Mediterranean', *Marine Environmental Research*, 169, p. 105387. doi: 10.1016/J.MARENVRES.2021.105387.

Morris, C. J. and Green, J. M. (2014) 'MPA regulations should incorporate adaptive management-The case of Gilbert Bay Labrador Atlantic cod (Gadus morhua)', *Marine Policy*, 49, pp. 20–28. doi: 10.1016/J.MARPOL.2014.03.025.

Nababan, B., Mastu, L. O. K., Idris, N. H. and Panjaitan, J. P. (2021) 'Shallow-water benthic habitat mapping using drone with object based image analyses', *Remote Sensing*, 13(21). doi: 10.3390/RS13214452.

O'Brien, K. R., Waycott, M., Maxwell, P., Kendrick, G. A., Udy, J. W., Ferguson, A. J. P., Kilminster, K., Scanes, P., McKenzie, L. J., McMahon, K., Adams, M. P., Samper-Villarreal, J., Collier, C., Lyons, M., Mumby, P. J., Radke, L., Christianen, M. J. A. and Dennison, W. C. (2018) 'Seagrass ecosystem trajectory depends on the relative timescales of resistance, recovery and disturbance', *Marine Pollution Bulletin*, 134, pp. 166–176. doi: 10.1016/J.MARPOLBUL.2017.09.006.

Oberle, F. K. J., Swarzenski, P. W., Reddy, C. M., Nelson, R. K., Baasch, B. and Hanebuth, T. J. J. (2016) 'Deciphering the lithological consequences of bottom trawling to sedimentary habitats on the shelf', *Journal of Marine Systems*, 159, pp. 120–131. doi: 10.1016/J.JMARSYS.2015.12.008.

Öndes, F., Emmerson, J. A., Kaiser, M. J., Murray, L. G. and Kennington, K. (2019) 'The catch characteristics and population structure of the brown crab (Cancer pagurus) fishery in the Isle of Man, Irish Sea', *Journal of the Marine Biological Association of the United Kingdom*, 99(1), pp. 119–133. doi: 10.1017/S0025315417001849.

Öndes, F., Kaiser, M. J. and Murray, L. G. (2016) 'Quantification of the indirect effects of scallop dredge fisheries on a brown crab fishery', *Marine Environmental Research*, 119, pp. 136–143. doi: 10.1016/J.MARENVRES.2016.05.020.

Öndes, F., Kaiser, M. J. and Murray, L. G. (2018) 'Fish and invertebrate by-catch in the crab pot fishery in the Isle of Man, Irish Sea', *Journal of the Marine Biological Association of the United Kingdom*, 98(8), pp. 2099–2111. doi: 10.1017/S0025315417001643.

Orth, R. J., Luckenbach, M. L., Marion, S. R., Moore, K. A. and Wilcox, D. J. (2006) 'Seagrass recovery in the Delmarva Coastal Bays, USA', *Aquatic Botany*, 84(1), pp. 26–36. doi: 10.1016/J.AQUABOT.2005.07.007.

OSPAR (2022) *Habitats | OSPAR Commission*. Available at: https://www.ospar.org/work-areas/bdc/species-habitats/list-of-threatened-declining-species-habitats/habitats (Accessed: 4 May 2022).

Poloczanska, E. S., Burrows, M. T., Brown, C. J., Molinos, J. G., Halpern, B. S., Hoegh-Guldberg, O., Kappel, C. V., Moore, P. J., Richardson, A. J., Schoeman, D. S. and Sydeman, W. J. (2016) 'Responses of marine organisms to climate change across oceans', *Frontiers in Marine Science*, 3(MAY). doi: 10.3389/FMARS.2016.00062.

Porskamp, P., Rattray, A., Young, M. and Ierodiaconou, D. (2018) 'Multiscale and hierarchical classification for benthic habitat mapping', *Geosciences (Switzerland)*, 8(4). doi: 10.3390/GEOSCIENCES8040119.

Proudfoot, B., Devillers, R., Brown, C. J., Edinger, E. and Copeland, A. (2020) 'Seafloor mapping to support conservation planning in an ecologically unique fjord in Newfoundland and Labrador, Canada', *Journal of Coastal Conservation*, 24(3). doi: 10.1007/S11852-020-00746-8.

Qui-Minet, Z. N., Davoult, D., Grall, J., Delaunay, C., Six, C., Cariou, T. and Martin, S. (2021) 'Physiology of maerl algae: Comparison of inter- and intraspecies variations', *Journal of Phycology*, 57(3), pp. 831–848. doi: 10.1111/JPY.13119.

Ricotta, C. and Pavoine, S. (2022) 'A new parametric measure of functional dissimilarity: Bridging the gap between the Bray-Curtis dissimilarity and the Euclidean distance', *Ecological Modelling*, 466, p. 109880. doi: 10.1016/J.ECOLMODEL.2022.109880.

Roland Pitcher, C., Lawton, P., Ellis, N., Smith, S. J., Incze, L. S., Wei, C. L., Greenlaw, M. E., Wolff, N. H., Sameoto, J. A. and Snelgrove, P. V. R. (2012) ‘Exploring the role of environmental variables in shaping patterns of seabed biodiversity composition in regional-scale ecosystems’, *Journal of Applied Ecology*, 49(3), pp. 670–679. doi: 10.1111/J.1365-2664.2012.02148.X.

Rowley, A. F., Cross, M. E., Culloty, S. C., Lynch, S. A., Mackenzie, C. L., Morgan, E., O’Riordan, R. M., Robins, P. E., Smith, A. L., Thrupp, T. J., Vogan, C. L., Wootton, E. C. and Malham, S. K. (2014) ‘The potential impact of climate change on the infectious diseases of commercially important shellfish populations in the Irish Sea - A review’, *ICES Journal of Marine Science*, 71(4), pp. 741–759. doi: 10.1093/ICESJMS/FST234.

Schéré, C. M., Dawson, T. P. and Schreckenberg, K. (2020) ‘Multiple conservation designations: what impact on the effectiveness of marine protected areas in the Irish Sea?’, *International Journal of Sustainable Development and World Ecology*, 27(7), pp. 596–610. doi: 10.1080/13504509.2019.1706058.

Schneider, C. A., Rasband, W. S. and Eliceiri, K. W. (2012) ‘NIH Image to ImageJ: 25 years of image analysis’, *Nature Methods*, 9(7), pp. 671–675. doi: 10.1038/NMETH.2089.

Sciberras, M., Jenkins, S. R., Mant, R., Kaiser, M. J., Hawkins, S. J. and Pullin, A. S. (2015) ‘Evaluating the relative conservation value of fully and partially protected marine areas’, *Fish and Fisheries*, 16(1), pp. 58–77. doi: 10.1111/FAF.12044.

Sheehan, E. V., Bridger, D., Cousens, S. L. and Attrill, M. J. (2015) ‘Testing the resilience of dead maerl infaunal assemblages to the experimental removal and re-lay of habitat’, *Marine Ecology Progress Series*, 535, pp. 117–128. doi: 10.3354/MEPS11400.

Switzer, T. S., Tyler-Jedlund, A. J., Keenan, S. F. and Weather, E. J. (2020) ‘Benthic Habitats, as Derived from Classification of Side-Scan-Sonar Mapping Data, Are Important Determinants of Reef-Fish Assemblage Structure in the Eastern Gulf of Mexico’, *Marine and Coastal Fisheries*, 12(1), pp. 21–32. doi: 10.1002/MCF2.10106.

Szostek, C. L., Murray, L. G., Bell, E., Lambert, G. and Kaiser, M. J. (2017) ‘Regional variation in bycatches associated with king scallop (Pecten maximus L.) dredge fisheries’, *Marine Environmental Research*, 123, pp. 1–13. doi: 10.1016/J.MARENVRES.2016.11.006.

Teagle, H., Hawkins, S. J., Moore, P. J. and Smale, D. A. (2017) ‘The role of kelp species as biogenic habitat formers in coastal marine ecosystems’, *Journal of Experimental Marine Biology and Ecology*, 492, pp. 81–98. doi: 10.1016/J.JEMBE.2017.01.017.

Trannum, H. C. (2017) ‘Drilling discharges reduce sediment reworking of two benthic species’, *Marine Pollution Bulletin*, 124(1), pp. 266–269. doi: 10.1016/J.MARPOLBUL.2017.07.044.

Ward, S. L., Neill, S. P., Van Landeghem, K. J. J. and Scourse, J. D. (2015) ‘Classifying seabed sediment type using simulated tidal-induced bed shear stress’, *Marine Geology*, 367, pp. 94–104. doi: 10.1016/J.MARGEO.2015.05.010.

Wilson, S., Blake, C., Berges, J. A. and Maggs, C. A. (2004) ‘Environmental tolerances of free-living coralline algae (maerl): implications for European marine conservation’, *Biological Conservation*, 120(2), pp. 279–289. doi: 10.1016/J.BIOCON.2004.03.001.

Appendices

Appendix I

List of taxa identified from benthic images taken from the Laxey MNR.

Phylum	Taxon
Porifera	Orange encrusting sponge sp.
	White encrusting sponge sp.
Bryozoa	*Bugula flagellata*
	Vesicularia spinosa
	Eucratea loricata
Cnidaria	*Adamsia palliata*
	Cerianthus lloydii
	Peachia cylindrica
	Nemertesia antennina
	Nemertesia ramosa
	Hydrallmania falcata
	Laomedea angulata
	Unidentified Hydroid sp.
Arthropoda	*Pagurus bernhardus*
	Pagurus prideaux
	Family Paguridae
	Corystes cassivelaunus
	Galathea intermedia
	Macropodia sp.
	Family Porcellanidae
	Pomatoceros triqueter (tubes)
	Family Spirorbidae (tubes)
	Balanus sp.
Annelida	*Eupolymnia nebulosa*
	Lanice conchilega
	Family Sabellidae
	Burrowing worm spp.
	Arenicola marina (casts)
Mollusca	*Glycymeris glycymeris*
	Spisula elliptica
	Aequipecten opercularis
	Lutraria lutraria (siphons)
	Patella sp.

Phylum	Taxon
Mollusca (cont.)	Unidentified bivalve sp.
	Euspira nitida
	Turritella communis
	Buccinum undatum
	Family Lacuninae
Echinoderms	*Psammechinus miliaris*
	Echinocardium cordatum
	Asterias rubens
	Ophiura ophiura
Chordata	*Callionymus lyra*
Rhodophyta	*Phymatolithon calcareum*
	Encrusting maerl sp.
	Phycodrys rubens
	Fine Rhodophyta spp.
	Branching Rhodophyta spp.
	Encrusting Rhodophyta spp.
Phaeophyta	*Himanthalia elongata*
	Dictyota dichotoma
	Chordraria flagelliformes
	Laminaria sp.
	Saccharina latissima
	Fine Phaeophyceae spp.
	Flat Phaeophyceae spp.
	Branching Phaeophyceae sp.
	Dark Brown encrusting algae sp.
	Brown encrusting algae sp.
Chlorophyta	*Ulva* spp.
	Chaetomorpha spp.
	Fine Chlorophyta spp.
Angiosperms	*Zostera marina*

Appendix II

Results of SIMPER analysis on biotope groupings identified from SIMPROF analysis of the Laxey dataset, along with the taxa that contributed most to the within-group similarity. Percentage cut-off for contributing taxa was 90%.

SIMPROF Cluster Number/Taxon	**Average abundance**	**Contribution %**	**Cumulative Contribution %**
Group 1: Average similarity 33.71%			
Maerl	0.79	55.66	55.66
Unidentified Hydroid spp.	0.47	18.85	74.51
Eucratea loricata	0.42	15.22	89.73
Fine Phaeophyceae spp.	0.26	4.74	94.45
Group 2: Average similarity 33.16%			
Maerl	0.72	46.41	46.41
Brown Encrusting Algae	0.61	35.44	81.85
Worm Casts	0.39	11.79	93.64
Group 3: Average similarity 17.41%			
Maerl	0.50	43.62	43.62
Fine Phaeophyceae spp.	0.50	31.49	75.11
Fine Rhodophyta spp.	0.33	9.57	84.68
Cerianthus lloydii	0.33	7.66	92.34
Group 4: Average similarity 59.71%			
Brown Encrusting Algae	1.00	72.41	72.41
Worm Casts	0.67	25.99	98.40
Group 5: Average similarity 70.01%			
Brown Encrusting Algae	1.00	86.98	86.98
Worm Casts	0.45	12.56	99.54
Group 6: Average similarity 80.06%			
Worm Casts	1.00	99.65	99.65
Group 7: Average similarity 81.49%			
Worm Casts	1.00	99.46	99.46
Group 8: Average similarity 14.69%			
Worm Casts	0.57	83.80	83.80
Brown Encrusting Algae	0.29	16.20	100.00
Group 9: Average similarity 52.37%			
Worm Casts	0.80	96.95	96.95
Group 10: Average similarity 77.43%			
Worm Casts	1.00	99.69	99.69

Group 11: Average similarity 82.62%			
Worm Casts	1.00	49.28	49.28
Zostera marina	1.00	49.28	98.56
Group 12: Average similarity 9.52%			
Unidentified Hydroid spp.	0.67	100.00	100.00
Group 13: Average similarity 70.77%			
Worm Casts	0.93	99.80	99.80
Group 14: Average similarity NA			
Less than 2 samples in group			
Group 15: Average similarity 33.33%			
Laminaria digitata	1.00	100.00	100.00
Group 16: Average similarity 51.24%			
Worm Casts	0.79	99.77	99.77
Group 17: Average similarity 16.67%			
Adamsia palliata	1.00	50.00	50.00
Pagurus prideaux	1.00	50.00	100.00

Appendix III

Biotopes identified in Laxey Bay MNR using EUNIS habitat classification. Descriptions informed by JNCC website, accessible via the URL: https://mhc.jncc.gov.uk/

Biotope code: SS.SMu.CSaMu

Biotope description: Circalittoral Sandy Mud

Wave exposure: Exposed to Very sheltered

Tidal streams: Moderately strong (1-3 knots) to Very weak (negligible)

Substratum: Mud with significant fine to very fine sand fraction

Zone: Circalittoral

Depth range: 5-100m

Description: Generally found in deeper areas of bays and marine inlets or offshore from less wave exposed coasts. Few floral and epifaunal species. Some hermit crabs (*Pagurus prideaux* and *Pagurus bernhardus*) and sea pens (*Nemertesia* spp.) observed, but sparsely distributed. Many worm casts indicative of lugworms (*Arenicola marina*). Sparsely scattered, small shell fragments were observed throughout this habitat. This was the most widely occurring habitat, though areas may differ in detailed substrate properties or by infaunal communities.

Biotope code: SS.SMp.SSgr.Zmar

Biotope description: *Zostera marina/angustifolia* beds on lower shore or infralittoral clean or muddy sand

Wave exposure: Moderately exposed to Extremely sheltered

Tidal streams: Moderately strong to Very weak

Substratum: Clean sand to muddy fine sand or mud

Zone: Infralittoral

Depth range: 0-10m, Lower shore

Description: Expanses of clean or muddy fine sand and sandy mud in shallow waters, similar to SS.SMu.CSaMu, but with patches of eelgrass (*Zostera marina*) throughout. The hydroid *Laomedea angulata* was also observed in this habitat, sometimes attached to eelgrass blades. Other species observed less consistently include hermit crabs *Pagurus bernhardus* and *Pagurus prideaux*, and various macroalgal species – both of Rhodophyta and Phaeophyceae.

Biotope code: SS.SSa.IMuSa

Biotope description: Infralittoral Muddy Sand

Wave exposure: Moderately exposed to Sheltered

Tidal streams: Moderately strong to very weak

Substratum: Fine to very fine sand with a silt fraction

Zone: Infralittoral

Depth range: 0-20m

Description: Non-cohesive muddy sand (5-20% silt/clay), with highly infrequent worm casts, cover more dominated by brown algae film. Some detritus of *Laminaria* spp. also observed throughout the habitat. Likely richer infaunal diversity, composed of polychaetes and bivalves.

Biotope code: SS.SMp.Mrl.PCal

Biotope description: *Phymatolithon calcareum* maerl beds in infralittoral clean gravel or coarse sand

Wave exposure: Moderately exposed to Extremely sheltered

Tidal streams: Moderately strong to weak (<1 knot)

Substratum: Maerl gravel and sand

Zone: Infralittoral

Depth range: 0-20m

Description: Primarily dead maerl (*Phymatolithon calcareum*), though some living structures were observed. Substratum also consisted of larger shells alongside finer gravel. Various small bryozoan/hydrozoan turf species (e.g. bryozoan *Eucratea loricata*) alongside patches of small Rhodophyta spp. were observed throughout this habitat. Designations of this habitat were sparse, usually being closely associated with SS.SCS.ICS and SS.SMp.Mrl.PCal.Nmix, though differing from these by biological communities and substrate types.

Biotope code: SS.SCS.ICS

Biotope description: Infralittoral Coarse Sediment

Wave exposure: Exposed to Sheltered

Tidal streams: Strong (3-6 knots) to Very weak

Substratum: Sand with gravel, pebbles and/or shingle

Zone: Infralittoral

Depth range: 0-20m

Description: Sand with some shell fragments, dead maerl fragments and some covering brown algae. Some fragments of living maerl, alongside occasional crustacean (*Pagurus* spp. and *Macropodia* spp.) and anemone (*Cerianthus lloydii*) species. Some small bryozoan species observed, though otherwise lacking in consistently occurring flora and fauna. Often better characterised by polychaete, cumacean and bivalve communities.

Biotope code: SS.SMp.Mrl.PCal.Nmix

Biotope description: *Phymatolithon calcareum* maerl beds with *Neopentadactyla mixta* and other echinoderms in deeper indralittoral clean gravel or coarse sand

Wave exposure: Exposed to Sheltered

Tidal streams: Moderately strong to Very weak

Substratum: Maerl gravel, coarse sand

Zone: Circalittoral – upper, Infralittoral – lower

Depth range: 5-30m

Description: Similar to SS.SMp.Mrl.PCal but characterised by the occurrence of the anemone *Cerianthus lloydii*, alongside occasional starfish *Asterias rubens*. This habitat was the furthest from the shoreline, which was still of depths <20m.

Appendix IV

Results of SIMPER analysis on biotope groupings identified from EUNIS allocation of the Laxey dataset, along with the taxa that contributed most to the within-group similarity. Percentage cut-off for contributing taxa was 90%.

EUNIS Habitat/Taxon	**Average abundance**	**Contribution %**	**Cumulative Contribution %**
SS.SMu.CSaMu: Average similarity 59.94%			
Worm Casts	0.87	99.00	99.00
SS.SMp.SSgr.Zmar: Average similarity 58.22%			
Worm Casts	1.00	75.44	75.44
Zostera marina	0.61	22.13	97.57
SS.SSa.IMuSa: Average similarity 63.57%			
Brown Encrusting Algae	0.94	87.23	87.23
Worm Casts	0.42	12.12	99.35
SS.SMp.Mrl.PCal: Average similarity 48.41%			
Unidentified Hydroid spp.	0.88	43.47	43.47
Maerl	0.88	43.47	86.93
Fine Phaeophyceae spp.	0.50	11.43	98.36
SS.SCS.ICS: Average similarity 34.13%			
Brown Encrusting Algae	0.70	46.91	46.91
Maerl	0.65	36.31	83.22
Worm Casts	0.40	12.45	95.67
SS.SMp.Mrl.PCal.Nmix: Average similarity 80.06%			
Maerl	0.74	63.73	63.73
Unidentified Hydroid spp.	0.37	11.31	75.04
Eucratea loricata	0.32	10.80	85.84
Cerianthus lloydii	0.32	4.43	90.27

Appendix V

List of taxa identified from benthic images taken from the Niarbyl MNR.

Phylum	Taxon
Porifera	Orange encrusting sponge sp.
	White encrusting sponge sp.
Bryozoa	*Vesicularia spinosa*
	Eucratea loricata
	Cellaria spp.
Cnidaria	*Cerianthus lloydii*
	Unidentified brown anemone sp.
	Nemertesia antennina
	Nemertesia ramosa
	Unidentified Hydroid spp.
Arthropoda	*Necora puber*
	Liocarcinus duperator
	Ebalia sp.
	Macropodia sp.
	Galathea intermedia
	Mysid shrimp sp.
	Pomatoceros triqueter (tubes)
	Family Spirorbidae (tubes)
	Balanus sp.
Annelida	*Oxydromus flexuosus*
	Tubulanus annulatus
	Eupolymnia nebulosa
	Lanice conchilega
	Family *Sabellidae*
	Arenicola marina (casts)
Mollusca	*Lutraria lutraria* (siphons)
	Unidentified bivalve sp.
	Flabellina lineata
	Turritella communis
	Buccinum undatum
	Family Littorinidae
Echinoderms	*Marthasterias glacialis*
	Asterias rubens
	Ophiura ophiura
	Ophiothrix fragilis
	Amphiura filiformis (arms)
	Antedon bifida
Chordata	*Blennius ocellaris*
	Parablennius gattorugine
	Gobius paganellus
	Diplecogaster bimaculata
	Ammodytes tobianus
	Orange fish sp.
Rhodophyta	*Phymatolithon calcareum*
	Encrusting maerl sp.
	Phycodrys rubens
	Fine Rhodophyta spp.
	Encrusting Rhodophyta spp.
Phaeophyta	*Dictyota dichotoma*
	Laminaria digitata
	Saccharina latissima
	Fine Phaeophyceae spp.
	Flat robust Phaeophyceae spp.
	Dark Brown encrusting algae sp.
	Brown encrusting algae sp.
Chlorophyta	*Ulva* spp.
	Filamentous Chlorophyta spp.

Appendix VI

Results of SIMPER analysis on biotope groupings identified from SIMPROF analysis of the Niarbyl dataset, along with the taxa that contributed most to the within-group similarity. Percentage cut-off for contributing taxa was 90%.

SIMPROF Cluster Number/Taxon	**Average abundance**	**Contribution %**	**Cumulative Contribution %**
Group 1: Average similarity 42.50%			
Brown Encrusting Algae	1.00	80.40	80.40
Cerianthus lloydii	0.60	16.43	96.83
Group 2: Average similarity 29.86%			
Brown Encrusting Algae	0.75	55.87	55.87
Cerianthus lloydii	0.83	24.27	80.14
Pomatoceros triqueter tubes	0.33	9.58	89.72
Fine Rhodophyta spp.	0.25	3.95	93.67
Group 3: Average similarity 15.41%			
Maerl	0.35	41.43	41.43
Fine Phaeophyceae spp.	0.47	35.60	79.02
Fine Rhodophyta spp.	0.29	14.12	93.14
Group 4: Average similarity 57.67%			
Encrusting Maerl	1.00	88.69	88.69
Maerl	0.27	3.34	92.03
Group 5: Average similarity 52.45%			
Brown Encrusting Algae	1.00	69.83	69.83
Encrusting Maerl	0.54	15.54	15.54
Maerl	0.33	6.04	91.42
Group 6: Average similarity 12.31%			
Fine Rhodophyta spp.	0.41	39.54	39.54
Pomatoceros triqueter tubes	0.26	20.35	59.88
Laminaria digitata	0.26	16.68	76.57
Fine Phaeophyceae spp.	0.22	10.11	86.68
Maerl	0.15	7.43	94.11
Group 7: Average similarity 69.30%			
Brown Encrusting Algae	1.00	58.94	58.94
Brittlestar Arms	0.85	37.77	96.70
Group 8: Average similarity 34.53%			
Brown Encrusting Algae	0.74	77.17	77.17
Brittlestar Arms	0.37	15.31	92.48

Group 9: Average similarity 20.47%			
Hydrozoan/Bryozoan Turf	0.44	33.02	33.02
Cerianthus lloydii	0.89	21.26	54.28
Fine Phaeophyceae spp.	0.44	17.73	72.01
Pomatoceros triqueter tubes	0.44	17.73	89.73
Fine Rhodophyta spp.	0.33	6.87	96.61
Group 10: Average similarity 36.78%			
Fine Rhodophyta spp.	0.96	42.03	42.03
Fine Phaeophyceae spp.	0.83	27.69	69.72
Pomatoceros triqueter tubes	0.50	10.45	80.17
Dictyota dichotoma	0.38	7.37	87.54
Clavelina lepadiformis	6.71	7.31	94.85
Group 11: Average similarity 29.33%			
Fine Rhodophyta spp.	0.92	22.48	22.48
Clavelina lepadiformis	10.85	22.06	44.54
Pomatoceros triqueter tubes	0.85	16.71	61.25
Encrusting Maerl	0.69	8.77	70.01
Fine Phaeophyceae spp.	0.62	8.42	78.43
Ophiura ophiura	1.92	7.14	85.56
Dictyota dichotoma	0.46	6.27	91.83
Group 12: Average similarity 51.84%			
Fine Rhodophyta spp.	1.00	89.84	89.84
Laminaria digitata	0.29	5.21	95.04
Group 13: Average similarity 65.35%			
Fine Rhodophyta spp.	1.00	45.91	45.91
Laminaria digitata	0.83	29.38	75.29
Fine Phaeophyceae spp.	0.75	22.79	98.08

Appendix VII

Biotopes identified in Niarbyl Bay MNR using EUNIS classification. Descriptions informed by JNCC website, accessible via the URL: https://mhc.jncc.gov.uk/

Biotope code: SS.SMp.KSwSS.LsacR.CbPb

Biotope description: Red seaweeds and kelps on tide-swept mobile infralittoral cobbles and pebbles

Wave exposure: Moderately exposed to Very sheltered

Tidal streams: Moderately strong to Very weak

Substratum: Gravel and coarse sand with some pebbles

Zone: Infralittoral

Depth range: 0-20m

Description: Mostly coarse gravel and round pebbles, with some patches of sand/mud, as well as dead shells/shell fragments. Frequent patches of small Rhodophyta and Phaeophyceae algae. Occasional sea pens (*Nemertesia antennina*), sea squirts (*Clavelina lepadiformis*) and anemones (*Cerianthus lloydii*) observed throughout this habitat. This habitat was generally designated close to the coastline, though one region north of 54°8'N was designated over 1km offshore.

Biotope code: SS.SSa.CMuSa

Biotope description: Circalittoral Muddy Sand

Wave exposure: Exposed to Moderately exposed

Tidal streams: Moderately strong to Very weak

Substratum: Fine to very fine sand with a fine silt fraction

Zone: Circalittoral

Depth range: 10-50m

Description: Sand with some shell fragments and brown algae film. Many brittlestar arms protruding from the seabed, believed to be *Amphiura filiformis*. Other common species include *Ophiura ophiura*, *Cerianthus lloydii* and the polychaete *Oxydromus flexuosus*. This habitat was mainly designated at the western border of the MNR, further offshore, though one region at the northernmost extent of the MNR closer to the coast was also designated as circalittoral muddy sand.

Biotope code: SS.SMx.CMx.ClloMx.Nem

Biotope description: *Cerianthus lloydii* with *Nemertesia* spp. and other hydroids in circalittoral muddy mixed sediment

Wave exposure: Moderately exposed to Very sheltered

Tidal streams: Moderately strong to Very weak

Substratum: Sandy muddy gravel with surficial cobbles, pebbles, and shells

Zone: Infralittoral – lower, Circalittoral

Depth range: 10-30m

Description: Many rounded pebbles with larger patches of sand than SS.SMp.KSwSS.LsacR.CbPb. Rare occasions of small Phaeophyceae/Rhodophyta spp., benthos occupied more by *Cerianthus lloydii*, brown algae film, and various hydroid species, including *Eucratea loricata* and *Hydrallmania falcata*. Some *Pomatoceros triqueter* tubes were also recorded, attached to dead shells.

Biotope code: SS.SMp.KSwSS,LsacR.Mu

Biotope description: *Saccharina latissima* with red and brown seaweeds on lower infralittoral muddy mixed sediment

Wave exposure: Moderately exposed to Very sheltered

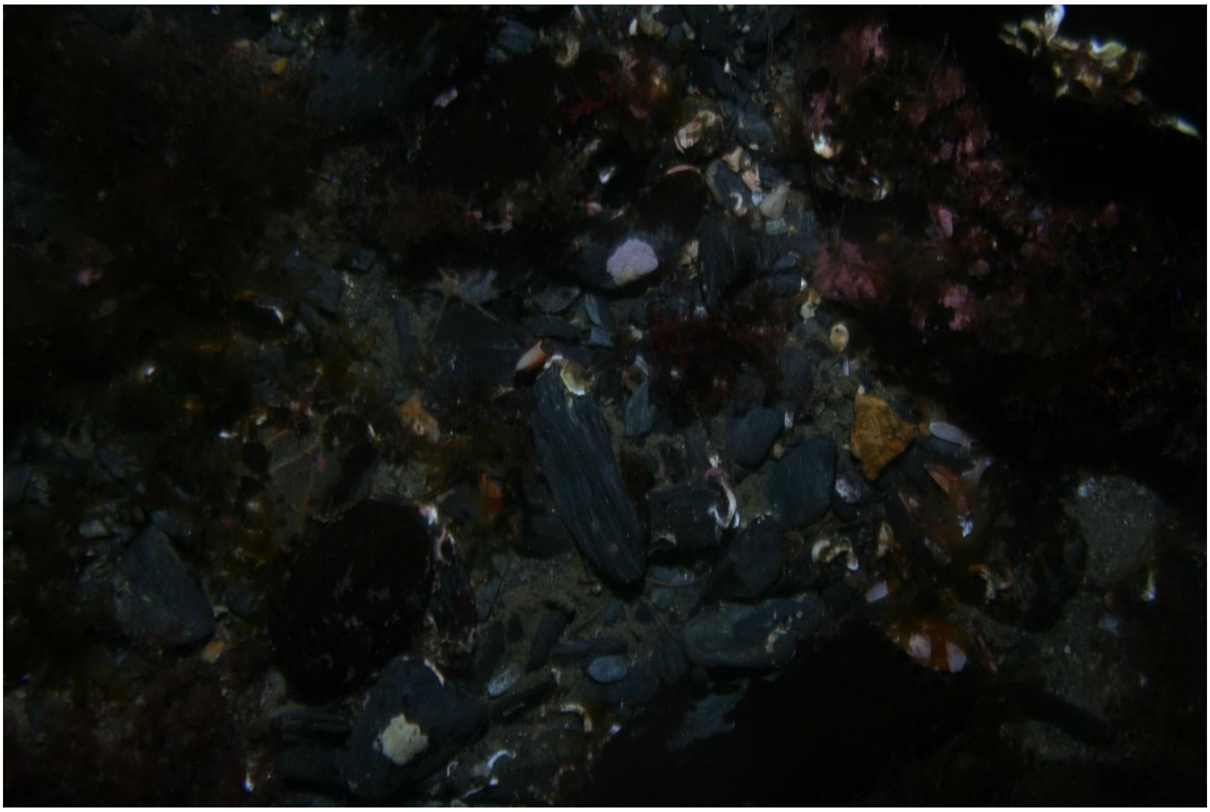
Tidal streams: Moderately strong to Very weak

Substratum: Sand with some gravel

Zone: Infralittoral

Depth range: 0-20m

Description: Similar to SS.SMp.KSwSS.LsacR.CbPb, but with higher densities of *Saccharina latissima*, Rhodophyta spp., and Phaeophyceae spp.. Other species frequently observed were *Clavelina lepadiformis*, tubes of *Pomatoceros triqueter* and encrusting maerl (*Lithothamnion* sp.). This habitat covered the 2nd smallest area of every habitat in Niarbyl, entirely below 54°7’N.



Biotope code: SS.SMx.CMx.OphMx

Biotope description: *Ophiothrix fragilis* and/or *Ophiocomina nigra* brittlestar beds on sublittoral mixed sediment

Wave exposure: Moderately exposed to Sheltered

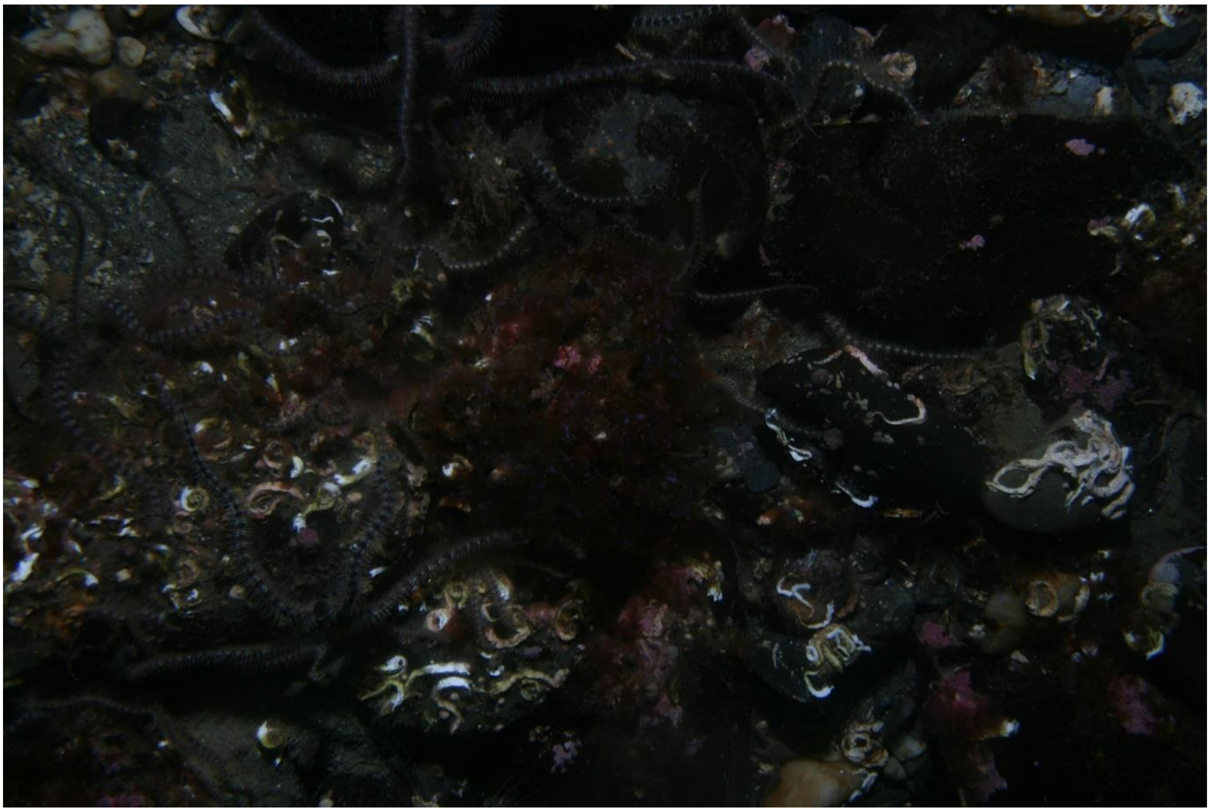
Tidal streams: Strong to Weak

Substratum: Mixed sediment, often with cobbles and pebbles

Zone: Circalittoral

Depth range: 5-50m

Description: Circalittoral sediment dominated by brittlestars – primarily *Ophiothrix fragilis*, though *Ophiura ophiura* was also frequently observed. Other frequently observed species include *Clavelina lepadiformis*, tubes of *Pomatoceros triqueter*, and the feather star *Antedon bifida*. Observed algae included various small Rhodophyta and Phaeophyceae spp. (both in fairly high densities), as well as encrusting maerl (*Lithothamnion* sp.). Despite being circalittoral, this habitat was designated close to the southern coastline, just north of 54°7'N.



Biotope code: SS.SCS.CCS

Biotope description: Circalittoral Coarse Sediment

Wave exposure: Exposed to Moderately exposed

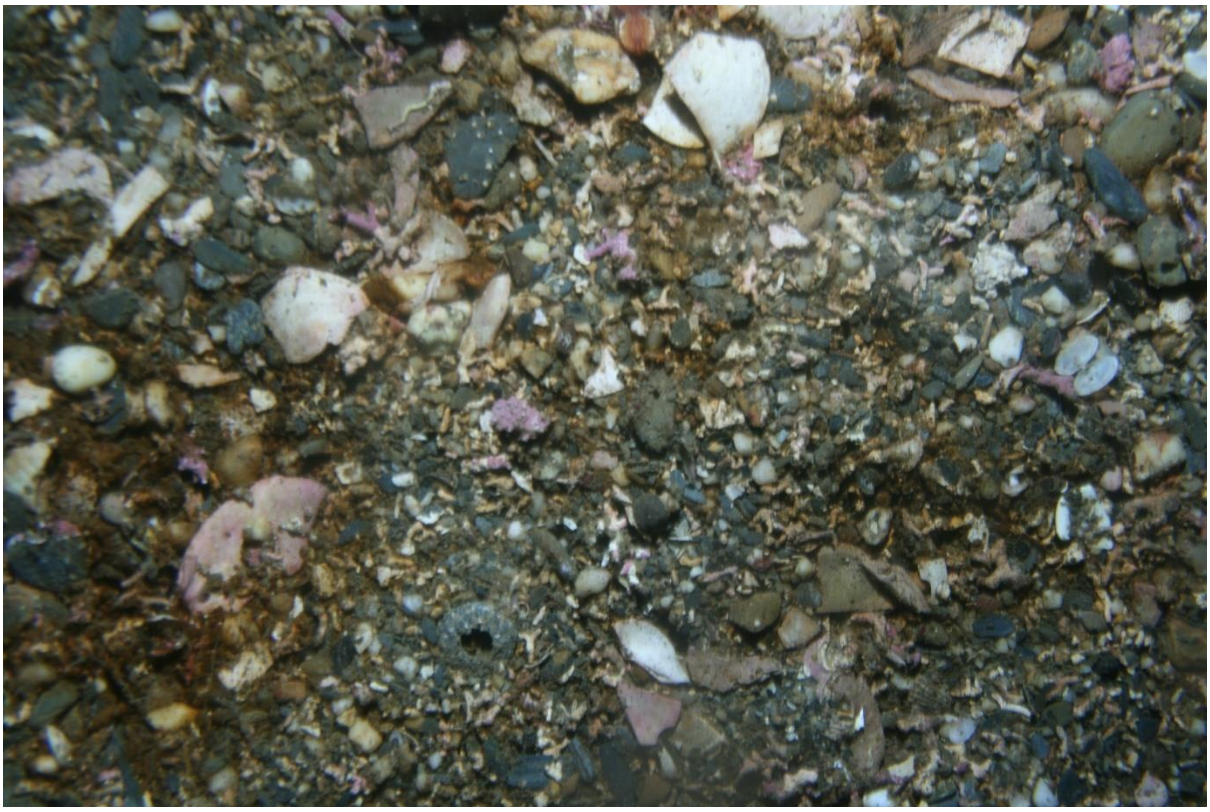
Tidal streams: Moderately strong to Very weak

Substratum: Coarse sand and gravel with a minor finer sand fraction

Zone: Infralittoral – lower, Circalittoral

Depth range: 10-50m

Description: Tide-swept circalittoral coarse sand, gravel, and shingle generally in depths of over 15-20m. Smaller, more rounded pebbles than SS.SMp.KSwSS.LsacR.CbPb, along with shell fragments of varying sizes. Generally sparse arrangement of flora and fauna. Uncommon instances of maerl, small Rhodophyta spp., Phaeophyceae spp., and brown algae film throughout the habitat. Observed species included *Cerianthus lloydii* and bivalve *Lutraria lutraria* (identified from protruding siphons).



Biotope code: SS.SMp.KSwSS.LsacR.Gv

Biotope description: *Saccharina latissima* and robust red algae on infralittoral gravel and pebbles

Wave exposure: Moderately exposed to Extremely sheltered

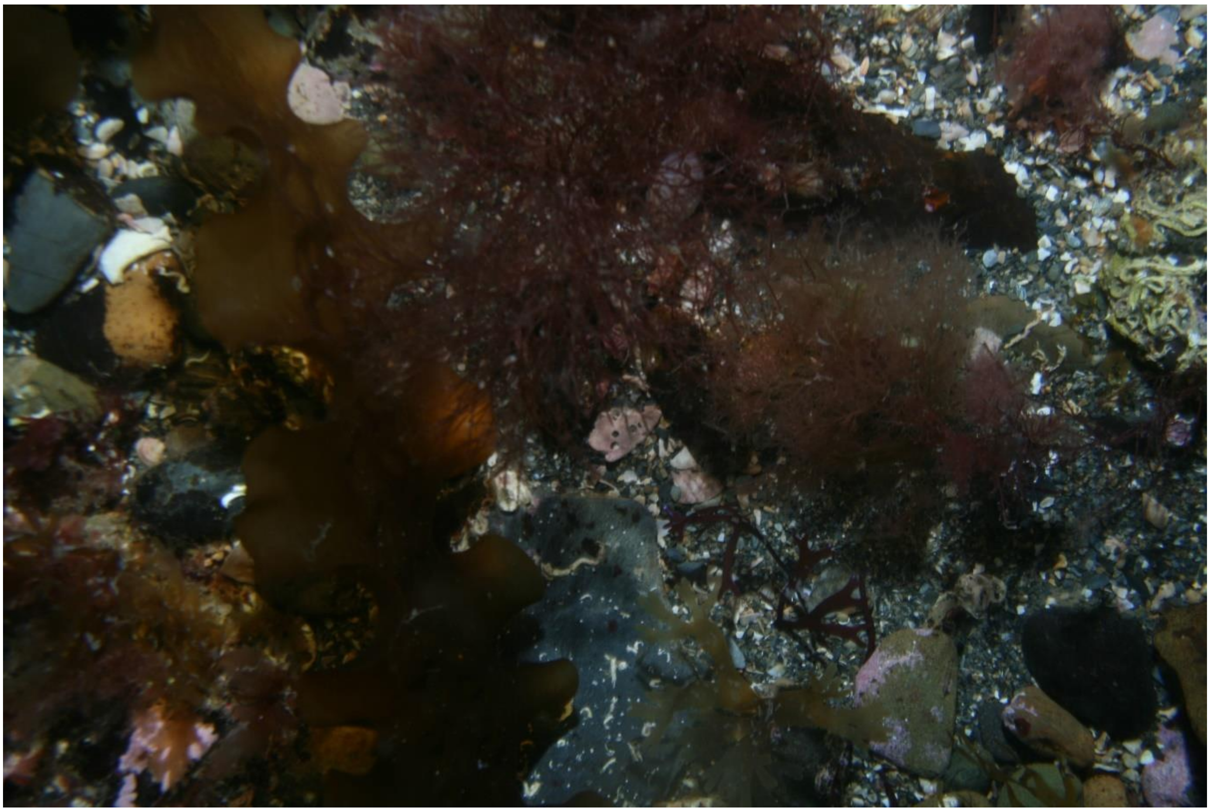
Tidal streams: Moderately strong to Very weak

Substratum: Muddy gravelly mixed sediment

Zone: Infralittoral

Depth range: 5-20m

Description: Similar to SS.SMp.KSwSS.LsacR.Mu, but greater densities of Rhodophyta spp. and Phaeophyceae spp., with gravel appearing finer where visible. Rich red algae undergrowth supported by canopy *Saccharina latissima*, though *Saccharina latissima* was not observed across the entire extent of the habitat, leaving patches of bare gravel in places.



Biotope code: SS.SMp.KSwSS.Tra

Biotope description: Mats of *Trailliella* on infralittoral muddy gravel

Wave exposure: Sheltered to Extremely sheltered

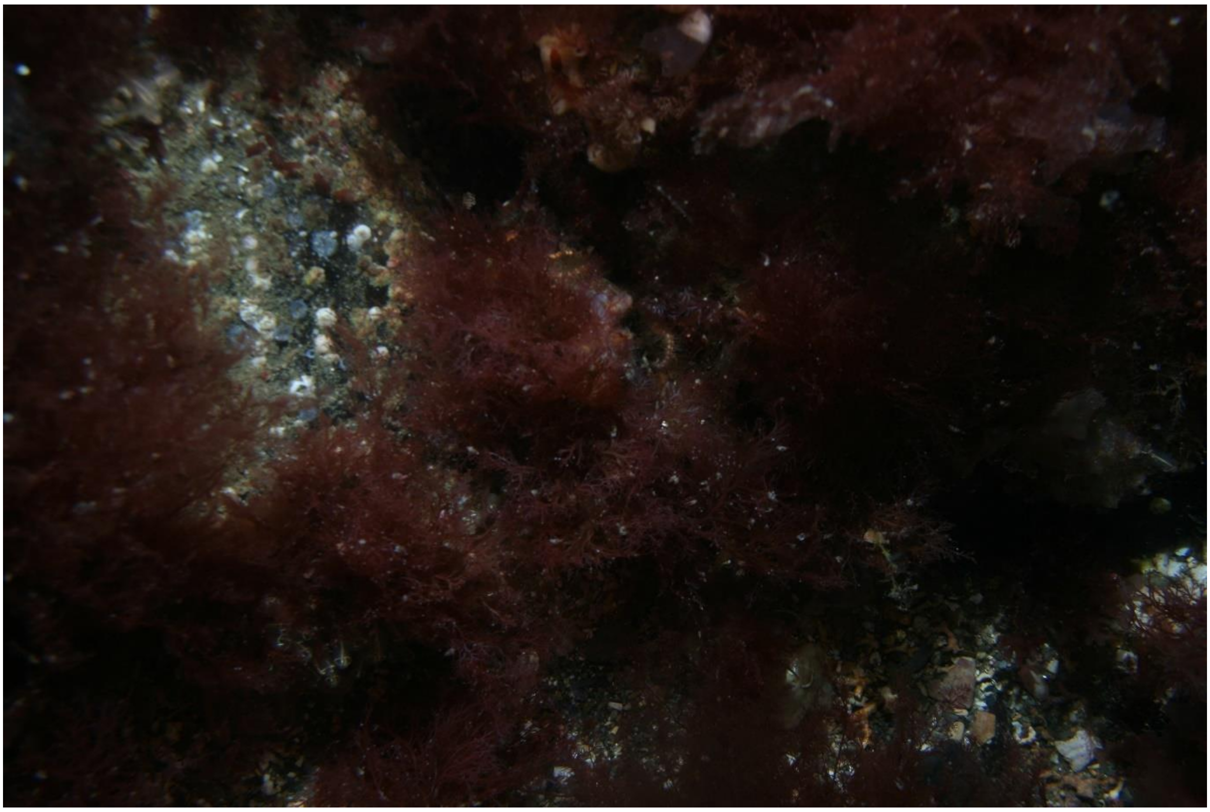
Tidal streams: Weak to Very weak

Substratum: Muddy gravel or muddy sand

Zone: Infralittoral

Depth range: 0-20m

Description: Dense loose-lying beds of the '*Trailliella*' phase of *Bonnemaisonia hamifera* in sheltered, shallow conditions. Occasional patches of gravel throughout the otherwise continuous mat of red algae. No other visible flora or fauna. This habitat had the smallest area of those identified within Niarbyl Bay.



Appendix VIII

Results of SIMPER analysis on biotope groupings identified from EUNIS allocation of the Niarbyl dataset, along with the taxa that contributed most to the within-group similarity. Percentage cut-off for contributing taxa was 90%.

EUNIS Habitat/Taxon	**Average abundance**	**Contribution %**	**Cumulative Contribution %**
SS.SMp.KSwSS.LsacR.CbPb: Average similarity 36.31%			
Fine Rhodophyta spp.	0.87	41.55	41.55
Fine Phaeophyceae spp.	0.71	25.76	67.32
Pomatoceros triqueter tubes	0.52	13.05	80.37
Dictyota dichotoma	0.45	9.55	89.92
Clavelina lepadiformis	1.00	3.86	93.78
SS.SS.SSa.CMuSa: Average similarity 55.15%			
Brown Encrusting Algae	0.90	64.32	64.32
Brittlestar Arms	0.68	31.46	95.77
SS.SMx.CMx.ClloMx.Nem: Average similarity 21.10%			
Cerianthus lloydii	0.74	48.53	48.53
Brown Encrusting Algae	0.39	23.76	72.29
Pomatoceros triqueter tubes	0.29	15.34	87.64
Hydrozoan/Bryozoan Turf	0.16	3.60	91.23
SS.SMp.KSwSS.LsacR.Mu: Average similarity 53.86%			
Pomatoceros triqueter tubes	1.00	28.50	28.50
Fine Rhodophyta spp.	1.00	28.50	57.01
Encrusting Maerl	0.75	12.27	69.27
Dictyota dichotoma	0.75	12.27	81.54
Fine Phaeophyceae spp.	0.75	12.27	93.81
SS.SMx.CMx.OphMx: Average similarity 34.13%			
Clavelina lepadiformis	22.58	48.56	48.56
Ophiothrix fragilis	4.08	12.41	60.97
Ophiura ophiura	2.42	10.72	71.70
Fine Rhodophyta spp.	0.92	9.86	81.55
Encrusting Maerl	0.83	8.70	90.25
SS.SCS.CCS: Average similarity 34.03%			
Brown Encrusting Algae	0.77	66.88	66.88

Encrusting Maerl	0.34	9.45	76.33
Maerl	0.30	8.63	84.95
Pomatoceros triqueter tubes	0.29	7.84	92.79
SS.SMp.KSwSS.LsacR.Gv: Average similarity 35.81%			
Fine Rhodophyta spp.	0.80	61.60	61.60
Laminaria digitata	0.49	20.46	82.06
Fine Phaeophyceae spp.	0.41	13.51	95.57
SS.SMp.KSwSS.Tra: Average similarity 38.28%			
Fine Rhodophyta spp.	1.00	92.08	92.08

Appendix IX

List of taxa viewed in BRUV footage, along with maxN or presence, with presence used for species whose maxN could not be feasibly counted, e.g. for macroalgal species.

Location	BRUV Number	Taxon	maxN or presence
Laxey	1	*Ophiura ophiura*	2
		Adamsia palliata	1
		Buccinum undatum	4
		Pomatoceros triqueter tubes	present
		Balanomorpha spp.	present
		Pagurus spp.	14
		Scyliorhinus canicula	2
	2	*Adamsia palliata*	2
		Buccinum undatum	1
		Pagurus bernhardus	15
		Pagurus prideaux	2
		Liocarcinus duperator	1
		Ammodytes tobianus	1
		Callionymus lyra	1
		Eutrigla gurnardus	1
		Scyliorhinus canicula	3
	3	*Pagurus bernhardus*	7
		Liocarcinus duperator	3
		Cancer pagurus	1
		Corystes cassivelaunus	1
		Scyliorhinus canicula	4
	4	Gastropod sp.	1
		Pagurus bernhardus	10
		Liocarcinus duperator	2
		Eutrigla gernardus	2
		Limanda limanda	1
		Scyliorhinus canicula	2
	5	*Buccinum undatum*	1
		Pagurus bernhardus	10
		Pagurus prideaux	1
		Limanda limanda	1
		Scyliorhinus canicula	3
	6	*Asterias rubens*	1
		Buccinum undatum	14
		Pagurus bernhardus	13
		Scyliorhinus canicula	2
Niarbyl	1	*Homarus gammarus*	1
		Laminaria digitata	present
	2	*Marthasterias glacialis*	1
		Necora puber	1
		Gobiusculus flavescens	1
		Pollachius pollachius	3
		Symphodus melops	1
		Unidentified small fish sp.	1

	Laminaria digitata	present
	Saccharina latissima	present
	Dictyota dichotoma	present
	Fine brown macroalgae sp.	present
	Flat brown macroalgae sp.	present
	Fine Rhodophyta sp.	present
3	*Ophiura ophiura*	8
	Astropecten irregularis	1
	Liocarcinus duperator	3
	Merlangius merlangus	1
4	*Cerianthus lloydii*	1
	Ophiura ophiura	3
	Brittlestar arms	present
	Astropecten irregularis	1
	Pagurus bernhardus	1
	Liocarcinus duperator	4
	Cancer pagurus	1
	Small fish sp.	1
	Scyliorhinus canicula	1
5	*Marthasterias glacialis*	2
	Liocarcinus duperator	3
	Cancer pagurus	1
	Pomatoschistus minutus (?)	5
	Juvenile schooling fish, resembling *Pollachius pollachius*	11
6	*Pollachius pollachius*	1
	Symphodus melops	2
	Laminaria digitata	present
	Fine brown macroalgae sp.	present
	Fine Rhodophyta sp.	present
7	*Marthasterias glacialis*	1
	Pagurus bernhardus	6
	Liocarcinus duperator	2
	Callionymus lyra	1
	Juvenile schooling fish, resembling *Pollachius pollachius*	2
8	*Liocarcinus duperator*	2
	Cancer pagurus	1
	Penaeid shrimp sp.	1
	Scyliorhinus canicula	1