Identifying habitat associations of European lobster, *Homarus gammarus* (L.) and brown crab, *Cancer pagurus* (L.) in an Isle of Man marine protected area

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In collaboration with the Department of Environment, Food and Agriculture, Isle of Man

Declaration

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This dissertation is being submitted in partial fulfilment of the requirement of the MSc in Marine Biology.

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Abstract

To incorporate ecosystem-based approaches into fisheries management, an understanding of patterns of habitat use during the key life stages of commercial species is fundamental. The main aim of this study was to provide a baseline survey of the benthic habitats in Baie ny Carrickey closed area, Isle of Man and to investigate habitat associations of commercially fished lobster *Homarus gammarus* and brown crab *Cancer pagurus*. Seabed habitats were sampled using non-destructive video techniques and benthic assemblages classified using the Marine Habitat Classification for Britain and Ireland in addition to multivariate approaches. Catch per unit effort data was calculated from fishermen's logbooks, and used to compare the abundance of juvenile and adult crustaceans across different habitats. The resultant habitat maps indicated that benthic assemblages were diverse across the study area, with large extents characterised by rocky reefs. Two habitats of conservation interest, maerl beds and seagrass patches (*Zostera marina*), were identified inside the marine protected area. It was found that adult *H. gammarus* and adult *C. pagurus* did not exhibit any habitat preferences. In contrast, juvenile lobster abundance was revealed to be positively associated with habitats dominated by kelp forests or macroalgae. In addition, juvenile crabs also indicated preferences to similar biotopes in coastal areas. These structurally complex biotopes are likely to serve as nursery areas for juvenile crustaceans and fish, providing shelter and refuge from predators. Overall, this study demonstrates the effectiveness of an integrated approach to fisheries management, combining conventional and ecosystem-based approaches. However, robust monitoring programmes are essential in achieving sustainable fisheries.

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Glossary of Terms

ANOSIM	Analysis of similarities
ANOVA	Analysis of variance
BAP	Biodiversity Action Plan
BNC	Baie ny Carrickey
BRUV	Baited Remote Underwater Video
CPUE	Catch per unit effort
DEFA	Department of Environment, Food and Agriculture
EBA	Ecosystem based approach
EU	European Union
EUNIS	European Nature Information System
JNCC	Joint Nature Conservation Committee
MHCBI	Marine Habitat Classification for Britain and Ireland
MLS	Minimum Landing Size
SE	Standard error
SIMPER	Similarity percentage analysis
UK	United Kingdom

1.0 Introduction

The diversity and abundance of marine organisms is greatly influenced by the availability of essential habitats on which they depend on during key life stages. By mapping benthic habitats, the spatial distribution of species can be inferred; a necessary and vital step in marine conservation and fisheries management (Cogan *et al*., 2009). Although there is some variation within the scientific literature, a habitat is generally defined as the place where an organism lives (Begon *et al*., 1996); characterised by specific physical and environmental features (e.g. depth, current exposure, substrate type). Both habitat structure and habitat heterogeneity, or patchiness, are important influences on benthic community composition (Sebens, 1991). The presence of biological organisms may further increase the physical complexity of a habitat, adding a three-dimensional component (Beukers-Stewart & Beukers-Stewart, 2009). In temperate coastal waters, habitats such as rocky reefs, biogenic structures (e.g. calcareous maerl beds and horse mussel *Modiolus modiolus* reefs), and vegetation (e.g. kelp forests, macroalgae communities, and eelgrass meadows) serve an important function by creating structurally complex habitats (Thrush *et al*., 2001). These complex structures may also provide essential habitat for commercial species during key life stages, serving as a nursery area for juveniles, providing spatial refuge from predators and harsh environmental conditions, or acting as spawning grounds for aggregational species (Walters & Juanes, 1993; Irlandi *et al*., 1999; Beck *et al*., 2001). The availability and extent of suitable habitats is therefore associated with greater yields of target species (Thrush *et al*., 2008). An understanding of the associations between the ecological characteristics of commercial species and the essential habitats that support them is necessary for the future of long-term sustainable fisheries.

1.1 The effects of fishing on marine habitats

Despite the important link between habitat complexity and the sustainability of commercial fisheries, disturbances caused by commercial fishing activities can have considerable consequences for marine environments and their associated benthic communities (Dayton *et al*., 2006). The severity of impact on the marine environment and subsequent recovery rate is strongly habitat-specific and associated with the spatial distribution of fishing effort and type of fishing gear (Kaiser *et al*., 2002). The use of bottom towed fishing gears, that have a direct interaction with the seabed, in particular can cause significant and long-lasting damage to marine benthic habitats (Jennings & Kaiser, 1998). The immediate effects of dredging result in benthic organisms being killed, damaged, or removed from their habitat with decreases in species abundance, diversity and richness strongly associated with increases in fishing effort (Kaiser & Spencer, 1994; Collie *et al*., 1997). Opportunistic scavengers, dominated by starfish, whelks and hermit crabs, may in fact benefit from dredging activities and feed on damaged and exposed fauna (Thrush *et al*., 1995; Veale *et al*., 2000), and communities dominated by such species are indicative of high levels of fishing disturbance. Periodic dredging of an area can also re-suspend fine sediments, leading to the smothering of sessile benthic fauna (Rogers, 1990), with larvae and juveniles more susceptible thus resulting in poor recruitment to adult populations (Pottle & Elner, 1982).

Chronic fishing disturbance reduces benthic productivity and homogenises surface substrates, and the removal of organisms may result in a reduction in habitat complexity (Kaiser *et al*., 2002). In stable habitats which contain emergent epifaunal organisms that increase the structural complexity of an area, the magnitude of this effect is increased. Biogenic habitats are severely impacted, and larger, slowing growing biota such as sponges and soft corals may take up to eight years to recover (Kaiser *et al*., 2006). Benthic communities in soft-sediments are also vulnerable to fishing disturbance, decreasing the biodiversity of epifaunal and infaunal species (Thrush *et al*., 2001). However less-complex habitats are capable of recovering relatively quickly (Kaiser *et al*., 2006).

Complex benthic communities may represent essential habitat for commercial species, providing shelter for refuge and feeding sites. Maerl beds, for example, are a complex and important biotope of considerable conservation value due to their association with high diversities of epibiota and infauna (Birkett *et al*., 1998). They can offer a long term benefit for species of economic value, such as shellfish, fish and crustaceans including the brown crab *Cancer pagurus* (Kamenos *et al*., 2004; Hauton *et al*., 2003). However, maerl beds are vulnerable to the use of towed demersal fishing gear, in particular scallop dredges, with a single tow observed to remove more than 70 % of the live maerl occurring in an area (Hall-Spencer & Moore, 2000). Whilst some benthic habitats show resilience to destructive fishing practises (Kaiser *et al*., 2006), for maerl beds there are likely to be long lasting effects, with characteristic slow growth rates resulting in longer recovery times (Hall-Spencer & Moore, 2000).

1.2 Ecosystem-based management as a solution

The adverse effects of fishing activities on marine ecosystems are now widely accepted and the integration of ecosystem-based approaches (EBA) into fisheries management is regarded as fundamental in creating long-term sustainable fisheries (Dayton *et al*., 1995; Turner *et al*., 1999). An EBA focuses on preserving and enhancing the entire ecosystem function, which is beneficial for target species that are part of a system of complex trophic interactions. In comparison, conventional methods of fisheries management typically take a single species approach where regulations on catches (e.g. minimum landing size (MLS) to allow at least one spawning event before harvesting, or catch quotas) and/or a reduction in fishing effort are enforced. These conventional fisheries management approaches have been successful towards developing more sustainable fisheries (Botsford *et al*., 2008). However, traditional management measures can only have limited success, as regulations alone are insufficient in mitigating the effects of destructive fishing practises (Reiss *et al*., 2010), and target species are reliant on essential habitats for multiple uses, such as recruitment, foraging and refuge from predators (Pikitch *et al*., 2004).

Marine Protected Areas (MPAs) are becoming increasing popular as a tool in marine conservation and as part of an EBA. The potential benefits of MPAs closed to demersal gear in achieving sustainable fisheries is well recognised; for example, increased species diversity and biomasses of both target and non-target species, with individuals capable of attaining greater ages with higher rates of reproduction (Roberts *et al*., 2003). Nonetheless, for a MPA to be an effective alternative to traditional resource management approaches, it is imperative that they are established with a prior understanding of underlying social and ecological factors, and that a post-monitoring programme is in place to evaluate the effectiveness of the EBA (Agardy *et al*., 2003; Levin *et al*., 2009). Only permanent closed areas with total protection from fishing disturbances can fully protect essential habitats or vulnerable species and allow for their recovery (Roberts *et al*., 2003).

1.4 Fisheries and conservation in the Isle of Man

The Isle of Man, as a UK Crown Dependency, is not a member of the European Union (EU) and therefore not subject to international conservation agreements, such as the EU Habitats Directive. However, the Isle of Man is dedicated to marine and coastal conservation and a signatory to several Conventions (e.g. the Convention on Biological Diversity, and the

Convention for the Protection of the Marine Environment of the North-East Atlantic), with obligations to identify priority species and habitats for conservation. The Department of Environment, Food and Agriculture (DEFA) is responsible for designating marine protected areas, and at present approximately 2.6 % of territorial waters are protected. A number of habitats of international conservation interest have been identified in Manx waters from broad-scale habitat mapping surveys (Hinz *et al*., 2009; White, 2011). Maerl beds, *M. modiolus* horse mussel reefs, the reef building polychaete *Sabellaria spinulosa*, and seagrass *Zostera marina* beds are known to occur in several locations off the island, all of which are UK Biodiversity Action Plan (BAP) priority species, and included in the OSPAR List of Threatened and/or Declining Habitats.

The Isle of Man boasts a small network of marine protected areas, with five areas designated as Fisheries Closed Areas or Restricted Areas, and a sixth area designated as a Marine Nature Reserve. As the Isle of Man's most economically important commercial fishery, the conservation of subtidal areas in Manx waters is primarily focused on the enhancement of king scallop *Pecten maximus* and queen scallop (or locally referred to as 'Queenies'), *Aequipecten opercularis* stocks. The most recently designated closed area is Baie ny Carrickey, established by DEFA in collaboration with local crustacean fishers as part of a scientific trial in 2012. The use of towed fishing gear by the scallop fishing industry is prohibited under fisheries legislation to allow for the recovery of European lobster *Homarus gammarus* and brown crab *Cancer pagurus* stocks in protected rocky habitats. The trial was successful and subsequently extended until 2016 with a view to maintain the ecological integrity of the area, and to enhance and maintain the crustacean fisheries inside the closure (Bloor *et al*., 2014)

1.5 *Homarus gammarus* and *Cancer pagurus* habitat associations

The lobster *Homarus gammarus* is of high economic value within the Isle of Man's commercial fisheries, with fishing activity occurring around all inshore areas. It is widely acknowledged that there are extensive gaps in knowledge with regard to the patterns of movement and habitat preferences of *H. gammarus*; both important determinants for distribution and stock delineation (Bowlby *et al*., 2008). Whilst primary literature has frequently studied the closely related American lobster *H. americanus* (e.g. Wahle & Steneck, 1991), comparisons made between the behaviour of species should be done so judiciously. As juvenile lobsters are rarely observed in the wild, research is often limited; studies of movement and habitat use have numerous issues, including bias towards larger individuals (Howard, 1980), the use of hatchery reared lobsters (Bannister *et al*., 1994), relocation of wild lobsters to artificial habitats (Jensen *et al*., 1994) or restrictions resulting from methodologies (Gibson, 1967). Despite this, the existing literature does indicate that there is differentiation in habitat preference between life stages for *H. gammarus*; during the early benthic phase, larvae are dependent on structurally complex habitats (Linnane *et al*., 2000); during the juvenile stage, lobsters select habitats with cobble or boulders offering suitable protection within crevices (Howard & Bennet, 1979; Bannister *et al*., 1994); whilst adult *H. gammarus* can be found in spatially simpler habitats (Messieh *et al*., 1991). *H. gammarus* has a limited home range; the extent of movement is size-dependent with larger individuals moving greater distances (Smith *et al*., 2001), and can be restricted by environmental conditions and depths between 0 – 50 m (Howard, 1980; Holthius, 1991). As such, the establishment of marine reserves in coastal environments would protect both adult individuals with limited movement, and conserve essential complex habitats which would allow for a higher recruitment into adult stocks.

The Isle of Man's fishery for the brown crab *Cancer pagurus* mainly operates to the west of the island, and limited to coastal waters to avoid negative impacts from the scallop fishery. Similar to the European lobster, its habitat preferences and ecology is poorly understood, although structurally complex habitats in coastal waters are likely to represent essential nursery habitats which recruit into offshore fisheries (Robinson & Tully, 2000; Pallas *et al*., 2006). There is further evidence for different habitat use between the key life stages for *C. pagurus,* since adults are less dependent on three dimensional habitats for shelter, and frequently observed scavenging on a range of substratum (Neal & Wilson, 2008). Mature female crabs exhibit extensive movement patterns, with their behaviour likely associated with reproduction (Ungfors *et al*., 2007). Identifying and conserving essential habitats where juvenile individuals seek shelter until they attain greater body sizes, could improve survival rates and create more sustainable fisheries.

1.6 Fishery and effort regulations for the Isle of Man crustacean fisheries

Stock assessments of lobsters and crabs present some difficulties, particularly as variation in size cannot be accurately related to age (Sheehy and Prior, 2008). A number of fishery and effort regulations have been implemented to maintain and enhance crustacean stocks within the Isle of Man's territorial waters. The use of escape panels, for example, is compulsory allowing undersized crabs and lobsters to escape whilst retaining individuals above the Minimum Landing Size (MLS). The introduction of escape gaps can also improve the efficiency of pots at catching larger individuals and reduce sorting time (Clark, 2007; Murray *et al*., 2008). Furthermore, the removal of berried females (carrying developing eggs) is illegal, and a V-notching scheme is in place for fishers whereby individuals cannot be landed for a further two or more moults.

Exclusively for the Baie ny Carrickey closed area, the MLS (carapace length) for lobsters has been increased to 90 mm and for crabs increased to 135 mm; comparatively higher than the rest of the Isle of Man, (87 mm and 130mm respectively, concurrent with EU regulations). A maximum MLS of 120 mm for lobsters is also imposed as very large individuals have a considerably higher reproductive capacity (Goni *et al*., 2003). Fishing licenses are required to fish within the closed area, and at present six commercial fishermen are permitted to catch crustaceans, in addition to several hobby potters who do not require a license. Since December 2014 the total maximum number of crustacean traps in BNC has been reduced from 650 to 410 pots, which are divided between the commercial fishermen according to vessel size. Both crustacean species are fished for using baited potting gear, which in contrast to gear used in scallop fisheries has no known impact on marine habitats and benthic communities (Eno *et al*., 2001; Coleman *et al*., 2013). The fishery is considered to be highly effective; bycatch is mostly composed of individuals under the MLS or soft-shelled from recent moulting (Bullimore *et al*., 2001).

1.7 Hypotheses and objectives

For the European lobster and brown crab fisheries in BNC, an integrated approach combining ecosystem-based and traditional fisheries management methods has been adopted, however, there is presently no robust monitoring scheme to determine the effectiveness of the marine protected area from demersal fishing gear. There is a distinct lack of knowledge regarding the spatial pattern of habitats and there is a need for baseline information using benthic mapping techniques. By defining and identifying essential habitats that are associated with key life stages of *H. gammarus* and *C. pagurus*, the long-term sustainability of these fisheries could be improved. The data presented in this study will aid in the future management of Baie ny Carrickey closed area and will contribute to the decision whether the closure is effective following the end of the scientific trial in 2016. The primary hypotheses and objectives of this study are as follows:

Hypotheses

H_1 Baie ny Carrickey closed area contains distinctive benthic communities and habitats as determined by certain environmental conditions

H_2 The distributions of juvenile lobster *Homarus gammarus*, and juvenile brown crab *Cancer pagurus*, are associated with structurally complex, essential habitats in Baie ny Carrickey closed area

H_3 Adult lobster *H. gammarus*, and adult brown crab *C. pagurus* are not dependent on a particular habitat, and can be found in both complex and non-complex habitats inside Baie ny Carrickey closed area

Objectives

1. Identify benthic communities in Baie ny Carrickey closed area, and to classify biotopes using both multivariate approaches with PRIMER software, and the Marine Habitat Classification for Britain and Ireland (Connor e*t al.*, 2004)
2. Create two fine-scale maps in ArcGIS indicating the distributions of biotopes identified using PRIMER and the Marine Habitat Classification for Britain and Ireland (Connor *et al*., 2004)
3. Generate a broad-scale habitat map of Baie ny Carrickey closed area, using environmental layers of data
4. Determine whether differences in catch per unit effort of species across fishing zones are linked to biotope distributions
5. Provide management recommendations towards the future conservation of Baie ny Carrickey closed area

2.0 Methods

2.1 Description of the study area

Baie ny Carrickey closed area is located in south of the Isle of Man, covering an area of approximately 8.7 km^2 (Figure 1). The boundary of the closed zone is marked between Black Head (54° 03.40'N, 004° 46.30'W) and Scarlett Stack (54° 03.70'N, 004° 40.00'W). The area contains a range of bathymetric conditions (0 – 30 m) and is characterised by limestone ledges and rocky reef habitats, including The Carrick (a rock formation protruding from the centre of the bay) and sandy bays on the western side of the area. Port St Mary harbour is located within the closed area, to the west of the bay.

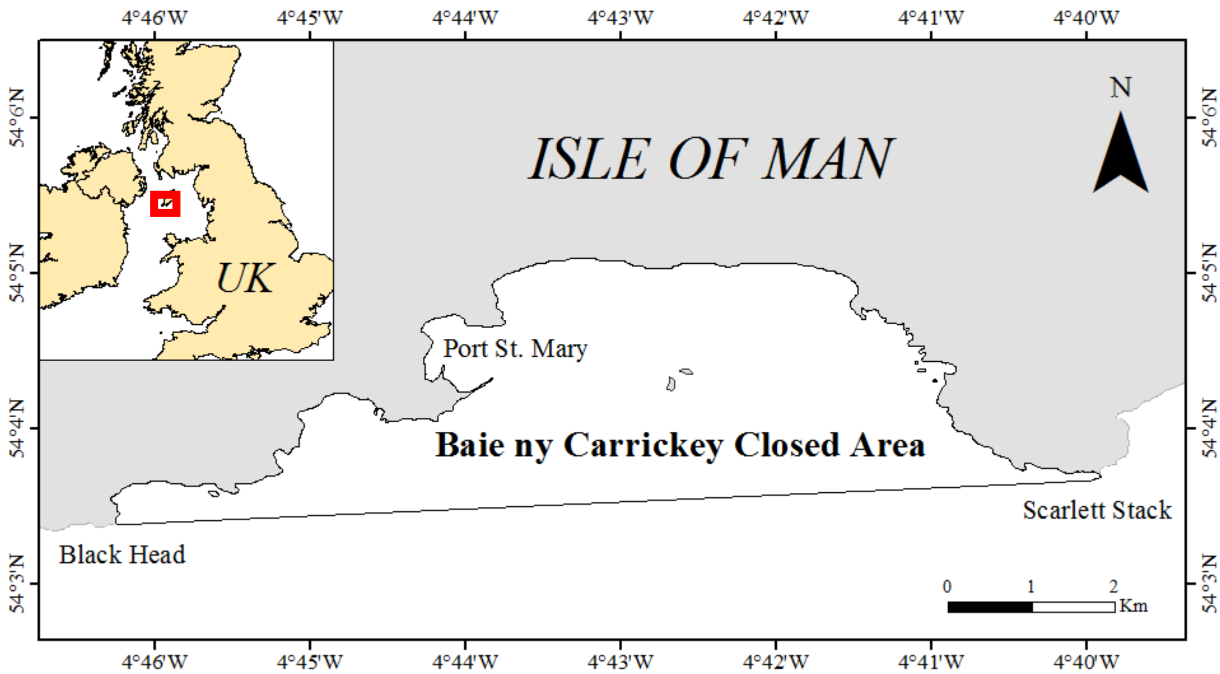

Figure 1. Location of Baie ny Carrickey closed area, Isle of Man. Black line indicates boundary of the closure

A broad-scale and fine-scale mapping project was undertaken in the study area to provide information on the type, distribution and extent of habitats and biotopes and compare these results to *H. gammarus* and *C. pagurus* patterns of distribution. A low impact monitoring approach was essential with several survey techniques being utilised to collect information on the different ecological components of the study area. The drop down camera system was used to cover large areas quickly and to identify different benthic habitats, and the Baited Remote Underwater Video system (BRUV) was used to provide additional information on the habitat preferences of mobile species, such as fish and crustaceans. Data from BNC closed area was collected between June 2015 and August 2015. All sampling efforts were restricted to sites with depths exceeding 1 m, as the video equipment could not be safely deployed at shallower depths.

2.2 Survey designs and data collection methods

2.2.1 Habitat mapping

Drop down camera sites were created using the ArcMap program in ESRI's ArcGIS 10.2 software package. Bathymetric data was obtained from the EDINA Marine Digimap Service. A random stratified survey design was chosen. The area was divided into subsections representing four depth ranges (0-7 m, 7-14 m, 14-21 m and 21-28 m) and 25 survey locations were generated at random within each depth subsection. Sampling stations were placed at a minimum distance of 150 m apart to ensure a good spread of sites across the closed area and minimise pseudoreplication. A survey conducted by divers in 2014 mapped a small area of *Zostera marina* in the north west of the bay (Haywood & Hextall, 2014); during this study a drop down was deployed at the same location to confirm these observations.

Two drop down camera frames were used for the purpose of this study. The initial design, a GoPro Hero 3 camera mounted on a frame (0.25 m^2) was deployed at 31 sites. The small size and weight of the design resulted in some drops falling sideways, especially in areas of strong current, substantial kelp cover or substrates with small boulders. For all subsequent sites (52) an alternate design was employed, with a larger area (1.13 m^2) and higher frame.

At each site the drop down system was deployed with the GoPro camera on video setting (1080 dp and 60 frames per second). Replicates were obtained by allowing the frame to first reach the seabed and record a short video clip (approximately 5 seconds). The frame was then hauled upwards several metres from the bottom whilst allowing the boat to drift, before being allowed to reach the seabed again. This process was repeated until four replicates were achieve. Latitude and longitude, time of day and depth were recorded at each site. Latitude and longitude, time of day and depth were recorded at each site. For several sites, the close proximity of static gear prevented the camera from being deployed at the exact coordinates initially selected and instead the system was deployed at the nearest possible location.

2.2.2 BRUV sampling

The Baited Remote Underwater Video apparatus was designed as a horizontal look-outward system established on the seabed. Based on the designs of Bullimore (2011) and Howarth (2012), a 'D' shaped lobster pot frame was mounted with a GoPro Hero 3 camera and a plastic bait holder extended 60 cm from the front of the camera. The GoPro was set to 1080 dp and 60 frames per second. Initial trials indicated that oily fish were a suitable bait. Approximately 220 g of coarsely cut salmon heads were placed inside the bait container prior to BRUV deployment. The BRUV was equipped with a red filtered light positioned above the bait, as the use of brighter white lights has been shown to alter fish behaviour (Harvey *et al*., 2012). All BRUVs were deployed from the fishing vessel the *Auk*, with sites chosen at random across a range of depths and with a minimum of three replications for each broad habitat. Sampling time was limited to between 0600 and 1800 hours, although time from low tide, and time of day were random. Time, date, latitude and longitude were recorded for each site. Each BRUV was deployed for a minimum of 60 minutes, with the exception of two deployments that had to be moved earlier due to poor weather conditions.

2.3 Habitat mapping

2.3.1 Video analysis

Drop-down camera deployments were viewed in VLC media player and still photo frames were extracted from each video using the VLC screen-shot feature. Subsequent inspection of each image scored each frame according to visibility and quality, using the criteria outlined in Table 1, adapted from Hannah and Blume (2012). Frame grabs that scored 0 for either the visibility or quality category were excluded from further analysis. The 'fisheye' distortion effect from the GoPro camera was removed and the contrast of colours in frame extracts were digitally enhanced in Adobe Photoshop CS4 11.0.

Table 1. Criteria used for the selection of photo frames extracted from drop-down camera surveys in Baie ny Carrickey

Category	Score	Criteria
Visibility	0	Field of view is totally obscured by suspended sediments, or frame lens is blurred
	1	Field of view is partially obscured, limited viewing distance limited by suspended sediments
	2	Clear view of substrate
Quality	0	Camera is on side and faces open water, or majority of screen (>60 %) is obscured by marine flora (e.g. kelp fronds)
	1	Camera view is at acceptable angle, although some of substrate view is blocked
	2	Good view and quality of photograph

The program ImageJ was used to extract quantitative information photo extracts. The area of each image analysed was standardised to 0.25 m^2 to account for the larger frame size of the second drop down camera system. The abundance of sessile macrofauna and algal species were measured in terms of percent cover, and mobile species were recorded as individual counts. With the exception of the large hydroid species *Nemertesia ramosa* and *Nemertesia antennina* and the bryozoan *Flustra foliacea*, all other hydroids and bryozoans could not be identified with confidence, and percent cover of these species was recorded as ‘Mixed hydroid and bryozoan turf’. Most red algae could not be identified to species without a microscope, and was therefore broadly classified as ‘Foliose Rhodophyceae’ or ‘Filamentous Rhodophyceae’. Brittle star species (*Ophiothrix fragilis* and *Ophiocomina nigra*) were observed in dense quantities and also recorded as percent cover rather than as an abundance count. All organisms were identified to the lowest possible taxon. Where two similar individuals could not be identified to species level, but could be clearly distinguished from one another, the two species would be described as 'A' and 'B', e.g. *Porifera* A and *Porifera* B. The substratum type in each photo was described according to the visual appearance of the surface sediments, based on the Wentworth scale (Wentworth, 1922). It was not possible to distinguish between coarse sands, fine sands, mud etc. from the photos, therefore these substrates were broadly classed as sand.

2.3.1 Integration of datasets

A combination of a bottom-up approach and a top-down approach were used during this study to assess datasets and produce habitat maps (Galparsoro *et al*., 2015). The bottom-up approach aims to determine biotopes by concentrating on biological assemblages and subsequently identifying the environmental variables that best describe the differences. The top down approach instead assumes that specific environments contain distinct biological communities. This approach was used for creating habitat and biotope maps by classifying maps in accordance with The Marine Habitat Classification for Britain and Ireland.

All multivariate analyses were performed using the PRIMER v. 6 software package (Clarke & Gorley, 2006). Prior to statistical analysis, rare mobile taxa that were observed less than 3 times and sessile taxa occurring in less than 3 replicates unless the most dominant taxa, were excluded from community analysis. Organisms recorded by mobile counts were excluded from further community analysis as these could not be compared to data recorded by percent cover means. Datasets were pre-treated using a square root transformation to reduce the influence of dominant taxa on the community structure and the Bray-Curtis similarity coefficient matrix was calculated for each pair-wise combination of sampled sites.

2.3.2. Bottom-up approach

To identify significant groupings of sites based on benthic community structure, the CLUSTER analysis was performed. Similarity tests (SIMPROF) tests were integrated into the CLUSTER analysis to determine statistically significant clusters ($P < 0.001$) from an *a priori* unstructured grouping of sites. A non-metric Multi-Dimensional Scaling (MDS) ordination plot was generated to visualise patterns of communities identified. Significant clusters were analysed using the similarity percentage analysis (SIMPER) procedure to examine the contribution of each taxa to the similarity within clusters. An analysis of similarity (ANOSIM) was performed on the Bray-Curtis similarity matrix of community data, to test for statistical differences observed within the data and the *a priori* factors defined from the SIMPROF test. The relationships between environmental variables (depth, substrate from images, and categorical substrate data from MaxSea data) and benthic community composition were explored using the BEST function in PRIMER.

Substrate information was acquired from MaxSea software aboard the fishing vessel the *Nancy Ellen*. The software is capable of generating a seabed classification by estimating the hardness and roughness of the seafloor, calculated from a SeaScan ground discrimination unit and a Furuno depth sounder equipped on the vessel. The MaxSea data was imported into ArcMap by georeferencing known waypoints due to the raw data being encrypted. Ground-truth stations were chosen by selecting drop down camera sites that fell into the centre of a MaxSea seabed class.

The communities identified from the cluster analysis were plotted in ArcMap. The point data was crudely extrapolated to create a map of categorical feature classes (biotopes) covering the whole study area by using a Euclidean allocation tool that designates the biotope type of an unknown cell based on the biotope in closed proximity.

2.3.3 Top-down approach

The Marine Habitat Classification for Britain and Ireland (MHCBI), developed and managed by the Joint Nature Conservation Committee (JNCC), is a comprehensive classification system and provides a tool to facilitate the management and conservation of marine benthic habitats (Connor et al., 2004). This national classification system contributes to the larger European Nature Information System (EUNIS) habitat classification.

Both classification systems use a hierarchical structure to describe the different levels of habitat (Table 2). Environmental conditions are the only criteria required to assign rocky habitat types up to Level 3; progression to biotope or sub-biotope classification requires biological community information. For habitats with sedimentary substratum rather than rock, biological community information is first required at Level 5. Biotopes and sub-biotopes found in similar environmental conditions are therefore differentiated from one another by their differences in benthic community structure. Each hierarchical level is described by its characteristic features, and allocated an alpha-numeric code. The full MHCBI is available from the JNCC website (JNCC, 2015).

Table 2. Hierarchical format of the Marine Habitat Classification for Britain and Ireland with examples at each level of the classification.

Level	Description	Example	Code
1	Environment	Marine	
2	Broad habitat types	Infralittoral rock (and other hard substrata)	IR
3	Habitat complexes	Moderate energy infralittoral rock	IR.MIR
4	Biotope complexes	Kelp and red seaweeds	IR.MIR.KR
5	Biotopes	*Laminaria hyperborea* and foliose red seaweeds on moderately exposed infralittoral rock	IR.MIR.KR.Lhyp
6	Sub-biotopes	*Laminaria hyperborea* forest and foliose red seaweeds on moderately exposed upper infralittoral rock	IR.MIR.KR.Lhyp.Ft

The first step in the top-down process was to produce a broad-scale habitat map to Level 3 of the MHCBI classification. The broadscale habitat map was created using four physical characteristics; biological zone, substrate type, and the relative amount of exposure to wave and current energy. Data on wave and current exposure was obtained from the UKSeaMap (McBreen *et al*., 2011), a broad-scale project mapping seabed habitats in UK waters. The energy layer was calculated by differentiating between the relative exposures of areas to kinetic energy from tidal forces. The classes were defined using thresholds as set out by UKSeaMap for wave energy; low (< 0.21 N m^{-2}, moderate (0.21 – 1.20 N m^{-2}), and high areas (> 1.20 N m^{-2}); and for current energy; low (< 0.13 N m^{-2}), moderate (0.13 – 1.16 N m^{-2}) and high areas (> 1.16 N m^{-2}). Once each energy layer was classified, the wave and current layers were combined using algebra in ArcMap. As described by UKSeaMap, when two layers are combined and one is higher, the greater class is selected to describe the energy regime in the area.

The biological zone describes the vertical zonation of communities related primarily to depth, but also the proportion of light reaching the seabed and wave energy at the seafloor. Bathymetric data (EDINA) and broad-scale light attenuation data acquired from UKSeaMap (2010) was used to predict the ranges for biological zonation across the study area. The upper limit of the infralittoral zone was determined by the mean low water mark, and the lower limit was defined by a minimum of 1 % light reaching the seabed, required for kelp growth. The littoral zone was defined as areas above the mean low water mark, and the circalittoral zone was approximated from depth (> 20 m) and light below 1 %.

At Level 3 of the EUNIS classification, the substratum is broadly classed into rock or sediments. ‘Rock’ comprises of bedrock and boulders, and ‘sediment’ comprises of boulders, cobbles, pebbles, gravels, sands, muds and mixed sediments. The substrate layer was created by differentiating between sediment and rock by ground truthing the MaxSea data. For areas that were data deficient, the distribution of sediment and rock habitats were estimated from extrapolated substratum information from the drop down surveys, mapped using a Euclidean allocation analysis. To produce the final broad-scale Level 3 habitat map, each layer (biological zone, substrate, combined energy) was imported into ArcMap 10.2.2 as a raster. Layers were combined using simple algebra equations.

An integrated assessment of both the sessile and mobile species datasets and the abiotic characteristics at each site were used to assign Level 5 biotopes to survey sites. Firstly, the broad habitat map was used to determine the Level 3 habitat at each drop down camera site. Physical and biological comparative tables (available from the JNCC website) were used to compare environmental and biological characteristics within the smallest groupings identified from the cluster analysis and resulting dendrograms. If no notable differences were detected within cluster groups, then all sites were assigned the same biotope using the MHCBI hierarchy. To ascertain whether the new biotopes contained distinct benthic assemblages, an ANOSIM test was performed on the Bray-Curtis similarity matrix of biological data. A non-metric MDS plot was created to visualise the MHCBI classified biotopes.

2.4 BRUV

All BRUV videos were reviewed prior to analysis. One video was excluded from statistical analysis due to extremely poor visibility, and another as the BRUV landed sideways and the field of view was restricted, which was also excluded. Data analysis began two minutes after the BRUV stabilised on the seabed to allow for suspended sediments to settle. For each BRUV video the following was recorded; a qualitative description of the surrounding habitat and sediment type, the total number of species, and the maximum number of individuals of a species at any one time within 1 minute video segments (MaxN); this measure gives a conservative estimate of relative density and avoids counting fish species more than once. Marine organisms, such as echinoderms, that were present in the field of view immediately at the start of the video and seemed unaffected by the presence of the BRUV were excluded from abundance counts. The size of individuals could not be accurately determined from the use of a single horizontal BRUV (in comparison to BRUV stereo systems) and therefore rough size measurements were estimated for any crabs or lobsters that entered the frame.

All multivariate analyses were performed using PRIMER v.6. To standardise all videos, the mean MaxN was calculated for each species at each site. Relative abundance data was square-root transformed and a Bray-Curtis similarity matrix was calculated. A non-metric MDS ordination plot of relative abundance estimates (MaxN) was generated to visualise patterns of fish and invertebrate assemblages between broad habitat types. The SIMPER function was used to show contribution of each species to the similarity within habitats.

2.5 Logbook data

The scientific monitoring plan for Baie ny Carrickey Closed Area requires members fishing with commercial licenses to provide monthly data from shellfish pots (with escape gaps), scientific shellfish pots (lacking escape panels) and prawn pots. For the purpose of this study, information on pot location (according to zones; Figure 2) pot type, date, number and size of lobster and crab (measuring carapace length and carapace width respectively), and bycatch species, was used to determine patterns of habitat preference within different species and size classes.

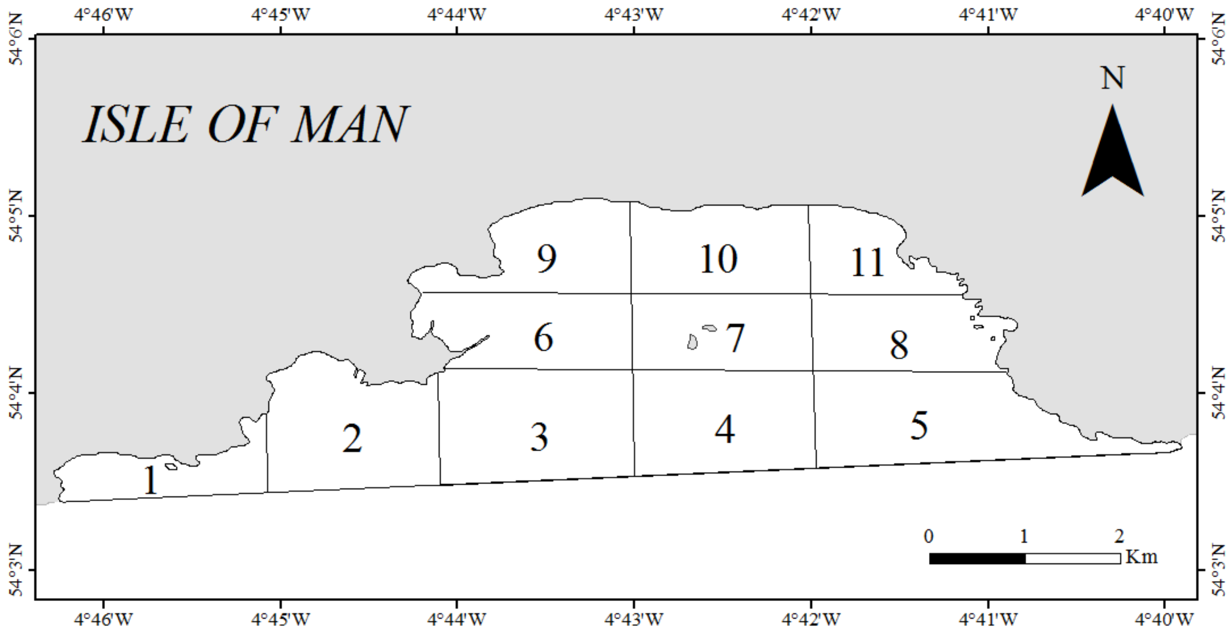

Figure 2. Distribution of fishing zones in Baie ny Carrickey, used for recording catch information

Catch per unit effort (CPUE) was determined, and used as a proxy for relative abundance of species. Differences in catch numbers per pot for different soak times was tested using analysis of variance (ANOVA). There was no significant effect of soak time on catch rates for all zones. CPUE was calculated for each zone and thereafter defined as the number of individuals per pot haul. *H. gammarus* and *C. pagurus* individuals under MLS (90 mm and 135 mm respectively) were classed as juveniles and all other species were classed as bycatch. The CPUE data were not normally distributed (Kolmogorov-Smirnov test) and variance was heterogeneous (Levene's test), therefore differences in CPUE between scientific and fishing pots were tested using Mann-Whitney *U* tests, with the statistical package SPPS v.22. Multiple non-parametric Kruskal-Wallis tests were performed to determine differences in mean CPUE between fishing zones.

To determine the association between habitat type and the distribution of juvenile and adult *H. gammarus*, *C. pagurus*, and bycatch species, the area (km^2) of each biotope within each fishing zone was calculated using ArcMap. The biotope map that was created using the MHCBI approach was selected over the biotope map created from the bottom-up approach, as the former takes into account dominant or characteristic species that enhance the structural complexity of a habitat whilst the multivariate approach using PRIMER down weights the importance of abundant organisms.

The biotopes were subsequently divided into one of two categories; structurally complex or non-complex habitats. Complex habitats included those containing a high percentage of macroalgae (on both bedrock and cobbles/pebbles), such as *Laminaria hyperborea* kelp forest on rocky reefs. Simple habitats included sublittoral sediments or sand scoured reefs with sparse fauna and no algae, or mixed substratum typically containing high quantities of shell hash found in strong environmental conditions. The relationship between habitat complexity and abundance of commercial and bycatch species was analysed using Pearson's correlation. The correlation coefficients identified any significant associations between the amount of complex/non-complex biotopes within fishing zones and the relative CPUE of juvenile lobsters, juvenile crabs, adult lobsters, adult crabs and bycatch. Prior to analyses, variables were tested for normality using the Kolmogorov-Smirnov test.

A series of Kruskall-Wallis H tests were used to investigate the associations between specific biotopes and species preferences. The proportion of different biotopes within each fishing zone were compared to the CPUE data of crabs, lobsters and bycatch species caught within the same zone.

3.0 Results

3.1 Habitat mapping

A total of 84 sites were surveyed covering a depth range between 0.5 m and 28.5 m (Figure 3). Seven sites fell on the boundary line of the closed area or just outside it. The seabed substratum was heterogeneous including sands, gravel ridges and shell hash, and bedrock outcrops, as shown by both the MaxSea substrate data and the drop down camera survey.

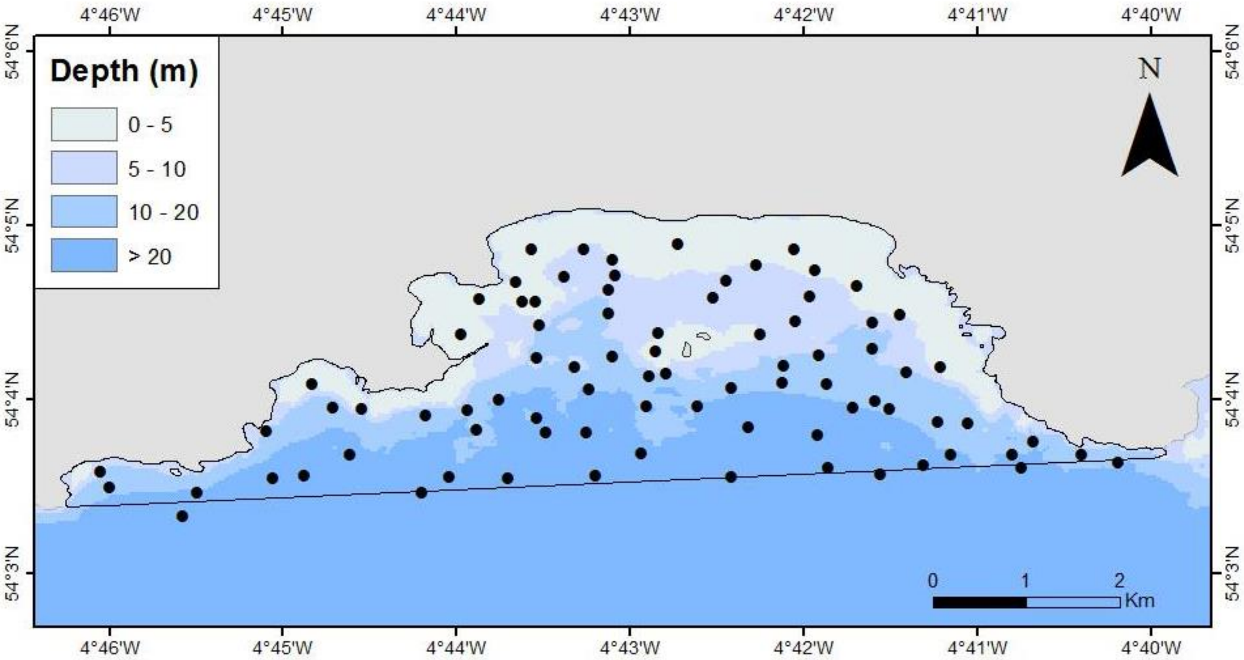

Figure 3. Distribution of sites surveyed using the drop down camera system in Baie ny Carrickey closed area.

3.1.1 Photo quality and general trends and distributions of taxa

All photo extracts were deemed as ‘acceptable’ or of ‘good’ visibility, and none were excluded for this reason. The use of a small-sized drop down camera in infralittoral habitats dominated by forest kelp, *Laminaria hyperborea*, resulted in a small number of frames (2.4 %) being excluded as the substrate view was either completely obscured by kelp fronds or the drop-down structure was overturned. The drop-down structure also overturned in habitats characterised by stronger tidal currents (0.9 %) or containing a high proportion of large boulders (1.5 %).

A total of 76 taxa were identified from the drop down camera photo analysis, with 51 taxa recorded as sessile and measured in terms of percent cover, and 16 as mobile and recorded as abundance counts (see Appendix I for a full species list). General trends of the distribution of Mollusca showed that *Littorina obtusata* only occupied shallow sites (< 10 m), *Gibbula* spp. were common and observed throughout the infralittoral zone, while the deepest areas (> 22 m) were populated by king scallops *P. maximus* The common sea urchin *Echinus esculentus* was present in a range of habitats and sites from 8 m to 26 m. Colonies of the soft coral *Alcyonidium digitatum*, the boring sponge *Cliona celata*, the demosponge *Tethya aurantia* and the sea squirt *Clavelina lepadiformis* were observed in increasing abundances at intermediate and deeper depths where rocky substrate was common. No megafauna were observed on sandy substrates, although there was some evidence of bioturbation fauna. For algae species, kelp forests of *Laminaria hyperborea* were abundant on rocky substrates, with some *Saccorhiza polyschides*, and *Saccharina latissima* observed at sheltered, shallower sites. Corallinaceae was commonly found in all substrates except for sand. The UK BAP priority species eelgrass *Zostera marina* and maerl (most likely to be the common species *Phymatolithon calcerum*) were observed inside the closed area (Figure 4). Maerl beds were observed at several deeper sites, although were found to contain a high proportion of dead nodules. The presence of a small *Z. marina* bed was confirmed to the north-west of the bay. *C. pagurus* was also observed on two occasions in the drop down cameras, at deep sites with mixed substratum. Figure 5 shows the distributions of characteristic benthic taxa in the study area.

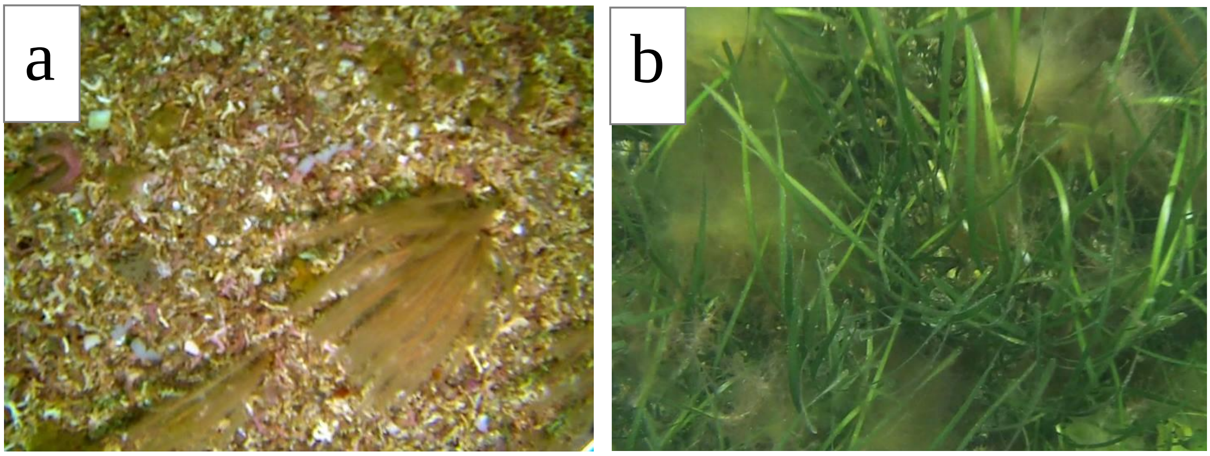

Figure 4. Examples of UK BAP priority habitats a) maerl and b) seagrass *Zostera marina* found in Baie ny Carrickey closed area

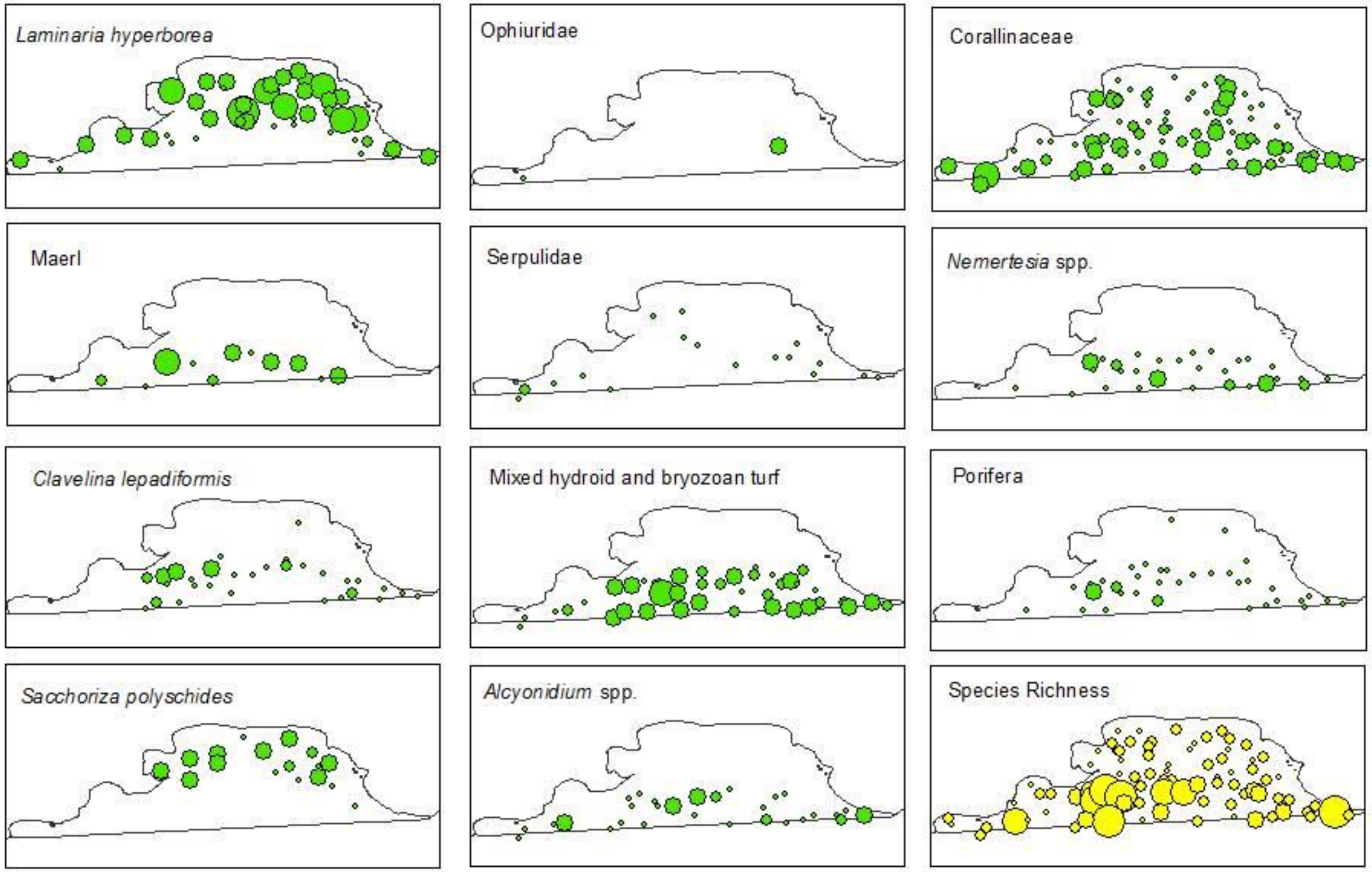

Figure 5. Distribution of major benthic taxa and species diversity in Baie ny Carrickey Closed Area. For each taxon, the circle size indicates the percent cover from the drop down camera survey. Species richness has a separate legend, with larger circles corresponding to a greater diversity

3.1.2 Bottom-up approach to mapping

The CLUSTER analysis combined with the SIMPROF test (P = 0.01) identified fourteen significantly different clusters, which indicated the presence of fourteen distinct community assemblages, or biotopes in BNC. Each biotope was assigned a unique letter code; their distributions across BNC closed area are shown in Figure 6. The largest group was N which consisted of 31 sites confined to shallow water (< 20 m). Three sites (E, F, I) consisted of a single site (Figure 7).

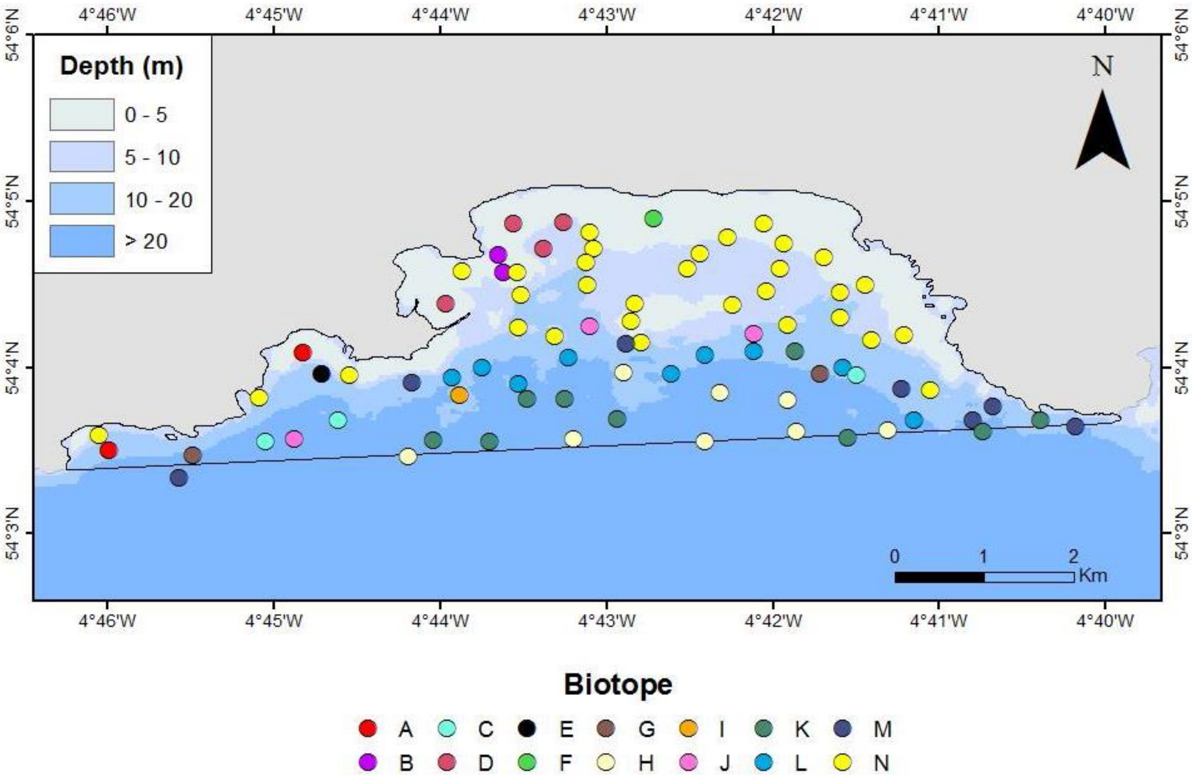

Figure 6. Distribution of biotopes in Baie ny Carrickey closed area. Biotope groupings correspond to the results of the SIMPROF test (P = 0.01) as part of the cluster analysis.

A two-dimensional non-metric MDS ordination plotted by the significant groups from the SIMPROF test, illustrates how the different benthic assemblages were generally well clustered, although there was some overlap between groups (Figure 8). The plot also revealed that group A was markedly different to the other clusters. The sites this group were sampled on fine sand and with a presence of bioturbation organisms, but otherwise no algae or sessile fauna was present.

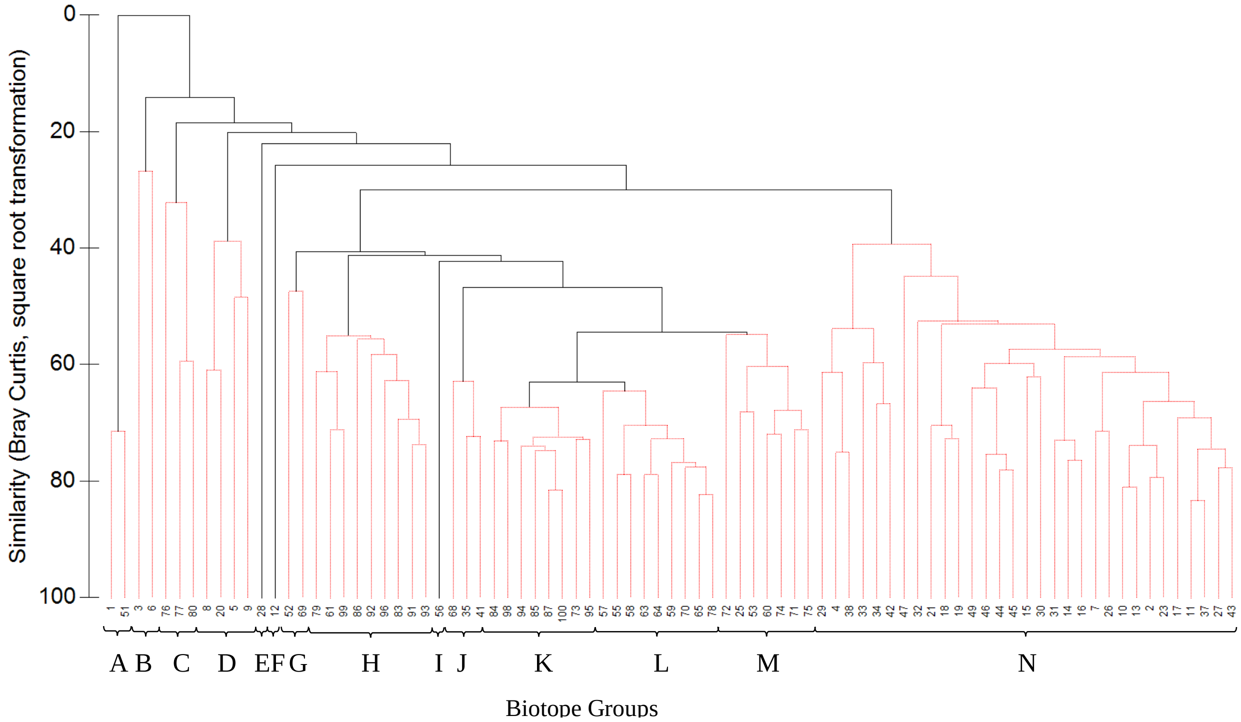

Figure 7. Dendrogram showing clusters of benthic communities using group average linking of Bray Curtis similarities calculated on square root transformed data. Black lines and letter codes correspond to significant a posteriori groups of sites identified by the SIMPROF procedure (P = 0.01)

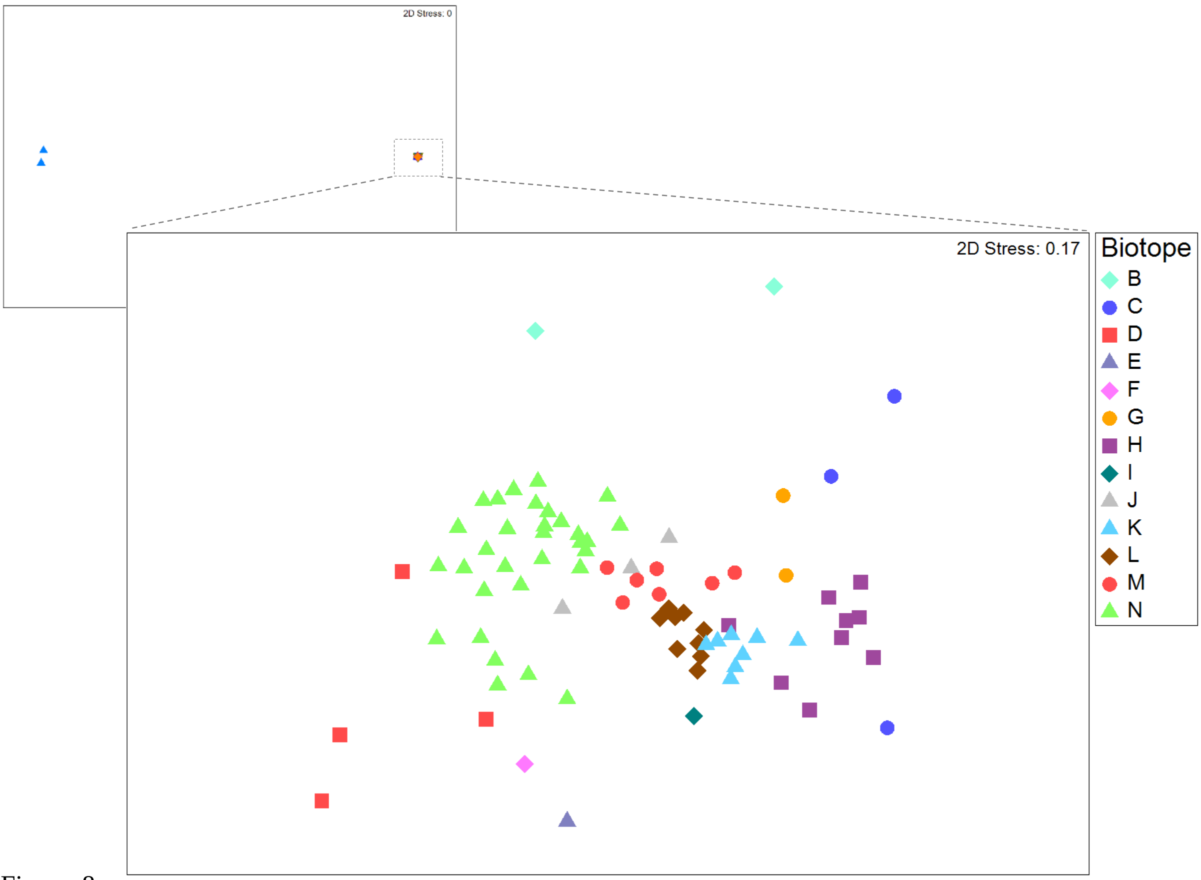

Figure 8.
Non-metric MDS ordination plot of benthic communities surveyed in Baie ny Carrickey Closed Area, based on square root transformed data and a Bray Curtis similarity matrix. Groupings are based on the results of the SIMPROF analysis (P = 0.01). The upper MDS ordination plot indicates outliers (Biotope A)

The groupings identified in the SIMPROF test were then explored further by applying the SIMPER analysis. The SIMPER procedure indicated that the similarities of taxa contributing within assemblages varied from 26.8 % to 71.36 % (Table 3). The similarities between sites were generally good to high, with the exception of sites in group B. Macroalgae and Corallinaceae were the dominating taxa for most groups. Pairwise testing confirmed that there were strong and significant differences between the benthic communities identified from the cluster analysis (Global R = 0.735, P = 0.001).

The environmental variable that best described the benthic communities was depth (Rho = 0.595, P = 0.001). Patterns in biological communities could also be explained by a combination of the MaxSea acoustic data and depth (Rho = 0.461, P =0.001). Substrate type observed from the drop down cameras was found to be a poorly explain community structure.

Table 3. SIMPER analysis results for significant biotope groups identified from the SIMPROF procedure. Stations E, F, and I are not displayed as represented by a single site. Percent cut-off for contributing taxa was 90 %

Taxa	Av.abund	Contrib %	Cum.contrib %
Group A: average similarity 71.36 %			
Bioturbation fauna	0.37	100.00	100.00
Group B: average similarity 26.80 %			
Laminaria digitata	3.50	46.36	46.36
Fucus serratus	4.52	41.63	88.00
Corallinaceae	2.06	12	100.00
Group C: average similarity 41.19 %			
Corallinaceae	1.60	55.78	55.78
Serpulidae spp.	0.50	27.56	83.34
Mixed hydroid and bryozoan turf	0.93	16.66	100.00
Group D: average similarity 44.04 %			
Saccharina latissima	4.92	59.89	59.89
Filamentous rhodophyceae	2.39	26.05	85.94
Cystoseira spp.	2.72	8.48	94.42
Group G: average similarity 47.33 %			
Corallinaceae	5.45	42.29	42.29
Hildenbrandia spp.	1.79	17.21	59.50
Mixed hydroid and bryozoan turf	1.75	9.04	68.54
Ophiocomina nigra	2.28	8.93	77.46
Foliose rhodophyceae	1.48	8.29	85.75
Alcyonidium digitatum	0.93	7.47	93.23
Group H: average similarity 58.12 %			
Mixed hydroid and bryozoan turf	3.21	32.02	32.02
Corallinaceae	2.92	26.66	58.67
Maerl	2.92	17.56	76.24
Nemertesia antennina	1.16	7.75	83.99
Hildenbrandia spp.	1.09	7.38	91.37
Group J: average similarity 65.96 %			
Filamentous rhodophyceae	7.26	52.24	52.24
Foliose rhodophyceae	3.31	16.05	68.29
Corallinaceae	2.02	11.15	79.44
Hildenbrandia spp.	1.88	10.62	90.06

Table 3. (continued)

Taxa	Av.abund	Contrib %	Cum.contrib %
Group K: average similarity 70.84 %			
Mixed hydroid and bryozoan turf	5.27	28.56	28.56
Corallinaceae	3.61	17.26	45.83
Foliose rhodophyceae	2.50	10.89	56.72
Clavelina lepadiformis	1.72	8.89	65.61
Hildenbrandia spp.	1.81	8.23	73.85
Alcyonidium digitatum	1.93	6.67	80.52
Filamentous rhodophyceae	1.48	6.21	86.74
Nemertesia antennina	1.50	5.17	91.91
Group L: average similarity 71.30 %			
Foliose rhodophyceae	3.42	15.44	15.44
Mixed hydroid and bryozoan turf	3.69	14.96	30.40
Filamentous rhodophyceae	3.67	14.12	44.52
Corallinaceae	2.71	12.32	56.85
Clavelina lepadiformis	2.81	10.96	67.80
Dictyota dichotoma	2.19	9.30	77.10
Hildenbrandia spp.	2.04	9.08	86.18
Nemertesia antennina	1.70	6.36	92.54
Group M: average similarity 61.52 %			
Corallinaceae	3.71	19.34	19.34
Filamentous rhodophyceae	3.28	17.06	36.40
Dictyota dichotoma	2.61	13.71	50.10
Foliose rhodophyceae	2.61	12.11	62.21
Laminaria hyperborea	2.90	10.91	73.12
Mixed hydroid and bryozoan turf	2.08	10.51	83.63
Hildenbrandia spp.	1.75	10.10	93.73
Group N: average similarity 51.70 %			
Laminaria hyperborea	4.46	28.33	28.33
Filamentous rhodophyceae	3.82	25.15	53.48
Foliose rhodophyceae	2.45	13.55	67.04
Corallinaceae	1.86	11.00	78.03
Saccorhiza polyschides	1.77	5.84	83.88
Hildenbrandia spp.	0.95	4.35	88.22
Delesseria sanguinea	0.98	3.72	91.94

3.1.3 Top-down approach to mapping

3.1.3.1 Broad-scale habitat map

A broad-scale habitat map was produced using the MHCBI system by combining environmental layers (Figure 9) with descriptions of the codes presented in Table 4. The habitat map shows that the distribution of marine environments across BNC closed area is heterogeneous. Sublittoral sediments were more extensively found in the deeper circalittoral zone. However, it was not possible to classify sublittoral sediments (SS) to Level 3 of the MHCBI hierarchy without the addition of biological community data or an accurate method of interpreting the size of sand particles from the camera (i.e. fine sand vs. coarse sand). The infralittoral zone covered a large area with the majority is subjected to a high energy regime. Using the thresholds as set out by UKSeaMap, no regions of low energy were identified in the area. The west of the study area generally has a moderate energy regime, in comparison to the east which is higher and more exposed.

Table 4. Descriptions for habitats and broad habitats in Baie ny Carrickey, identified using determined using environmental layers (biological zone, energy level and substrate type) and classified using the Marine Habitat Classification for Britain and Ireland

Level	Habitat code	Description	Depth range (m)
2	SS	Sublittoral sediments	0 - 100
3	IR.HIR	High energy infralittoral rock	0 - 20
3	IR.MIR	Moderate energy infralittoral rock	0 - 20
3	CR.HCR	High energy circalittoral rock	10 – 30
3	CR.MCR	Moderate energy circalittoral rock	10 - 30
2	LR	Littoral rock	Eulittoral

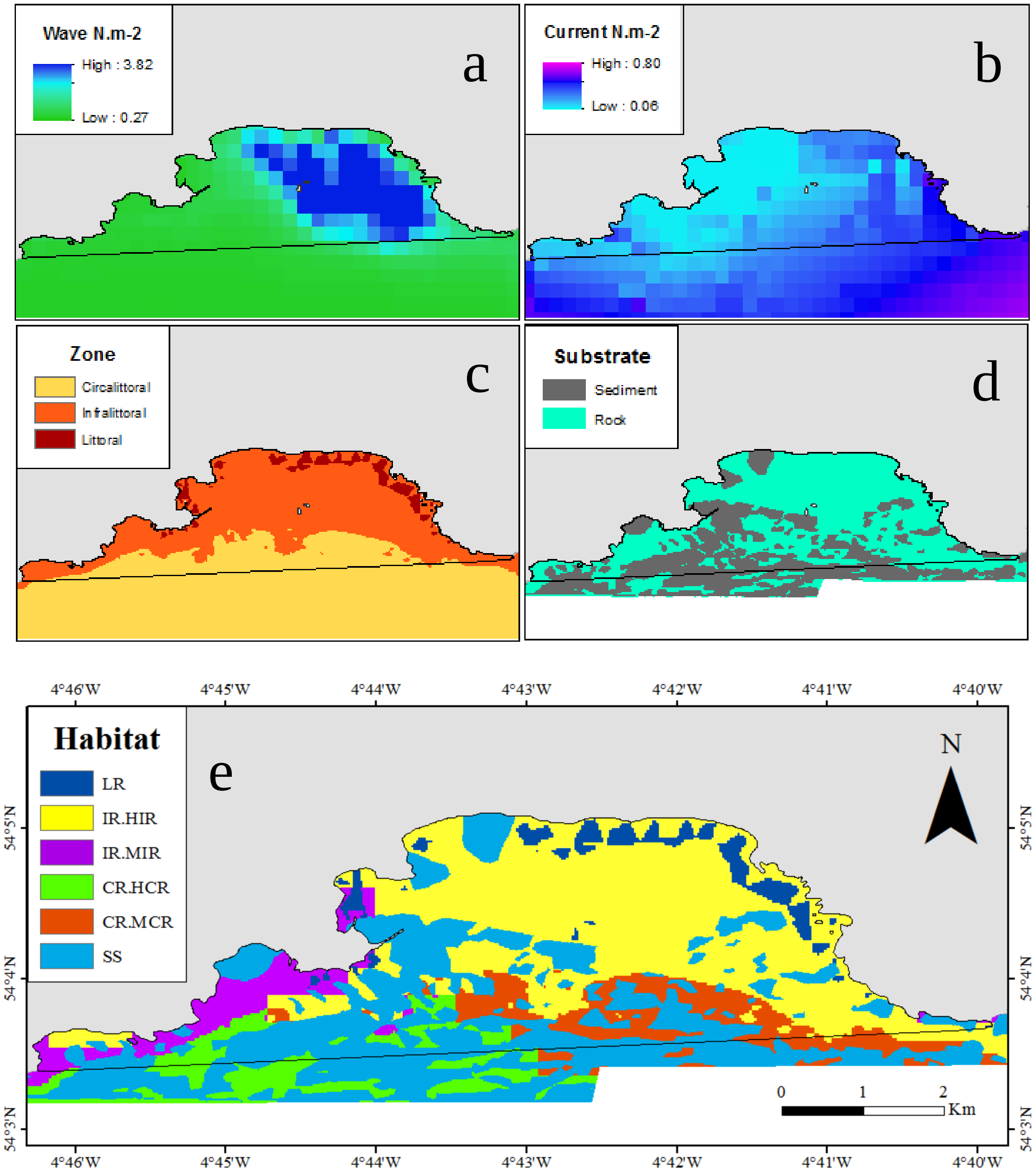

Figure 9. Primary layers of abiotic variables for Baie ny Carrickey Closed Area. a) wave energy at the seabed, b) current exposure at the seabed, c) biological zone and d) broad substrate type. Wave and current maps are derived from UKSeaMap data (McBreen *et al.*, 2011). e) Layers were combined in ArcMap 10.2 to produce a habitat map based on the Marine Habitat Classification Scheme for Britain and Ireland. White colour indicates no data is available.

3.1.3.2 Assignment of sites to Marine Habitat Classification for Britain and Ireland Level 5 biotopes.

The smallest groupings from the cluster analysis and resulting dendrogram (Figure 7) were scrutinised and compared with environmental characteristics such as Level 3 EUNIS habitat and substrate type identified from the drop down camera extraction. The combined analysis resulted in the identification of sixteen Level 5 biotopes (Figure 10). Two biotopes from sublittoral sediment habitats could not be identified to Level 5 of the classification. For SS.Ssa.IFiSa (Infralittoral fine sand) there was no presence of marine organisms, and areas containing low abundances of bryozoan and hydroid turf, Corallinaceae and *Serpulidae* spp. on mixed sediments did not match predefined MHCBI biotopes therefore were classified to Level 4: SS.SMx.CM (Circalittoral mixed sediments). A short description of each biotope is presented in Table 5, and full descriptions with representative images are presented in the Appendices.

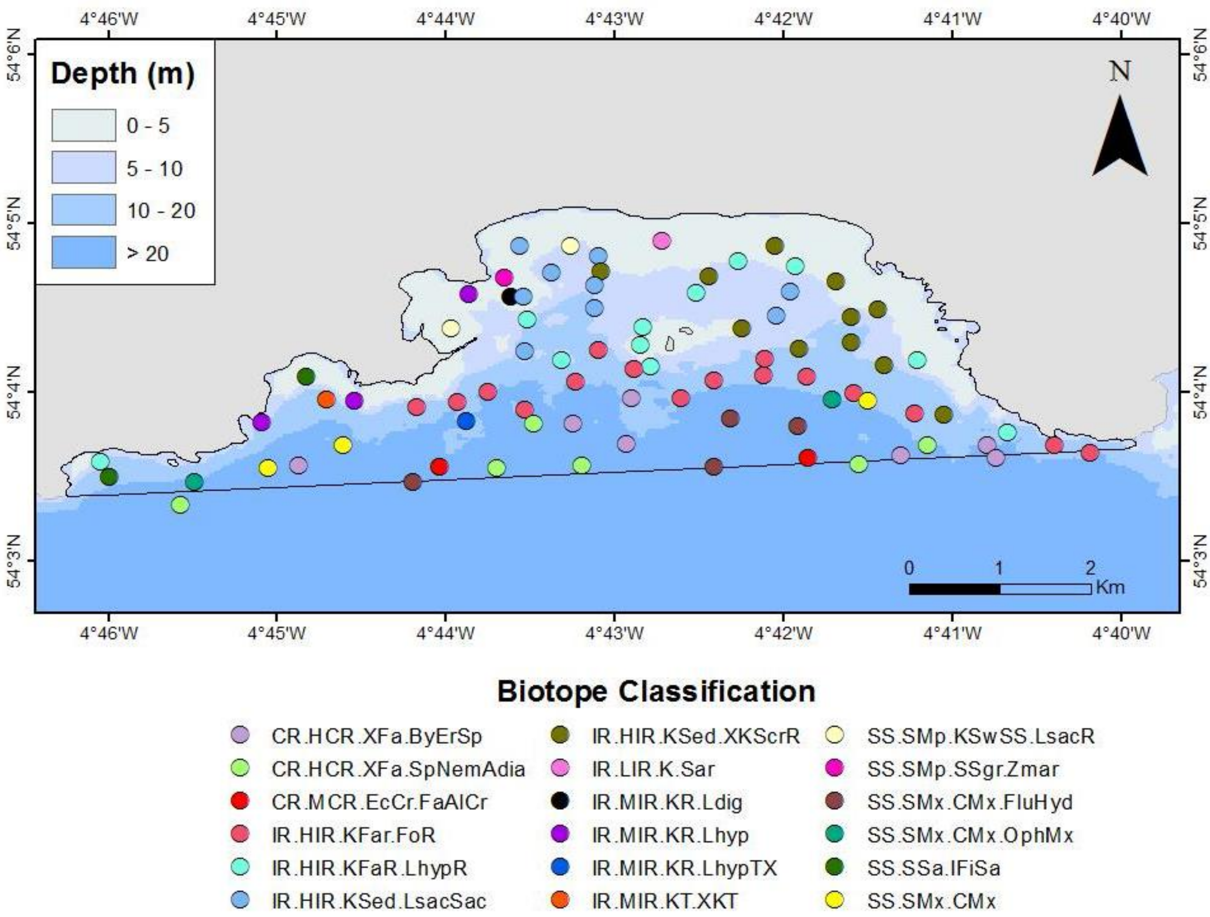

Figure 10. Distribution of biotopes in Baie ny Carrickey closed area. Biotopes area assigned according to the Marine Habitat Classification for Britain and Ireland.

Table 5. Community descriptions for biotopes in Baie ny Carrickey identified using the Marine Habitat Classification for Britain and

Level	Habitat code	Description	Substratum
5	CR.HCR.XFa.ByErSp	Bryozoan turf and erect sponges on tide-swept circalittoral rock	Bedrock, boulders
5	CR.HCR.XFa.SpNemAdia	Sparse sponges, *Nemertesia* spp. and *Alcyonidium diaphanum* on circalittoral mixed substrata	Boulders, cobbles, pebbles
5	CR.MCR.EcCr.FaAlCr	Faunal and algal crusts on exposed to moderately wave-exposed circalittoral rock	Boulders, cobbles, pebbles
5	IR.HIR.KFaR.FoR	Foliose red seaweeds on exposed lower infralittoral rock	Bedrock, stable boulders
5	IR.HIR.KFaR.LhypR	*Laminaria hyperborea* with dense foliose red seaweeds on exposed infralittoral rock	Bedrock, boulders
5	IR.HIR.KSed.LsacSac	*Laminaria saccharina* and/or *Saccorhiza polyschides* on exposed infralittoral rock	Bedrock, boulders, cobbles
5	IR.HIR.KSed.XKScrR	Mixed kelps with scour-tolerant and opportunistic foliose red seaweeds on scoured or sand-covered infralittoral rock	Bedrock, boulders
5	IR.LIR.K.Sar	*Sargassum muticum* on shallow slightly tide-swept infralittoral mixed substrata	Mixed substrata
5	IR.MIR.KR.Ldig	*Laminaria digitata* on moderately exposed sublittoral fringe rock	Bedrock, boulders
5	IR.MIR.KR.Lhyp	*Laminaria hyperborea* and foliose red seaweeds on moderately exposed infralittoral rock	Bedrock, boulders
5	IR.MIR.KR.LhypTX	*Laminaria hyperborea* on tide-swept infralittoral mixed substrata	Boulders, cobbles, pebbles, gravel
5	IR.MIR.KT.XKT	Mixed kelp with foliose red seaweeds, sponges and ascidians on sheltered tide-swept infralittoral rock	Bedrock, boulders and cobbles
5	SS.SMp.KSwSS.LsacR	*Laminaria saccharina* and red seaweeds on infralittoral sediments	Mixed muddy sand with gravel/pebbles/cobbles
5	SS.SMp.SSgr.Zmar	*Zostera marina*/*angustifolia* beds on lower shore or infralittoral clean or muddy sand	Medium to fine sandy muds
5	SS.SMx.CMx.FluHyd	*Flustra foliacea* and *Hydrallmania falcata* on tide-swept circalittoral mixed sediment	Boulders, cobbles, pebbles, with gravel/sand
5	SS.SMx.CMx.OphMx	*Ophiothrix fragilis* and/or *Ophiocomina nigra* brittlestar beds on sublittoral mixed sediment	Mixed sediment, often with cobbles/pebbles
4	SS.SSa.IFiSa	Infralittoral fine sand	Medium to fine sand
4	SS.SMx.CMx	Circalittoral mixed sediment	Mixed sediment with stones and shells

There was some difficulty is assigning biotope classifications to sites that were located on the boundary of the circalittoral/infralittoral broad habitat and the sublittoral sediment broad habitat, and in particular when the substratum comprised of cobbles or pebbles which can be classified into either the 'rock' or 'sediment' classes. A non-metric MDS ordination plot was created to visualise the groupings of the benthic assemblages according to their MHCBI groupings (Figure 11). Pairwise comparisons revealed significant differences in benthic community assemblages for the MHCBI allocated biotopes (ANOSIM Global R = 0.749 P = 0.001).

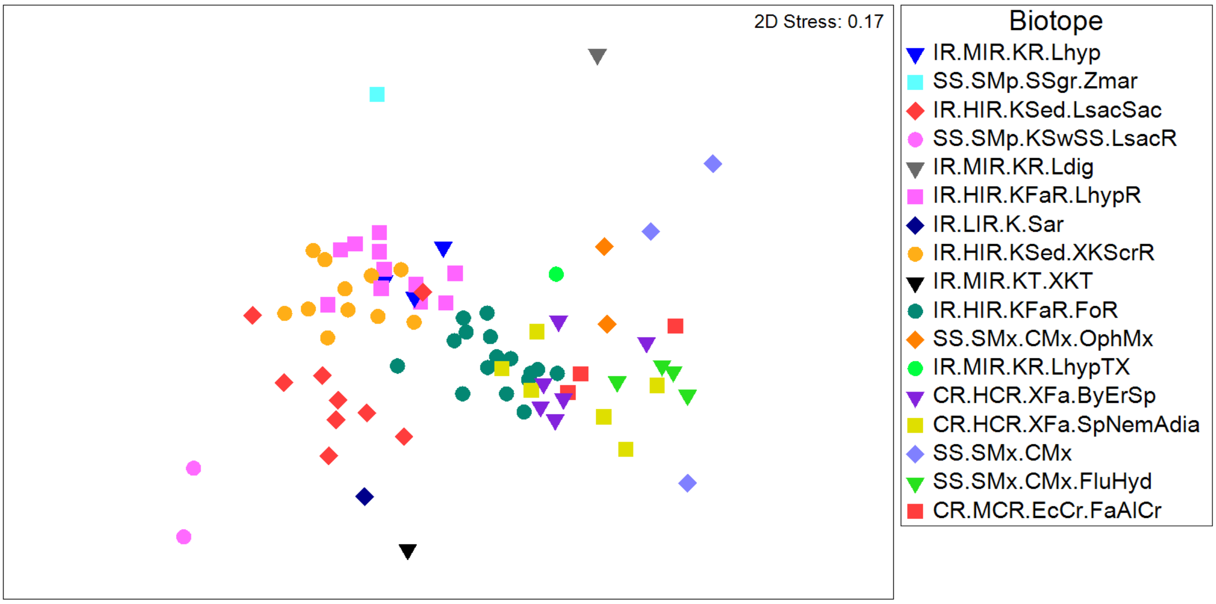

Figure 11 Non-metric MDS ordination plot of benthic communities surveyed in Baie ny Carrickey Closed Area, based on square root transformed data and a Bray Curtis similarity matrix. Groupings are based on the results of the biotope assignment of sites according to the Marine Habitat Classification for Britain and Ireland. As an outlier, SS.SSa.IFiSa is excluded.

3.1.4 Biotope map comparisons

The top-down classification approach identified 18 biotopes compared to the bottom-up approach where 14 biotopes were identified from multivariate analyses in PRIMER. Euclidean allocation analysis of point samples generated two maps using the different mapping approaches (Figure 12). Comparisons between maps indicated stark differences in biotopes located in the infralittoral zone. The MHCBI was capable of differentiating between the different kelp communities; *Laminaria hyperborea* dominated kelp forests with dense foliose red seaweeds (IR.HIR.KFaR.LhypR), mixed kelps (*L. hyperborea*, *Saccharina latissima* and *Saccorhiza polyschides*) with scour-tolerant opportunistic foliose seaweeds (IR.HIR.KSed.XKScrR) and lastly biotopes characterised by *S. latissima* and/or *S. polyschides* (IR.HIR.KSed.LsacSac). In comparison, the cluster analysis in PRIMER identified these biotopes in the same group (N) as the data was transformed to down-weight the prevalence of dominant taxa. The use of the MHCBI as a tool in classifying biotopes was also able to distinguish between IR.MIR.KR.Ldig and SS.SMp.SSgr.Zmar. Both biotopes are found in the upper infralittoral zone but one is characterised by seagrass *Z. marina*; the SIMPROF test identified both sites as being in the same cluster but with a low average group similarity of 26 %.

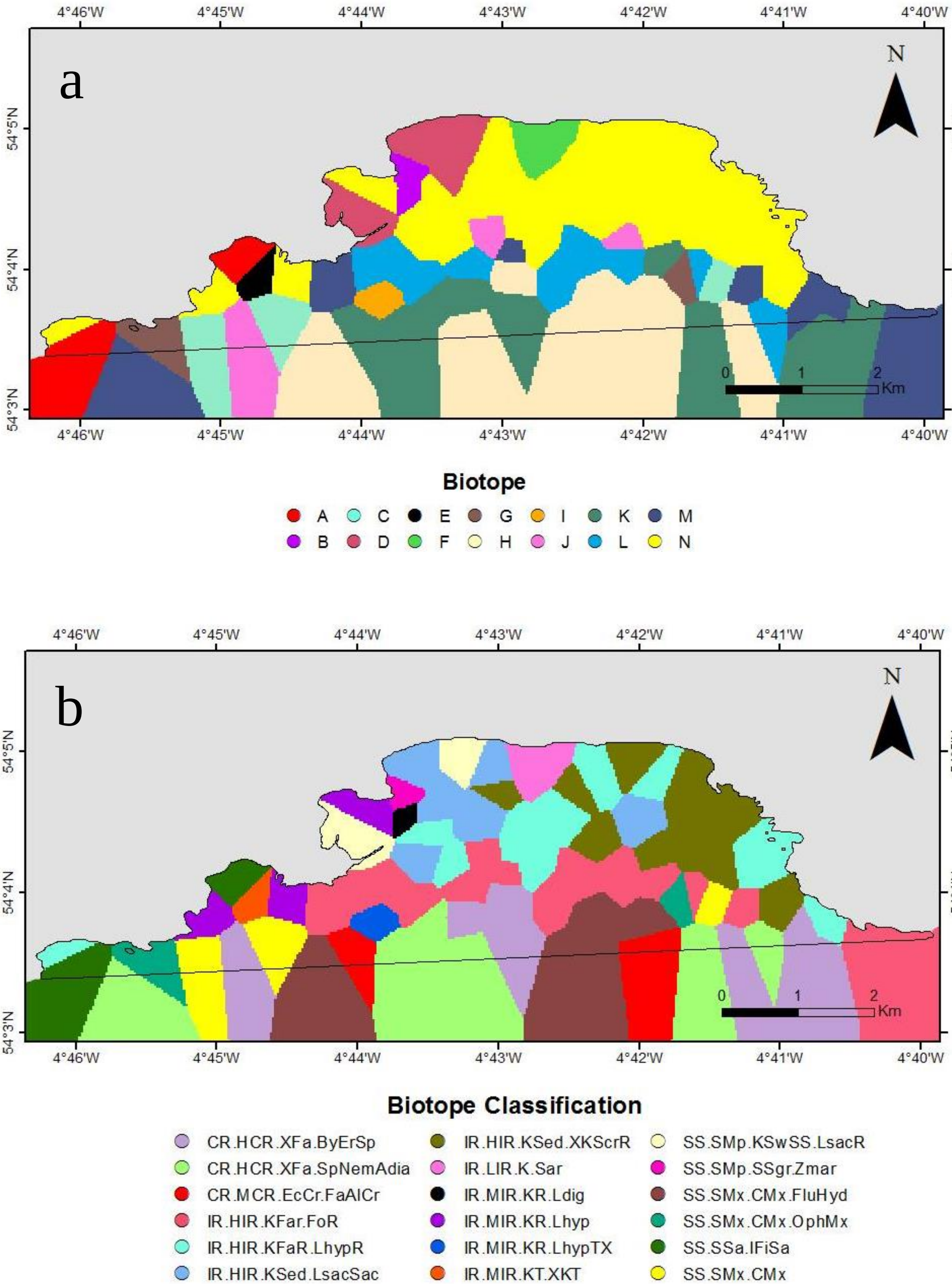

Figure 12. Distribution of biotopes using Euclidean allocation analysis in Baie ny Carrickey closed area, based on a) biotopes determined from the cluster analysis as part of the bottom-up approach and b) biotopes classified using the Marine Habitat Classification for Britain and Ireland as part of the top-down approach

3.2 BRUV

A total of twelve BRUVs were deployed, covering a range of depths from 0.6 to 27.7 metres (Figure 13). Five different habitats were sampled; rock habitats were most frequently sampled, representing a total of six out of twelve sites, whilst seagrass, macroalgae, sand and pebble habitats were also sampled (Figure 14). Due to adverse weather conditions, insufficient replicates were obtained for seagrass and macroalgae dominated habitats (with 1 replicate each), and for sand and pebble/cobble habitats (with 2 replicates each). A total of 20 species were observed during the BRUV surveys, representing 14 families (see Appendix II for a full species list). The cuckoo wrasse *Labrus mixtus*, and the Atlantic pollack, *Pollachius pollachius* were most frequently observed and found at eight of the sites, although the cuckoo wrasse was found in greater abundances.

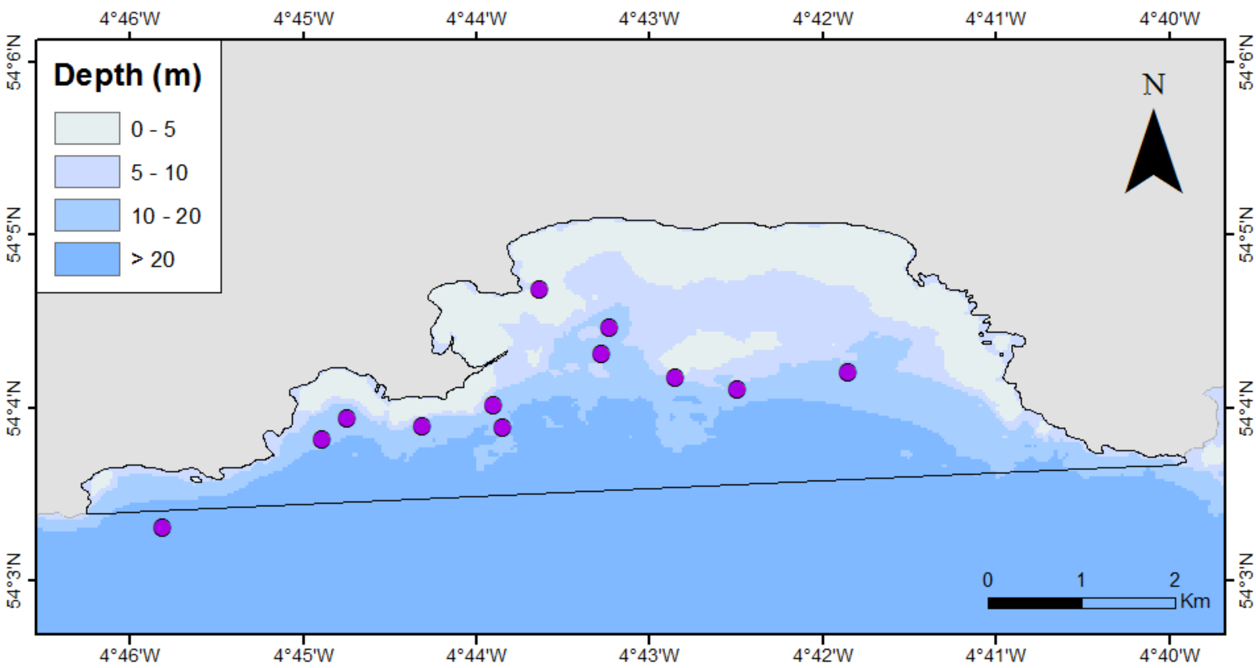

Figure 13. Distribution of sites surveyed using the BRUV system in Baie ny Carrickey closed area.

A non-metric MDS ordination plot was generated of relative abundance estimates of species (mean MaxN per site) to visualise patterns of fish and invertebrate assemblages among broad habitat types (Figure 15). Sites surveyed on pebble substrates and macroalgae were distinctive from other habitats. Sites surveyed in sand habitats were most similar to rocky reef habitats in terms of species composition. There was a significant difference between the benthic taxa composition of rock and pebble habitats (ANOSIM: R = 0.708, P = 0.036). Pairwise testing indicated no other significant differences between habitats (ANOSIM: Global R = 0.373, P = 0.068).

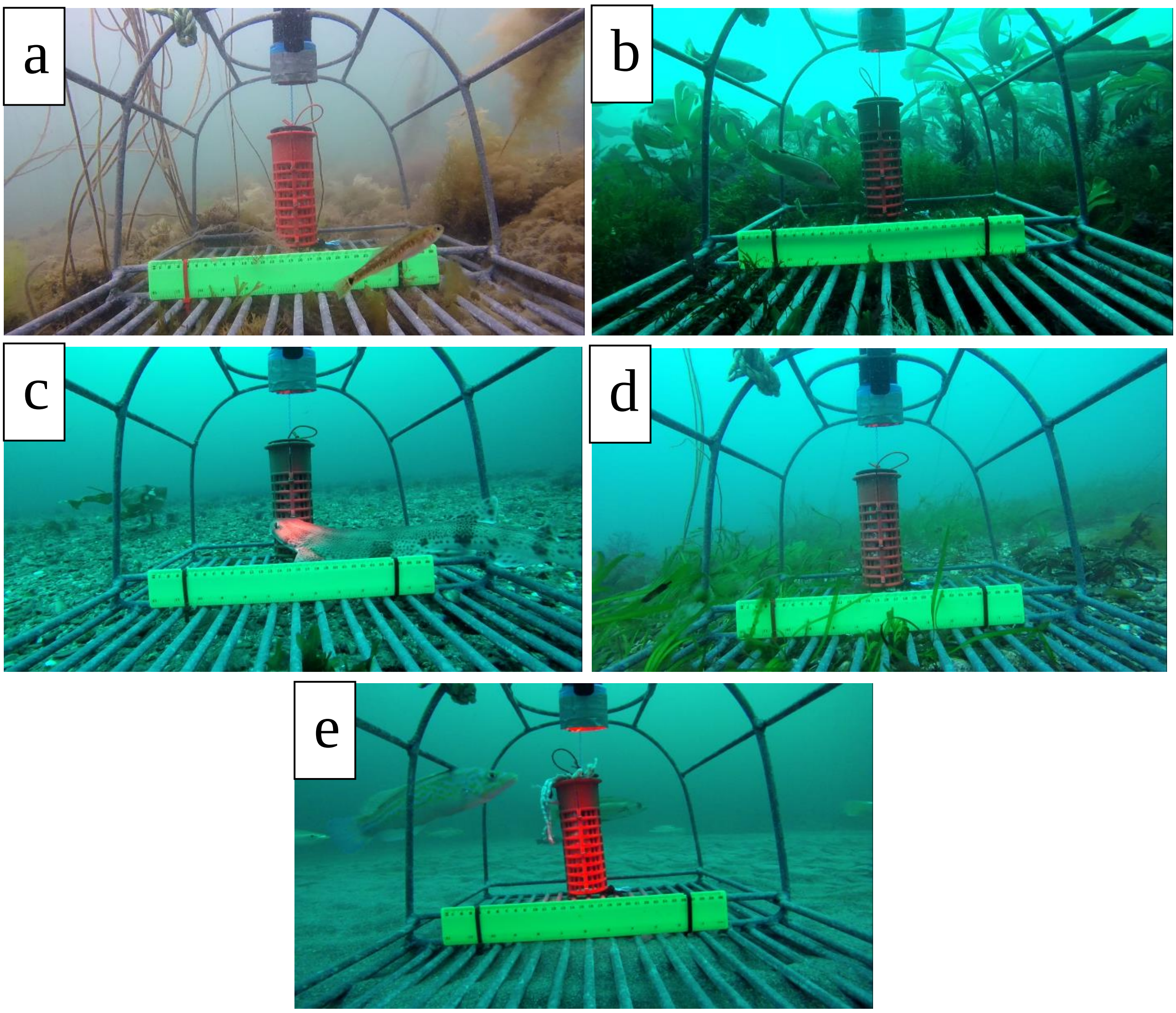

Figure 14. Examples of BRUV deployments in each habitat a) Macroalgae, b) Rocky reef, c) Pebble, d) Seagrass and e) Sand

The results of the SIMPER analysis was performed for habitats containing more than one site, indicated that there was variation of species within habitats (Table 6). Pebble habitats were characterised by scavenger species, (hermit crabs *Pagurus* spp. and small-spotted catshark *Scyliorhinus canicula*), whilst in both rock and sand habitats high abundances of the cuckoo wrasse *L. mixtus* were observed. Finally, the RELATE function showed that there was no significant correlation between depth and species composition (Spearman’s rank correlation: R = 0.058, P = 0.349).

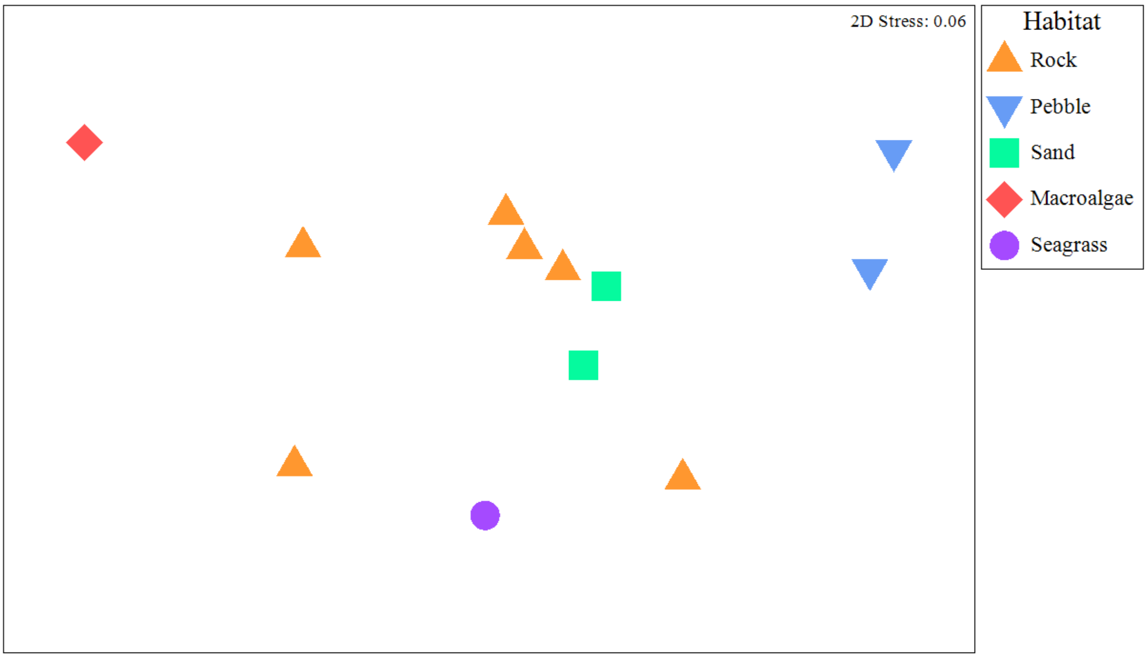

Figure 15. Non-metric MDS ordination plot of fish and invertebrate communities surveyed during the BRUV survey, in Baie ny Carrickey Closed Area

Table 6. SIMPER outputs for indicating species primarily responsible for differences within habitats. Percent cut-off for contributing taxa was 90 %.

Taxa	Av.abund	Contrib %	Cum.contrib %
Rock habitat: average similarity 23.25 %			
Labrus mixtus	0.83	48.11	48.11
Ctenolabrus rupestris	0.41	24.37	72.48
Pollachius pollachius	0.28	15.42	87.9
Labrus bergylta	0.12	5.33	93.23
Pebble habitat: average similarity 43.30 %			
Pagurus spp.	1.73	79.94	79.94
Scyliorhinus canicula	0.54	20.06	100
Sand habitat: average similarity 45.34 %			
Labrus mixtus	1.1	69.78	69.78
Pollachius pollachius	0.62	30.22	100

3.3 Logbook data

3.3.1 Effect of pot type on CPUE

Catch information was collected from a total of 189 fishing pots, 192 scientific pots and 58 prawn pots since November 2013 (Figure 16). The size of lobsters ranged from 32 mm to 145 mm, and the size of crabs ranged from 65 mm to 171 mm. The mean size of lobsters was greatest in fishing pots (91.20 mm ± 0.44 SE) whilst scientific pots (83.66 mm ± 0.36 SE) and prawn pots (53.54 mm ± 1.49 SE) were considerably smaller carapace length. For crabs, the fishing pots caught larger individuals (129.17 mm ± 2.66 SE) compared to scientific pots (115.02 mm ± 2.04 SE), and no brown crabs were recorded in the prawn pots. A total of 15 species of bycatch were recorded (see Appendix III for a full species list).

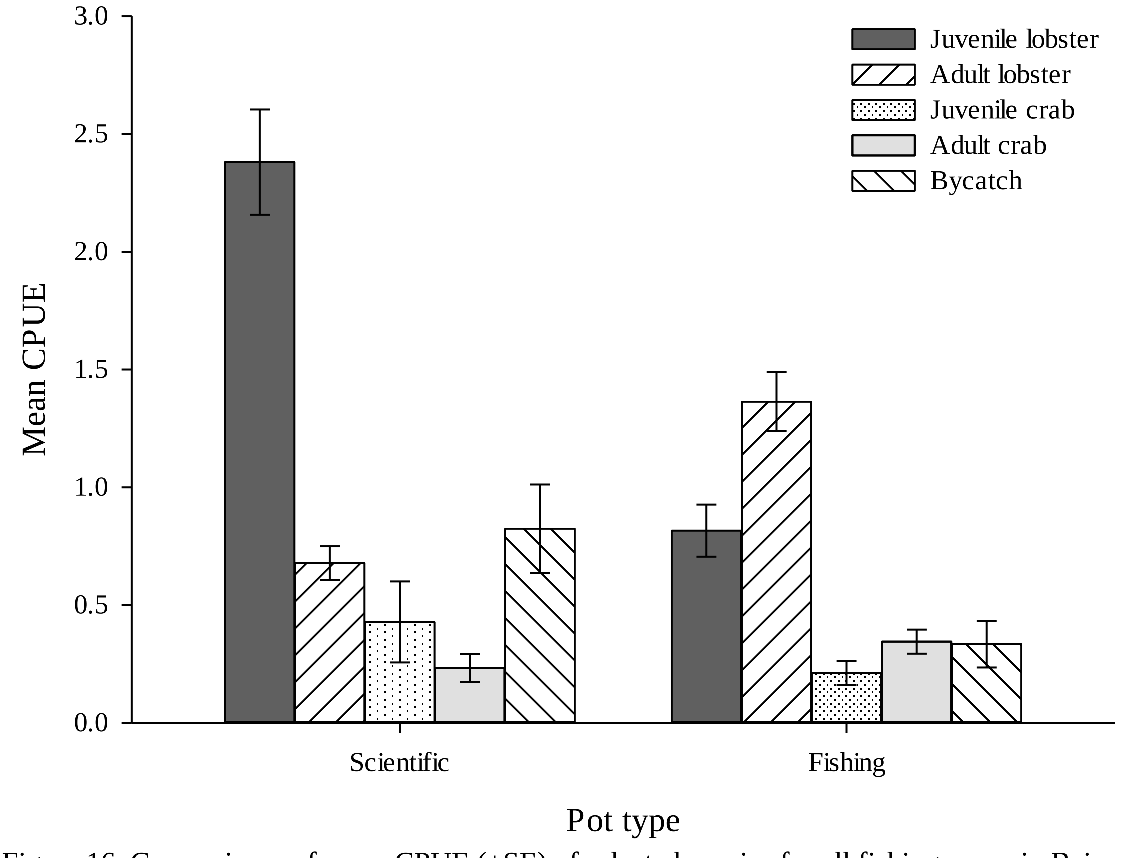

Figure 16. Comparisons of mean CPUE (±SE) of selected species for all fishing zones in Baie ny Carrickey for scientific pots and regular fishing pots

Multiple Mann-Whitney *U* tests for pairwise comparisons were calculated to ascertain whether there were statistical differences in CPUE between fishing pots and scientific pots. There was a significantly higher abundance of juvenile lobsters ($P < 0.001$), juvenile crabs ($P = 0.001$) and bycatch ($P = 0.005$) in the scientific pots lacking escape panels across the fishing zones. Pairwise comparisons also showed that CPUE of adult lobsters and adult crabs were significantly greater in the fishing pots ($P < 0.001$ and $P = 0.009$ respectively).

3.3.2 Differences between fishing zones

For all statistical analyses, zone 5 was excluded as data was only collected from one scientific pot and two fishing pots, and CPUE calculated with a low number of replicates is unlikely to be representative. Non-parametric Kruskal-Wallis H tests were used to determine if there were differences in CPUE of scientific pots across the 11 fishing zones. The distributions of CPUE across fishing zones was statistically significant for juvenile lobsters ($\chi^2_{(9)} = 27.24$, $P = 0.001$), juvenile crabs ($\chi^2_{(9)} = 37.23$, $P < 0.001$), and bycatch species ($\chi^2_{(9)} = 18.40$, $P = 0.031$). Kruskal-Wallis tests indicated no effect of zone on CPUE for crabs and lobsters above MLS. Pairwise comparisons were performed using Dunn's test to determine which fishing zones were different from each other. For juvenile lobsters the post-hoc test revealed differences in CPUE between zone 3 (mean = 1.36) and zone 9 (mean = 3.00; $P = 0.027$), and between zone 3 and zone 2 (mean = 3.06; $P = 0.007$). For juvenile crabs, CPUE in zone 9 (mean = 1.77) was found to be significantly greater in comparison to zones 1, 2, 3, 4 and 7 (mean range: 0.00 – 0.22, $P < 0.025$ for all). For bycatch species, post-hoc testing did not reveal where differences between zones lay.

For fishing pots with no escape panels, multiple Kruskal-Wallis H tests showed significant differences in the distribution of CPUE of adult lobsters ($\chi^2_{(9)} = 20.91$, $P = 0.013$) and bycatch ($\chi^2_{(9)} = 19.24$, $P = 0.023$) across fishing zones. There were no differences for juvenile lobsters or crabs. Post-hoc testing did not reveal which zones were statistically different for either adult lobsters or bycatch.

3.4 Habitat use of species

Trends in the distribution of MHCBI classified biotopes across fishing zones in Baie ny Carrickey can be seen in Figure 17. The scientific pots, that were not selective against size of individuals or species, were used to explore the effect of habitat type on the distribution of lobsters, crabs and bycatch species. The mean CPUE of different species and the proportion of complex habitats vs. non-complex habitats were calculated for each fishing zone (Table 7). All sublittoral sediments and biotopes characterised by faunal turfs were classed as non-complex, and biotopes dominated by macroalgae or found on rocky reefs were categorised as complex. All variables were found to be normally distributed, as assessed by the Kolmogorov-Smirnov test ($P > 0.05$). There was a significant positive correlation between juvenile lobster abundance and presence of complex habitats (Pearson's r = -0.633, P = 0.049), indicating a greater abundance of juvenile lobsters in fishing zones containing more structurally complex habitats (Figure 18). There were no significant correlations found between habitat complexity and adult lobsters (Pearson's r = 0. 031, P = 0.932), adult crabs (Pearson's r = 0.129, P = 0.722) or juvenile crabs (Pearson's r = 0.549, P = 0.101). Significant trends were evident between bycatch and habitat complexity, which correlated closely (Pearson's r = 0.707, P = 0.022).

Table 7. Proportion (%) of complex and non-complex habitats inside each fishing zone in Baie ny Carrickey marine protected area.

	Zone										
	1	2	3	4	5	6	7	8	9	10	11
Complex	58.5	34.8	50.4	63.1	0.0	0.0	0.1	0.0	0.0	0.0	58.4
Non-complex	41.5	65.2	49.6	36.9	100.0	100.0	99.9	100.0	100.0	100.0	41.6

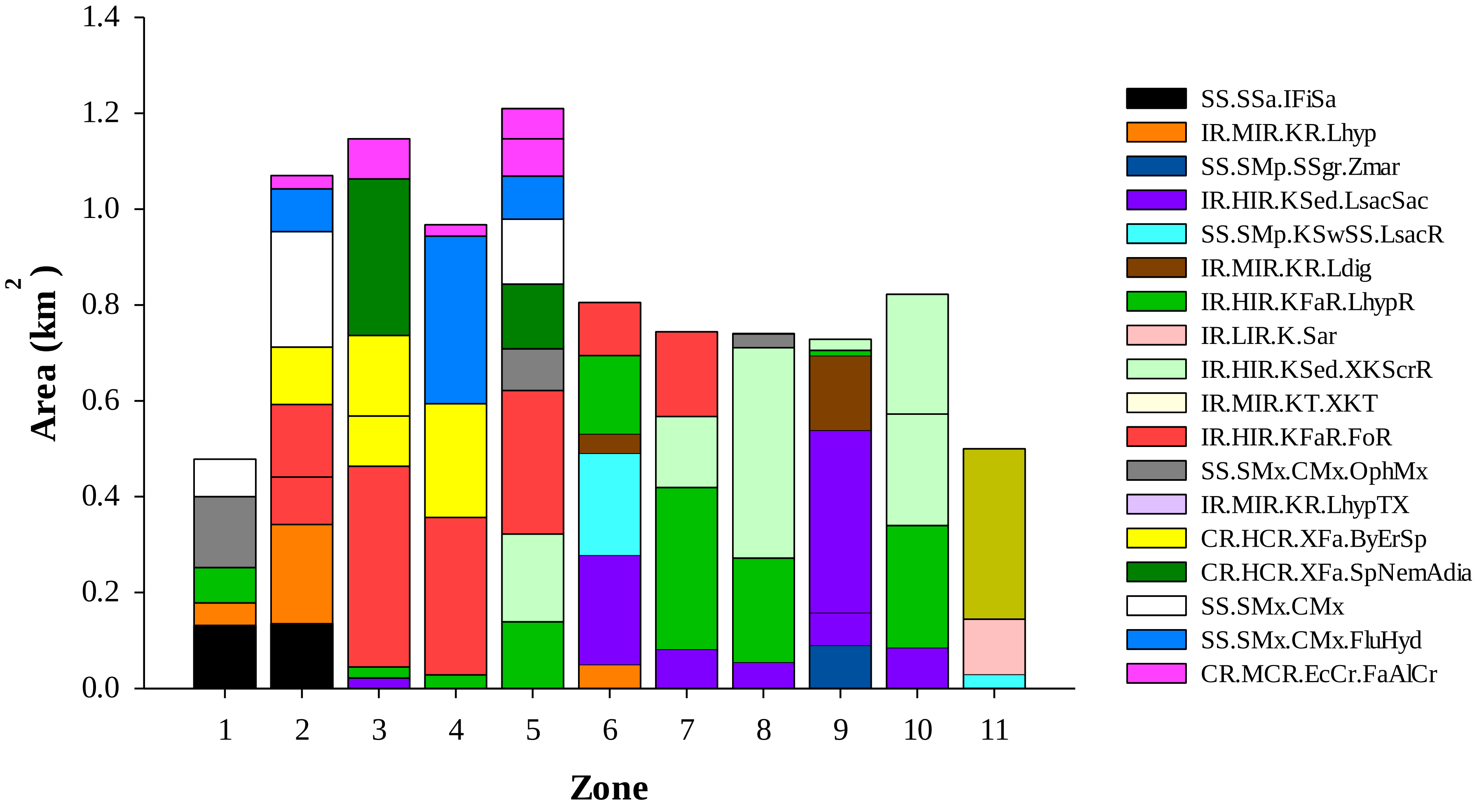

Figure 17. Composition of biotopes classified using the Marine Habitat Classification for Britain and Ireland for fishing zones in Baie ny Carrickey closed area.

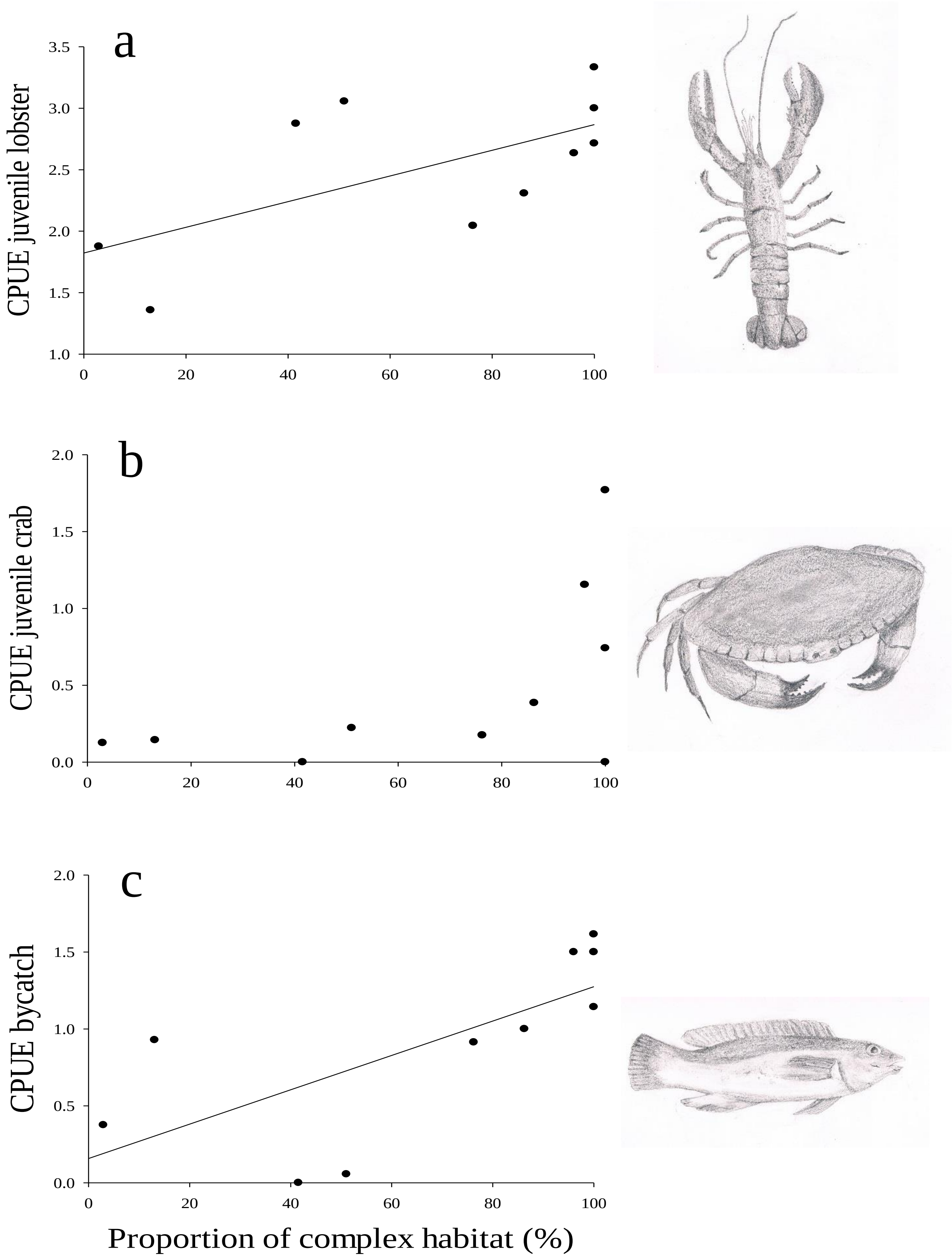

Figure 18. Pearson’s correlations for habitat complexity and a) abundance of juvenile lobsters b) abundance of juvenile crabs and c) abundance of bycatch species

Kruskal-Wallis tests showed that there was significant differences in the abundance of species across different biotopes (Table 8). Juvenile crabs and adults were found to have a varied distribution across a range of biotopes, with greater abundances in algae dominated habitats. No significant differences were found between adult lobsters and biotopes, signifying that their distribution was similar across all biotope types. The abundance of adult crabs were significantly different in smaller areas of IR.LIR.K.Sar and SS.SMx.CMx.OphMx compared to larger areas of these habitats.

Table 8. Significant Kruskall-Wallis test statistics (χ^2) testing for differences between percent of biotope (classified using the Marine Habitat Classification for Britain and Ireland) and species abundances based on CPUE data for fishing zones in Baie ny Carrickey closed area

Species	Biotope	χ^2	df	*P* value
Juvenile lobster	IR.HIR.KSed.LsacSac	20.07	7	0.005
	IR.HIR.KFaR.LhypR	27.23	8	0.001
	IR.MIR.KT.XKT	4.65	1	0.031
	IR.HIR.KFaR.For	25.41	6	0.000
	IR.MIR.KR.LhypTX	11.45	1	0.001
	CR.HCR.XFa.ByErSp	18.58	3	0.000
	CR.HCR.XFa.SpNemAdia	11.45	1	0.001
	SS.SMx.CMx.FluHyd	7.23	2	0.027
	CR.MCR.EcCr.FaAlCr	18.58	3	0.000
Juvenile crab	SS.SSa.IFiSa	6.23	2	0.044
	IR.MIR.KR.Lhyp	17.81	4	0.001
	SS.SMp.SSgr.Zmar	13.27	1	0.000
	IR.HIR.KSed.LsacSac	36.87	7	0.000
	SS.SMp.KSwSS.LsacR	13.29	2	0.001
	IR.MIR.KR.Ldig	13.29	2	0.001
	IR.HIR.KFaR.LhypR	23.54	8	0.003
	IR.HIR.KSed.XKScR	35.13	5	0.000
	IR.HIR.KFaR.For	20.25	6	0.003
	SS.SMx.CMx.OphMx	13.49	2	0.001
	CR.HCR.XFa.ByErSp	10.41	3	0.015
	SS.SMx.CMx	6.23	2	0.044
	SS.SMx.CMx.FluHyd	7.35	2	0.025
	CR.MCR.EcCr.FaAlCr	10.41	3	0.015
Adult crab	IR.LIR.K.Sar	4.79	1	0.029
	SS.SMx.CMx.OphMx	6.73	2	0.034
Bycatch	SS.SSa.IFiSa	8.92	2	0.012
	IR.MIR.KR.Lhyp	10.65	4	0.031
	IR.HIR.KSed.LsacSac	18.25	7	0.011
	IR.HIR.KSed.XKScR	15.49	5	0.008
	IR.MIR.KT.XKT	5.25	1	0.022
	CR.HCR.XFa.ByErSp	10.31	3	0.016
	SS.SMx.CMx	8.92	2	0.012
	SS.SMx.CMx.FluHyd	9.59	2	0.008
	CR.MCR.EcCr.FaAlCr	10.31	3	0.016

4.0 Discussion

To determine the effectiveness of a marine protected area, as part of an integrated approach to fisheries management, baseline information on the distribution of commercial species and the habitats that support them is essential. The habitats in Baie ny Carrickey closed area were found to be diverse, although rocky reef habitats dominated by kelp forests were prominent and covered large extents. This study characterised benthic biotopes within the Bay ny Carrickey closed area at a much finer spatial resolution than previous studies (Hinz *et al*., 2009; White, 2011); these studies were conducted across the entire Isle of Man territorial sea and identified only a single biotope within Baie ny Carrickey closed area. Structurally complex habitats were found to play an important role for juvenile lobsters and contained greater species diversity. In addition, this study also found that adult crustaceans of commercial interest show no preference towards habitat type and can be found in a range of diverse environments. The information interpreted from this study is important for the future management of Baie ny Carrickey.

4.1 Habitat mapping

Seabed habitats were mapped in Baie ny Carrickey closed area, and the spatial distribution of benthic communities estimated using both multivariate approaches and the hierarchical Marine Habitat Classification Scheme for Britain and Ireland. The use of photographic techniques to map seabed habitats proved both cost effective and non-destructive. Data analysis, although sometimes subjective, was found to be quick and efficient. Whilst proficient in observing epibiota, the drop down camera system was unable to detect infaunal species found in soft sediment habitats. Infaunal benthos are an integral part of a benthic community, and their diversity and distribution in an environment can be an indicator of anthropogenic disturbance (Elliott, 1994). Characterisation of infaunal benthic communities is important in understanding the predator-prey relationships with large mobile predators (Virnstein *et al*., 1977). However, whilst infauna were not sampled during this study, only 10 of the 84 sites sampled contained any soft-sediments likely to contain polychaetes and venerid bivalves which can define a community (Thrush *et al*., 2006). The taxonomic resolution, whereby organisms could not be identified to species level with confidence from images, and the exclusion of mobile species from multivariate community data analyses were also found to be limitations. Although these drawbacks have also been documented in similar studies (e.g. Kostylev *et al*., 2001; Collie *et al*., 2006), benthic community patterns in Baie ny Carrickey could still be determined.

Comparisons between the two mapping techniques revealed some differences. The bottom-up approach which identified habitats using multivariate techniques in PRIMER grouped together sites that were clearly different from one another. Transformed data down weighted the influence of dominant taxa, and in once instance a site dominated by seagrass and a shallow sublittoral site containing no seagrass were classified together (Group B). The top-down approach, utilising the MHCBI was able to distinguish between sites dominated by different kelps (*L. hyperborea, S. latissima* and *S. polyschides*), which were classified as the same community using the bottom-up approach.

Spatial datasets describing the abiotic characteristics of the seabed were combined to create a Level 3 habitat map. Data obtained from UKSeaMap for current and wave energy was very broadscale (300 m) and data at a finer scale would have improved map accuracy. The substrate layer was created from vessel backscatter data covering 60 % of the study area, and the substrate or the remaining area was inferred from the drop down cameras. A major caveat in the use of the MaxSea data is that the system is based on the operator designating habitats according to the backscatter, and the system needs to be continually refined. To distinguish between Level 3 'Sublittoral Sediment' habitats sedimentary characteristics are required; however it was not possible to distinguish between fine sand/muddy sand/ coarse sand etc. from the photographs alone. Although the resultant broadscale habitat map was limited by scale and cannot replace a more informative biotope map, its application is still relevant for marine spatial planning (Vasquez *et al*., 2015).

In generating a Level 5 biotope map, it was not possible to match all sites to a predefined description; a limitation frequently encountered in comparable studies assigning benthic communities using the MHCBI or EUNIS classification systems (e.g. White, 2011; Galparsoro *et al*., 2012; Henriques *et al*., 2015). The absence of biological data at infralittoral sediment sites impeded the assignment of infralittoral fine sand (SS.SSa.IFiSa) from a Level 4 to a Level 5 biotope. Further sites observed on circalittoral mixed sediments (SS.SMx.CMx) did not have a good biological fit with any predefined Level 5 biotope, most likely due to the inability to sample infaunal species which define sedimentary communities. Whilst conducting benthic surveys using alternate methods such as grab sampling or dredges (Van Rein *et al*., 2009) would overcome this shortcoming, destructive techniques are not appropriate in marine protected areas. The MHCBI also does not consider biological and anthropogenic impacts on benthic communities, such as scallop dredging (Connor *et al*., 2003). Within replicates for each site, there was considerable variation in the patchiness and spatial variation of biological communities; this is frequently observed in deeper waters that support a mosaic of species but presents difficulties when assigning biotopes within the classification (Connor *et al*., 2003). Nevertheless, the MHCBI is still a valuable tool in benthic habitat mapping; the hierarchical system reflects the integration of multiple biological and environmental data and results from its application are comparable to other studies adopting the EUNIS classification scheme across Europe.

4.2 Habitats of interest

Habitats of international conservation interest were identified inside Baie ny Carrickey closed area. Seagrass (*Z. marina*) was observed in the north-west of the bay, in agreement with previous work conducted by Haywood and Hextall (2014). The important function of seagrass as a nursery area supporting a high diversity of marine organisms is well documented throughout primary literature (Irlandi *et al*., 1999; Beck *et al*., 2001). However, the same conclusion could not be drawn from this study; most likely attributed to insufficient BRUV replicates conducted in the area, and the seagrass patch being particularly small (1 443 m^2). The members of the commercial fishing community have voluntarily agreed not to place gear in the area (pers. comm, G. Sutton). It is recommended that hobby potters be made aware of the existence of the seagrass bed so that they may avoid it. In the future if the bed is shown to be persistent then future designation and protection could be considered.

Maerl, a UK BAP priority habitat, were observed at several deep sites, however were comprised mostly of dead nodules. As no previous benthic studies have quantified the condition or extent of maerl prior to the implementation of the closed area, it cannot be inferred that the high proportion of dead maerl was caused by demersal fishing gear, or that the presence of live maerl indicates recovery. However, the present study was conducted nearly three years after the introduction of byelaws prohibiting the use of mobile gear in the closed area, and the results of this study could be compared with future research to monitor long term recovery. As a biotope, dead maerl beds may continue to support a high diversity of benthic communities, although not as rich as beds composed of living nodules (Keegan, 1974). Static gear has little impact on marine habitats (Eno *et al*., 2001), it is not necessary to further protect maerl habitats inside Baie ny Carrickey, beyond the twenty year ban on mobile gear currently in place. However, as scallop dredging has been shown to have a profound impact on maerl beds (Hall-

Spencer & Moore, 2000), future management recommendations would be to continue the ban on mobile bottom gear in the area and continue monitoring the closure for signs of recovery.

4.3 Species and habitat associations

Habitat heterogeneity is an important mechanism in determining local biodiversity, with such areas providing more ecological niches to support a higher diversity of marine organisms (Tews *et al*., 2004). In complex habitats, the abundance and diversity of bycatch species was found to be greater in comparison to simpler habitats. Patterns of fish and invertebrate communities were varied across habitats during the BRUV surveys. Active scavenger species, including brittle stars and hermit crabs were only observed on mixed pebble and cobble substrates, whilst wrasse were common in all other areas. The presence of bait in the camera trap is biased towards predatory or scavenging species, whilst herbivorous species or omnivorous species are attracted less. As insufficient replicates were deployed during this survey, the video footage collected may not be representative of an area, this study should be continued in future to allow for a quantitative assessments of fish and invertebrate assemblages and their habitat preferences.

The positive relationship detected between juvenile lobster abundance and the presence of complex habitats supports the concept that biotopes comprised of three-dimensional structures can act as essential habitats for demersal species during key life stages (Cacabelos *et al*., 2010). Although *H. gammarus* and its habitat preferences are relatively unstudied, these findings are consistent with those of Howard & Bennet (1979), and Bannister *et al*., (1994). The results of this study indicate that both juvenile lobsters and juvenile brown crab are likely to be restricted to coastal waters, where habitats are characterised by dense cover of kelp, macroalgae, or rock formations; these essential habitats act as nursery areas by providing suitable shelter and refuge from predators.

Marine habitats rarely have a definitive start and end point; more often gradational shifts in conditions are observed between different habitats. Therefore whilst structurally complex habitats are often associated with specific life processes a species will usually, throughout its life history, exploit a much broader range of biotopes within an ecosystem (Weins, 1989). In this study adult lobster *H. gammarus* and adult brown crab *C. pagurus*, which were recorded across a range of habitats within Baie ny Carrickey closed area. As individuals attain greater sizes, predation pressure decreases and movement increases, habitat associations diffuse (Hines *et al*., 1995). During this study, CPUE data from baited pots was used as a proxy for the abundance of species. Adult crustaceans may still be associated with complex habitats, although exploit a greater range when feeding. Future study recommendations would include the tagging of lobsters and crabs to further understand their movement patterns (Moland *et al*., 2015). The shallow distribution of commercial crustaceans in Baie ny Carrickey closed area makes them particularly vulnerable to overexploitation. An integrated ecosystem-based approach combined with conventional fisheries management is crucial for the long-term sustainable fishery of this species.

4.4 Fisheries management

The use of traps with escape panels has been shown to a highly effective fisheries management strategy in BNC closed area. Significantly fewer lobsters below MLS were caught in traps with escape panels, whilst the scientific pots without panels retained a high number of individuals. However, as individuals under the MLS were still found frequently in traps with escape panels, it is imperative to measure individuals on board before landing. Furthermore, the mean CPUE of lobsters equal to or above the MLS of 90 mm was found to be significantly greater in traps with escape panels than the scientific traps with no escape panels. This is concurrent with reports from local fishermen in Baie ny Carrickey, who have observed a higher number of lobsters equal to or above the MLS in parlour pots since the compulsory introduction of escape panels, as juvenile individuals are able to escape and create more room for larger individuals (pers. comm., G. Sutton). This study has built on the previous work of Murray *et al.* (2009), who also concluded that the fitting of escape panels to traps in the Isle of Man was effective in allowing undersized lobsters to escape. However, Murray and colleagues were unable to show differences in CPUE of lobsters above MLS between different pot types, including traps located at Port St. Mary, in Baie ny Carrickey. Whilst the number of lobster traps studied in the present study was much greater than Murray and likely to give a better estimation, more work should be undertaken to better understand the effectiveness of escape panels on the CPUE of individuals both above and below MLS.

Although not assessed during this study, it is most probable that the use of escape panels reduces the amount of damage sustained by juvenile lobsters. *H. gammarus* are highly territorial, and intraspecific aggression is commonly associated with claw damage or body damage, with the smaller juvenile lobsters more susceptible to harm when confined to traps

(Jørstad *et al*., 2001). Baited traps attract individuals of all sizes, and for traps without escape panels handling and sorting is necessary to discard individuals under MLS, which may additionally cause damage. Once returned in this way, a juvenile lobster may be vulnerable to predators whilst in search of suitable habitat providing refuge. Lobster traps with escape panels are therefore efficient in reducing sorting time, at reducing bycatch including juvenile individuals, and reducing damage sustained to individuals.

4.5 Potential benefits for scallops

Whilst the importance of an ecosystem based fisheries management approach in BNC has been emphasised for the commercial *H. gammarus* and *C. pagurus* fisheries, the continuation of the marine protected area may also present long-term benefits for the scallop fishery. The king scallop, *P. maximus*, and queen scallop, *A. opercularis*, are found on sands, gravels, and occasionally muddy sands or biogenic reefs, such as horse mussel *M. modiolus* beds (Thouzeau *et al*., 1991). The results of the habitat mapping survey indicates that only a small area within the BNC closed area is actually suitable for supporting adult scallop populations. Information from vessel monitoring systems shows a high level of fishing effort before the establishment of the closed area (White, 2011), which is more likely to reflect the close proximity of Port St. Mary harbour as opposed to high abundances of adult scallops in BNC. However, the habitats in BNC may be suitable to support high abundances of juvenile scallops which in future would improve recruitment to the adult population outside the closed area. It has been well studied that complex habitats provide favourable conditions for juvenile scallops, with three dimensional structures providing settlement substrates for spat and influencing rates of survival and predation (Beukers-Stewart & Beukers-Stewart, 2009). In particular, maerl beds, coarse substratum such as shells, macroalgae and seagrass patches act as nursery areas supporting high densities of demersal commercial species (Howarth *et al*., 2011). Also located on the Isle of Man, Port Erin marine protected area, for example, has quantified considerable benefits for adjacent scallop stocks since the establishment of a no-take area. By protecting benthic habitats as part of a larger ecosystem based approach to fisheries management, a significant increase in the biomass and size of *P. maximus* within the closure was found to enhance local fisheries from spillover effects (Beukers-Stewart *et al*., 2005). Conflicts between mobile gear and static gear fishers are well documented (Messieh *et al*., 1991); and an integration of marine spatial planning and fisheries management options could ensure the future sustainability survival of both the crustacean and scallop fisheries.

5.0 Conclusion

This study set out to provide baseline information on the habitats in Baie ny Carrickey closed area and relate different habitats to the distributions of the commercial species brown crab *C. pagurus* and European lobster *H. gammarus.* Two methodologies were used in creating habitat maps; a bottom-up approach identified fourteen different biotopes using multivariate statistical packages, whilst a top-down approach assigned eighteen biotopes in accordance with the Marine Habitat Classification for Britain and Ireland system.

Traditional fisheries management strategies in the Isle of Man have been shown to be very effective. Nonetheless, to continue their conservation commitments, recommendations are made that Baie ny Carrickey closed area should be maintained as part of a network of MPAs following the end of the scientific trial in 2016. This would contribute to the Isle of Man's First Biodiversity Strategy which aims to increase its current 3 % of protected coastal and marine waters to 10 % by 2020 (Charter & Brown, 2014). The importance of habitat dependence for juveniles of commercial species has been demonstrated. In Baie ny Carrickey both crabs and lobsters preferentially select structurally complex habitats, e.g. kelp dominated rocky reefs, until they attain greater sizes whereupon they exhibited no habitat preferences in this study. The distribution of these essential habitats is predominantly coastal, leaving juveniles vulnerable to overfishing without the integration of an ecosystem-based fisheries approach. The continuation of the closed area may also benefit the adjacent scallop fishery, as previous studies have indicated that complex habitats act as nursery areas for juvenile scallops, contain high numbers of older individuals that are fecund and can contribute significantly to spat production (Howarth *et al*., 2011). Further study is recommended to monitor the rate of recovery in benthic habitats and to monitor the effectiveness of an integrated ecosystem-based approach for maintaining and further enhancing the crustacean fisheries in Baie ny Carrickey closed area.

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Appendices

Appendix I

Species list for taxa observed during the drop down camera surveys in Baie ny Carrickey closed area

Latin Name	Common Name	Family Name	Phylum
Alcyonidium diaphanum	Sea Chervil	Alcyonidiidae	Bryozoa
Alcyonium digitatum	Dead Man's Fingers	Alcyoniidae	Cnidaria
Aplidium punctum		Polyclinidae	Chordata
Chorda filum	Dead Man's Rope	Chordaceae	Orchrophyta
Chondrus crispus	Irish Moss	Gigartinaceae	Rhodophyta
Cladophora spp.	Rockweed	Cladophoraceae	Chlorophyta
Clavelina lepadiformis	Pin-head squirt	Clavelinidae	Chordata
Cliona celata	Boring Sponge	Clionaidae	Porifera
Cystoseira spp.		Cystoseiraceae	Ochrophyta
Delesseria sanguinea	Sea Beech	Delesseriaceae	Rhodophyta
Desmarestia aculeata		Desmarestiaceae	Ochrophyta
Dictyopteris polypodioides		Dictyotaceae	Ochrophyta
Dictyota dichotoma	Forkweed	Dictyotaceae	Ochrophyta
Dilsea carnosa	Red Rags		Rhodophyta
Echinus esculentus	Edible Sea-urchin	Echinidae	Echinodermata
	Filamentous red		Rhodophyta
	Filamentous brown		Ochrophyta
Flustra foliacea	Hornwrack	Flustridae	Bryozoa
	Foliose red		Rhodophyta
Fucus serratus	Toothed Wrack	Fucaceae	Ochrophyta
Gibbula spp.		Trochidae	Mollusca
Grantia compressa	Purse Sponge	Grantiidae	Porifera
Halecium halecinum	Herringbone Hydroid	Haleciidae	Cnidaria
Halidrys siliquosa	Sea Oak	Cystoseiraceae	Ochrophyta
Hemimycale columella	Crater Sponge	Hymedesmiidae	Porifera
Henricia spp.		Echinasteridae	Echinodermata
Hildenbrandia spp	Dark Encrusting Red	Hildenbrandiaceae	Rhodophyta

Appendix I continued

Latin Name	**Common Name**	**Family Name**	**Phylum**
Laminaria digitata	Oarweed	Laminariaceae	Ochrophyta
Laminaria hyperborea	Tangle	Laminarinceae	Ochrophyta
Leucosolenia spp.	Orange Pipe Sponge	Leucosoleniidae	Porifera
Lithothamnion glaciale	Maerl	Hapalidiaceae	Rhodophyta
Littorina obtusata	Flat Periwinkle	Littorinidae	Mollusca
Mastocarpus stellatus	False Irish Moss	Phyllophoraceae	Rhodophyta
Membranoptera alata	Sea Mat	Delesseriaceae	Rhodophyta
Mesogloia vermiculata		Chordariaceae	Ochrophyta
Nemertesia antennina	Sea Beard	Plumulariodea	Cnidaria
Nemertesia ramosa	Hydroid	Plumulariidae	Cnidaria
Pachymatisma johnstonia		Geodiidae	Porifera
Palmaria palmata	Dulse	Palmariaceae	Rhodophyta
Petalonia fascia		Scytosiphonaceae	Ochrophyta
Phorbas fictitus		Hymedesmiidae	Porifera
Phycodrys rubens		Delesseriaceae	Rhodophyta
Porifera spp.			Porifera
Polymastia boletiformis		Polymastiidae	Porifera
Saccharina latissima	Sugar Kelp	Laminariaceae	Ochrophyta
Saccorhiza polyschides	Furbelows	Phyllariaceae	Ochrophyta
Scyliorhinus canicula	Lesser Spotted Dogfish	Scyliorhinidae	Chordata
Spirobranchus spp.		Serpulidae	Annelida
Suberites ficus	Fig Sponge	Suberitidae	Porifera
Sycon ciliatum	Ciliated Sponge	Sycettidae	Porifera
Taonia atomaria		Dictyotaceae	Orchrophyta
Tethya aurantium	Golf Ball Sponge	Tethyidae	Porifera
Ulva spp.	Sea Lettuce, Gutweed	Ulvaceae	Chlorophyta

Appendix II

Species list for taxa observed during the BRUV survey in Baie ny Carrickey closed area

Latin Name	Common Name	Family Name	Phylum
Belone belone	Garfish	Belonidae	Chordata
Cancer pagurus	Brown Crab	Cancridae	Arthropoda
Centrolabrus exoletus	Rockcook Wrasse	Labridae	Chordata
Ctenolabrus rupestris	Goldsinny Wrasse	Labridae	Chordata
Eledone cirrhosa	Curled Octopus	Octopodidae	Mollusca
Gobiusculus flavescens	2 Spotted Goby	Gobiidae	Chordata
Labrus bergylta	Ballan Wrasse	Labridae	Chordata
Labrus mixtus	Cuckoo Wrasse	Labridae	Chordata
Lipcarcinus depurator	Harbour Crab	Polybiidae	Arthropoda
Maja squinado	Spidercrab	Majidae	Arthropoda
Marthasterias glacialis	Spiny Starfish	Asteriidae	Echinodermata
Mugil cephulus	Grey Mullet	Mugilidae	Chordata
Necora puber	Velvet Swimming Crab	Polybiidae	Arthropoda
Pagurus bernhardus	Hermit Crab	Paguridae	Arthropoda
Palaemon serratus	Common Prawn	Palaemonidae	Arthropoda
Pollachius pollachius	Pollack	Gadidae	Chordata
Pomatoschistus microps	Common Goby	Gobiidae	Chordata
Pomatoschitus minutus	Sand Goby	Gobiidae	Chordata
Scyllium canicula	Lesser Spotted Dogfish	Scyliorhinidae	Chordata
Trisopterus minutus	Poor Cod	Gadidae	Chordata
	Brittlestar	Ophiuridae	Echinodermata

Appendix III

Species list for bycatch recorded in fishermen's logbooks from prawn pots, fishing pots and scientific pots monitored in Baie ny Carrickey closed area

Latin Name	Common Name	Family Name	Phylum
Buccinum undatum	Common Whelk	Buccinidae	Mollusca
Carcinus maenas	Green Crab	Portunidae	Arthropoda
Eledone cirrhosa	Curled Octopus	Octopodidae	Mollusca
Gadus morhua	Atlantic Cod	Gadidae	Chordata
Gaidropsarus vulgaris	Rockling	Lotidae	Chordata
Galathea dispersa	Squat Lobster	Galatheidae	Arthropoda
Labrus	Wrasse	Labridae	Chordata
Labrus bergylta	Ballan Wrasse	Labridae	Chordata
Maja squinado	Spider Crab	Majidae	Arthropoda
Necora puber	Velvet Swimming Crab	Polybiidae	Arthropoda
Palaemon spp	Prawn	Palaemonidae	Chordata
Pollachius pollachius	Pollack	Gadidae	Chordata
Pollachius virens	Saithe	Gadidae	Chordata
Scyliorhinus canicula	Dogfish	Scyliorhinidae	Chordata
Zeugapterus punctatus	Topknot	Scophthalmidae	Chordata

Appendix IV

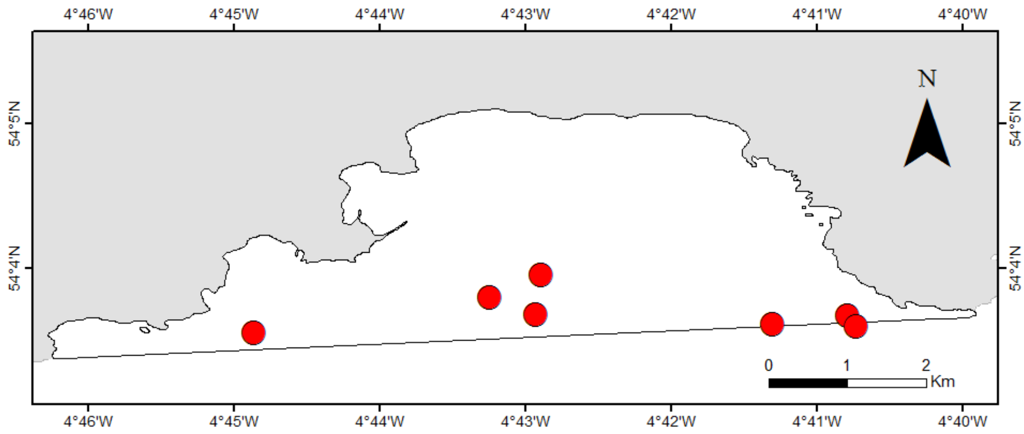
Representative examples of the eighteen biotopes classified using the Marine Habitat Classification for Britain and Ireland in Baie ny Carrickey

Marine Habitat Classification Scheme for Britain and Ireland

Biotope code: CR.HCR.Xfa.ByErSp

Biotope description: Bryozoan turf and erect sponges on tide-swept circalittoral rock**.**

Biological zone:	Circalittoral – lower
	Circalittoral – upper
Depth ranges:	10 – 20m, 20 – 30m
Wave exposure:	Extremely exposed to moderately exposed
Current exposure:	Strong to moderately strong



Description of community assemblages in Baie ny Carrickey:

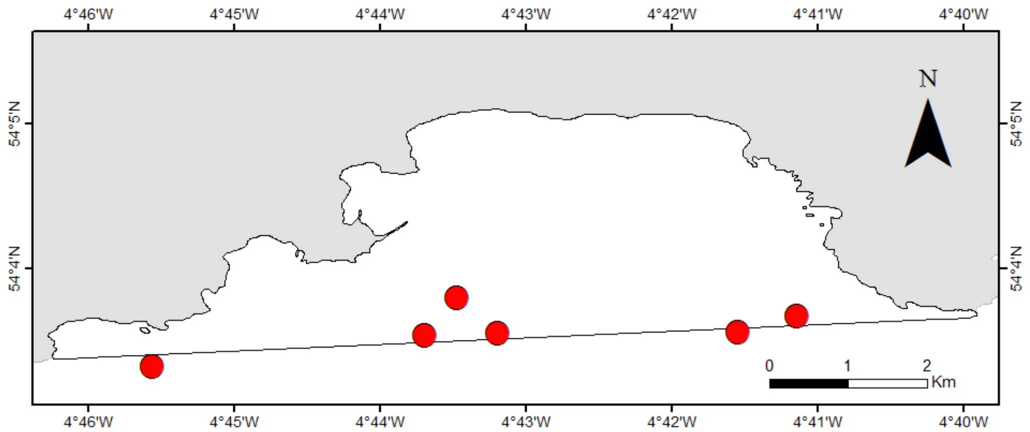
Biotopes occurred on bedrock. Abundant species *Echinus esculentus, Nemertsia antennina* and *Tethya aurantium*. *Alcyonium digitatum* and bryozoan turf was common. All biotopes present in the circalittoral zone

Marine Habitat Classification Scheme for Britain and Ireland

Biotope code: CR.HCR.Xfa.SpNemAdia

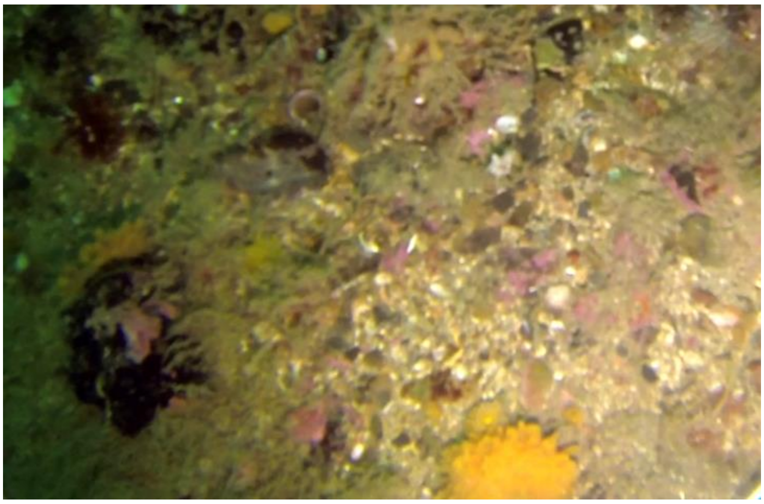
Biotope description: Sparse sponges, *Nemertesia* spp. and *Alcyonidium diaphanum* on circalittoral mixed substrata.

Biological zone:	Circalittoral
Depth ranges:	10 – 20m, 20 – 30m
Wave exposure:	Moderately exposed
Current exposure:	Moderately strong



Description of community assemblages in Baie ny Carrickey:

This community was observed on boulders, cobbles and pebbles in the circalittoral. *Nemertesia antennina*, *Clavelina lepadiformis* and mixed hydroid and bryozoan turf were found in patches. Sparse sponges also observed

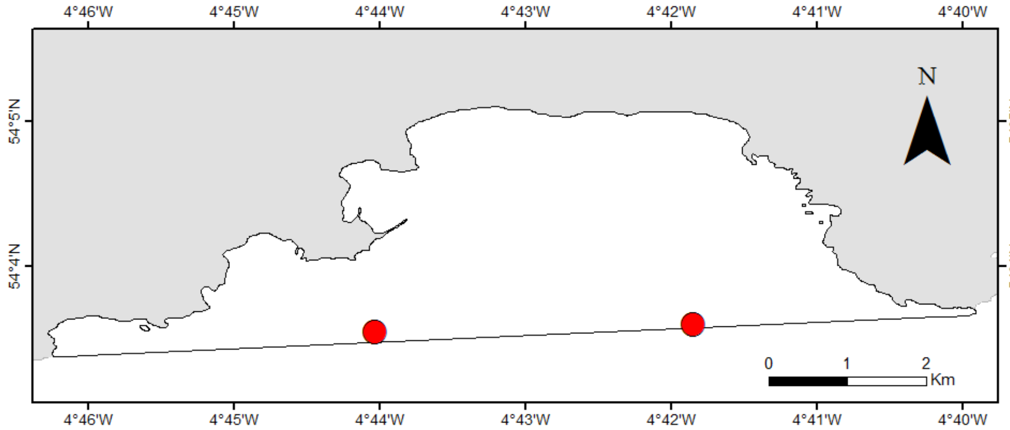


Marine Habitat Classification Scheme for Britain and Ireland

Biotope code: CR.MCR.EcCr.FaAlCr

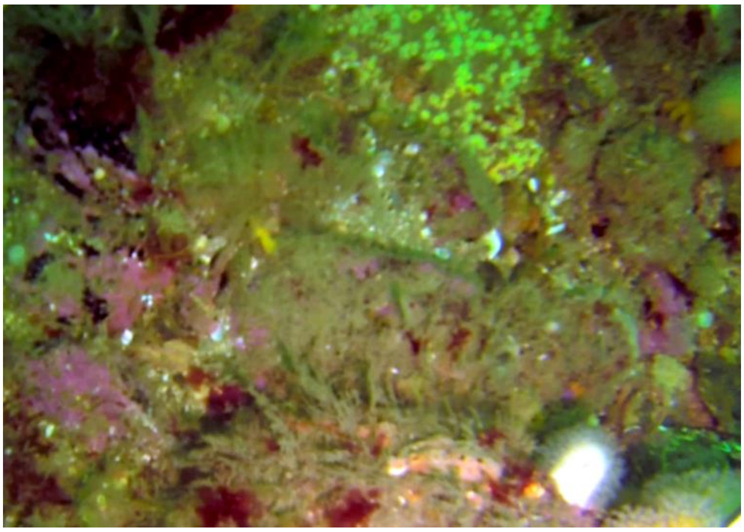
Biotope description: Faunal and algal crusts on exposed to moderately wave-exposed circalittoral rock.

Biological zone:	Circalittoral
Depth ranges:	10 – 20m, 20 – 30m, 30 – 50m
Wave exposure:	Exposed to moderately exposed
Current exposure:	Moderately strong to very weak



Description of community assemblages in Baie ny Carrickey:

Biotope observed at two sites on cobbles and boulders. *Alcyonium digitatum*, Corallinaceae and sponges were abundant

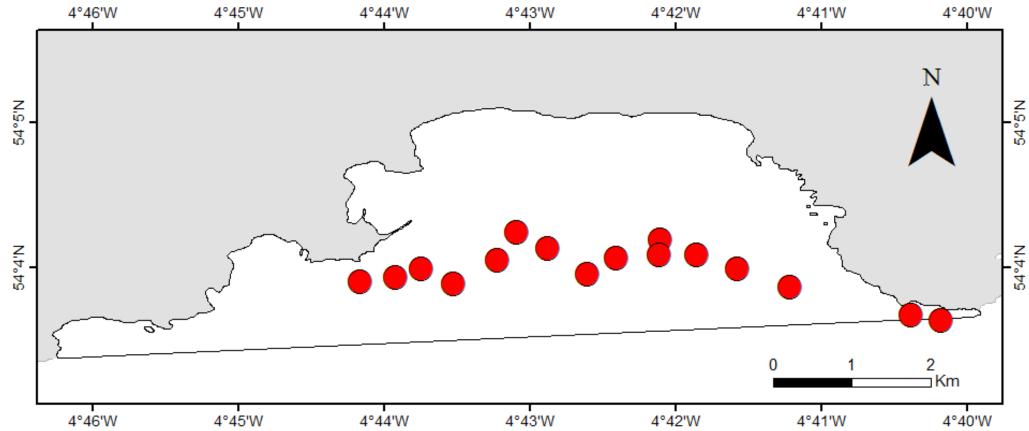


Marine Habitat Classification Scheme for Britain and Ireland

Biotope code: IR.HIR.KFar.FoR

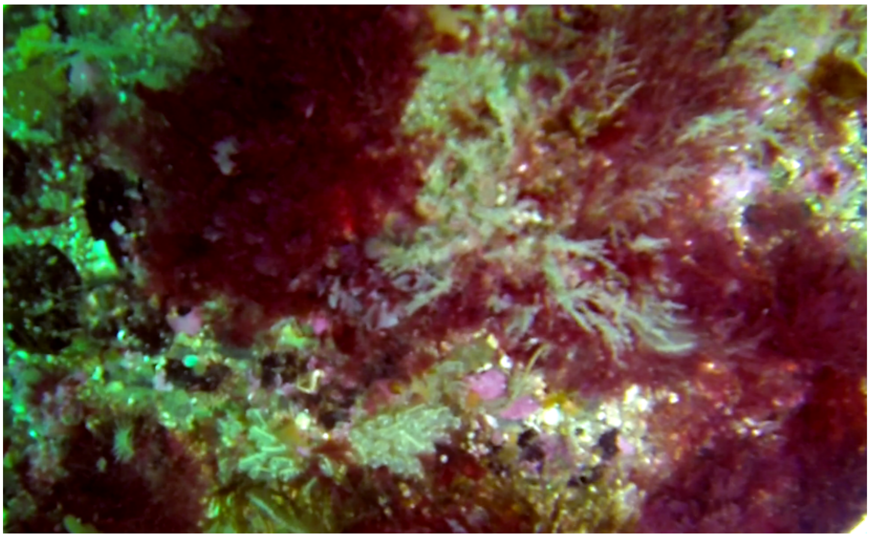
Biotope description: Foliose red seaweeds on exposed lower infralittoral rock.

Biological zone:	Infralittoral - lower
Depth ranges:	5 – 10m, 10 – 20m, 20 – 30m
Wave exposure:	Very exposed to moderately exposed
Current exposure:	Moderately strong to weak



Description of community assemblages in Baie ny Carrickey:

Frequently observed biotope in the infralittoral zone. Foliose and filamentous red algae, Corallinaceae, *Delesseria sanguinea* and the ascidian *Clavelina lepadiformis* were common

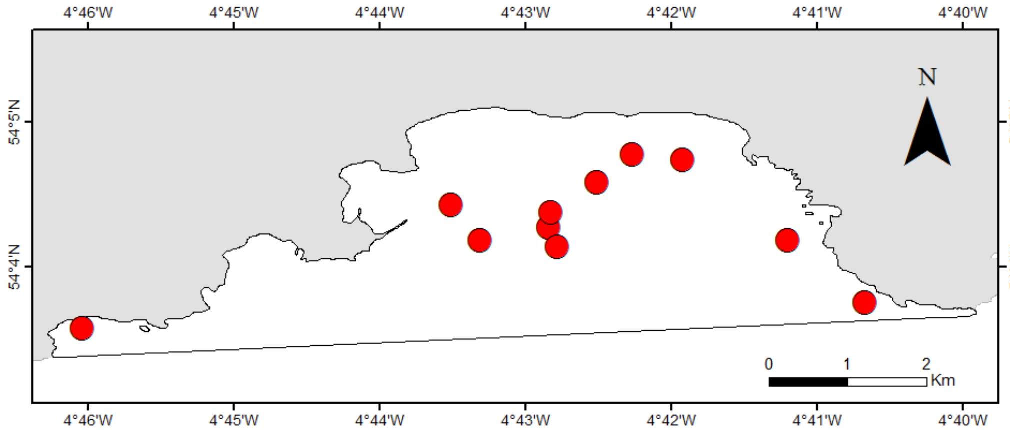


Marine Habitat Classification Scheme for Britain and Ireland

Biotope code: IR.HIR.KFaR.LhypR

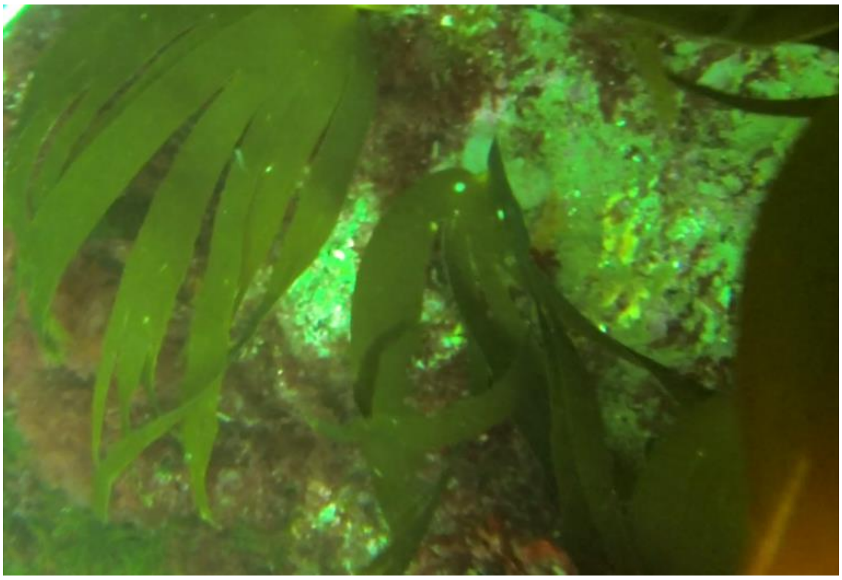
Biotope description: *Laminaria hyperborea* with dense foliose red seaweeds on exposed infralittoral rock.

Biological zone:	Infralittoral
Depth ranges:	0 – 5m, 5 – 10m, 10 – 20m, 20 – 30m
Wave exposure:	Extremely exposed to exposed
Current exposure:	Strong to very weak



Description of community assemblages in Baie ny Carrickey:

Biotopes were found on infralittoral exposed rock. Communities were dominated by Laminaria hyperborea, with dense foliose algae, including Delesseria sanguinea and Dictyota dichotoma found beneath

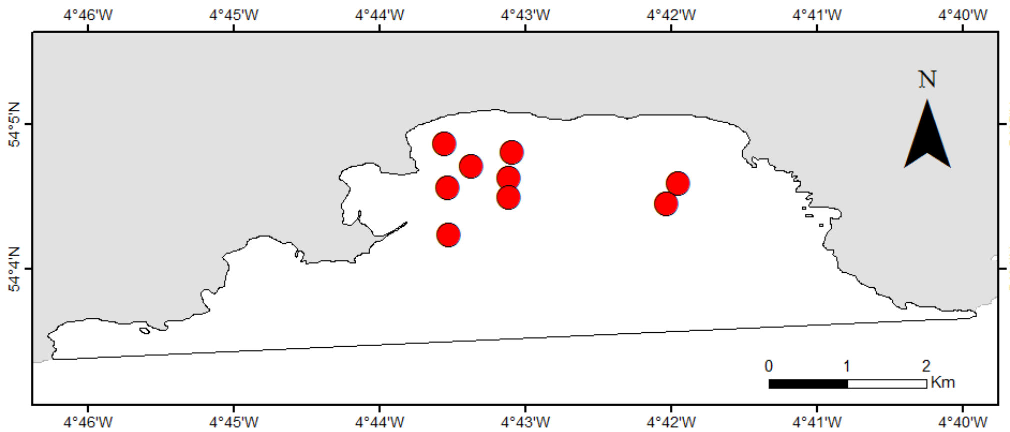


Marine Habitat Classification Scheme for Britain and Ireland

Biotope code: IR.HIR.K.Sed.LsacSac

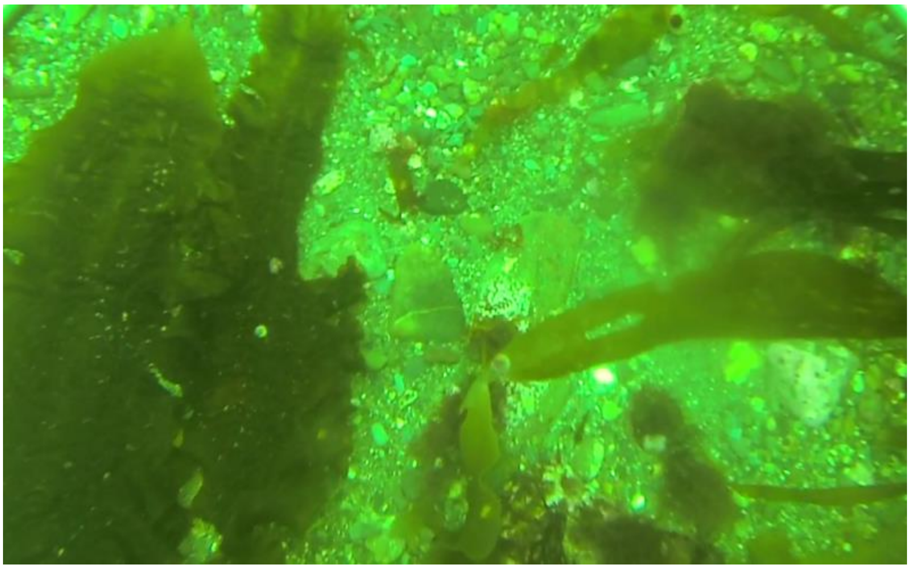
Biotope description: *Laminaria saccharina* and/or *Saccorhiza polyschides* on exposed infralittoral rock

Biological zone:	Infralittoral
Depth ranges:	0 – 5m, 5 – 10m, 10 – 20m, 20 – 30m
Wave exposure:	Very exposed to moderately exposed
Current exposure:	Moderately strong to weak



Description of community assemblages in Baie ny Carrickey:

Substratum varied considerably from pebbles to bedrock. *Saccharina latissimia* and *Sacchoriza polyschides* were dominant. *Desmarestua aculeata* and *Gibbula* spp. were frequently observed

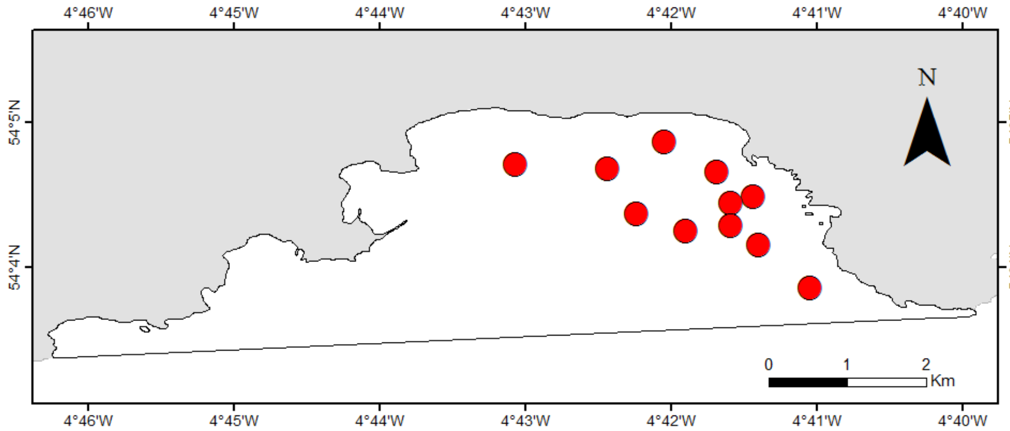


Marine Habitat Classification Scheme for Britain and Ireland

Biotope code: IR.HIR.KSed.XKScrR

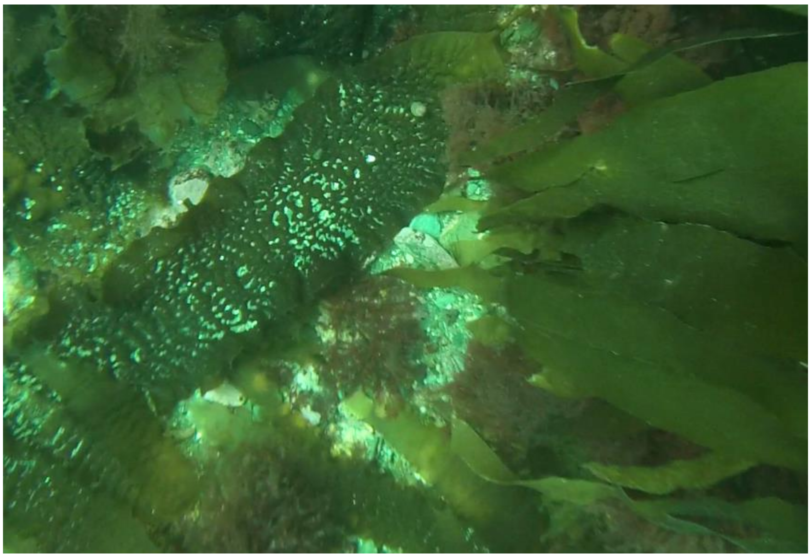
Biotope description: Mixed kelps with scour-tolerant and opportunistic foliose red seaweeds on scoured or sand-covered infralittoral rock.

Biological zone:	Infralittoral
Depth ranges:	0 – 5m, 5 – 10m, 10 – 20m
Wave exposure:	Exposed to moderately exposed
Current exposure:	Moderately strong to weak



Description of community assemblages in Baie ny Carrickey:

Biotopes were characterised *by Laminaria hyperborea, Saccharina latissima* and *Sacchoriza polyschides,* on sand scoured cobbles boulders and bedrock. Foliose red algae were abundant

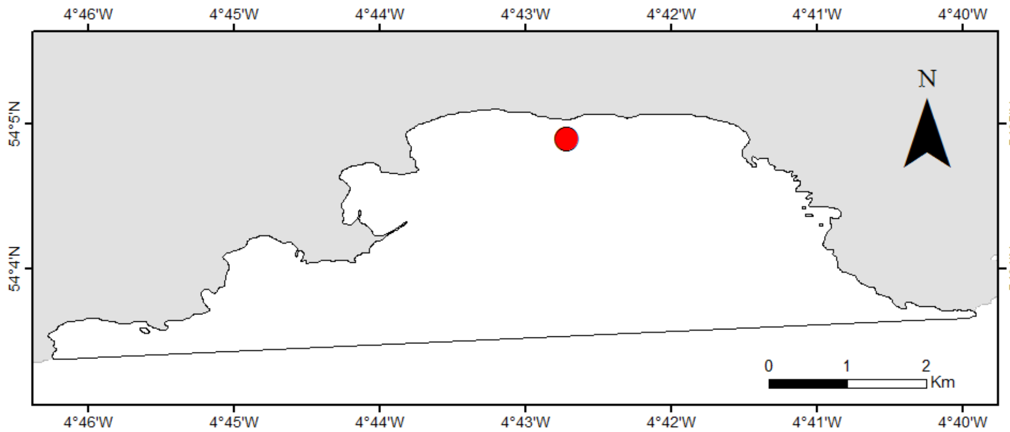


Marine Habitat Classification Scheme for Britain and Ireland

Biotope code: IR.LIR.K.Sar

Biotope description: *Sargassum muticum* on shallow slightly tide-swept infralittoral mixed substrata.

Biological zone:	Infralittoral – upper Sublittoral fringe
Depth ranges:	0 – 5m
Wave exposure:	Sheltered to extremely sheltered
Current exposure:	Moderately strong



Description of community assemblages in Baie ny Carrickey:

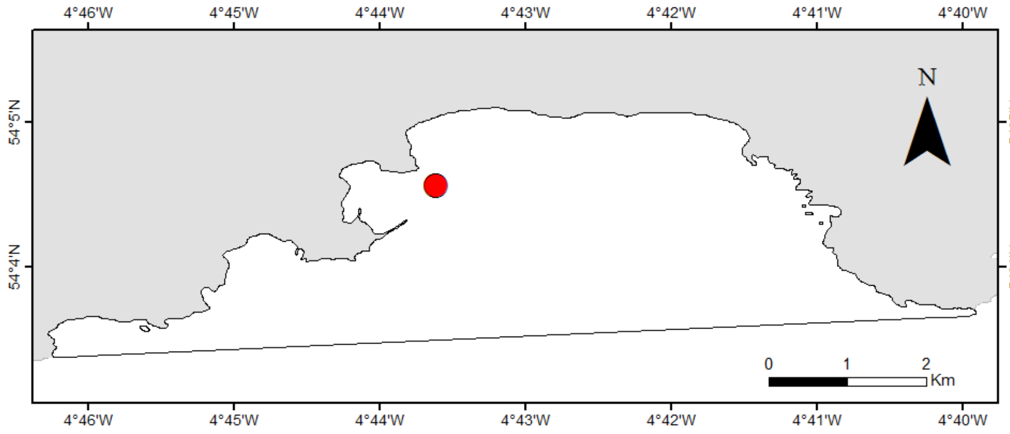
Sargassum muticum dominated communities, located in the sheltered, shallow infralittoral zone. *Ulva* spp., *Cystoseir*a spp and filamentous red algae were also present

Marine Habitat Classification Scheme for Britain and Ireland

Biotope code: IR.MIR.KR.Ldig.

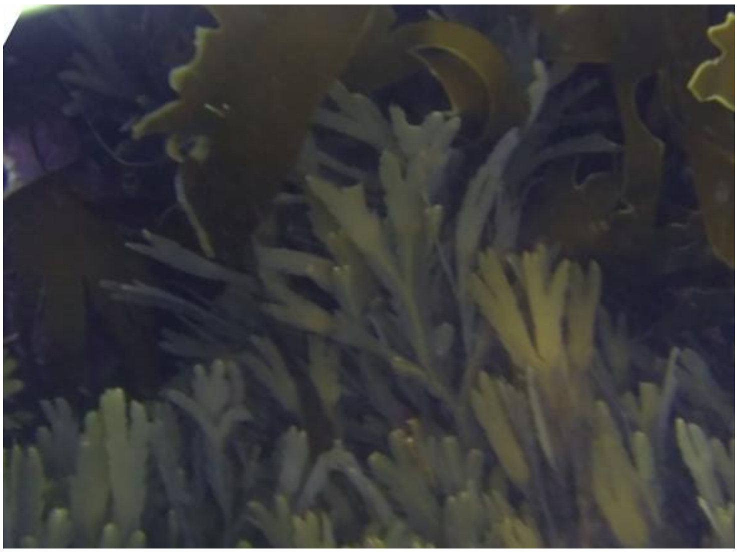
Biotope description: *Laminaria digitata* on moderately exposed sublittoral fringe bedrock.

Biological zone:	Sublittoral fringe
Depth ranges:	0 - 5m, lower shore
Wave exposure:	Exposed to sheltered
Current exposure:	Moderately strong to very weak



Description of community assemblages in Baie ny Carrickey:

Biotope community dominated by Fucus serratus, Laminaria digitate and Palmaria palmata on Corallinaceae encrusted bedrock. Found close to the sublittoral fringe.

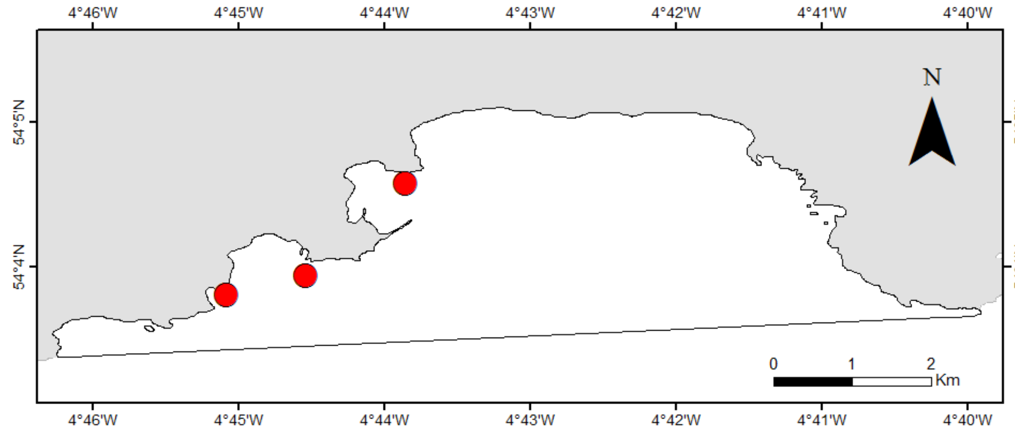


Marine Habitat Classification Scheme for Britain and Ireland

Biotope code: IR.MIR.KR.Lhyp

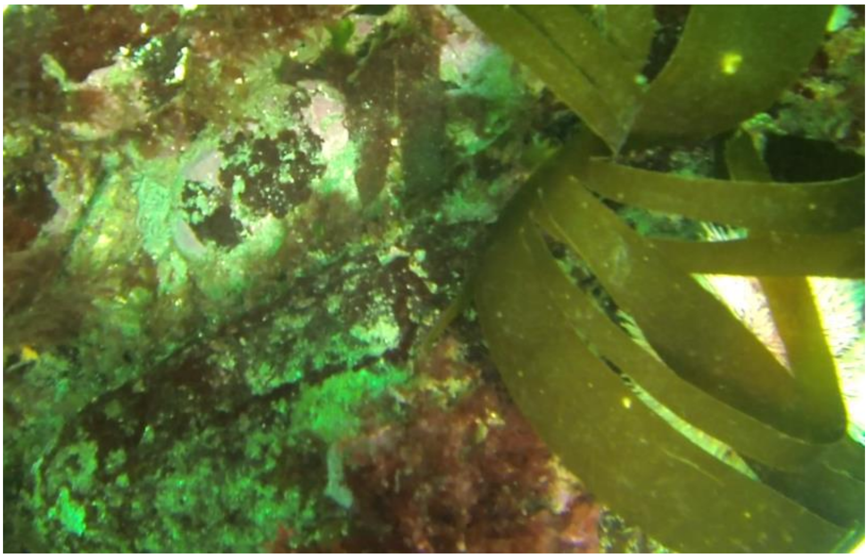
Biotope description: *Laminaria hyperborea* and foliose red seaweeds on moderately exposed infralittoral rock.

Biological zone:	Infralittoral
Depth ranges:	0 – 5m, 5 – 10m, 10 – 20m
Wave exposure:	Moderately exposed
Current exposure:	Strong to weak



Description of community assemblages in Baie ny Carrickey:

Occurring on moderately exposed infralittoral rock and boulders, this biotope was characterised by the kelp *Laminaria hyperborea*, with dense foliose seaweed found under the canopy. The sea urchin *Echinus esculentus* and snail *Gibbula* spp. were present

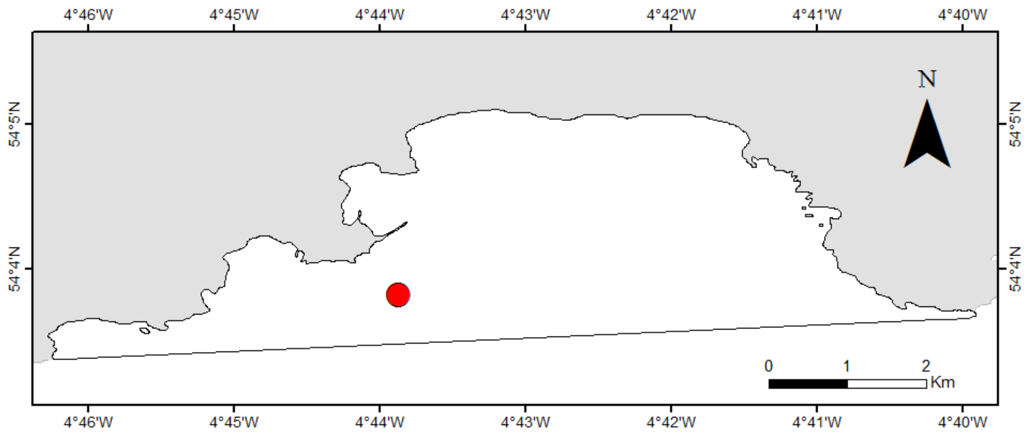


Marine Habitat Classification Scheme for Britain and Ireland

Biotope code: IR.MIR.KR.LhypTX

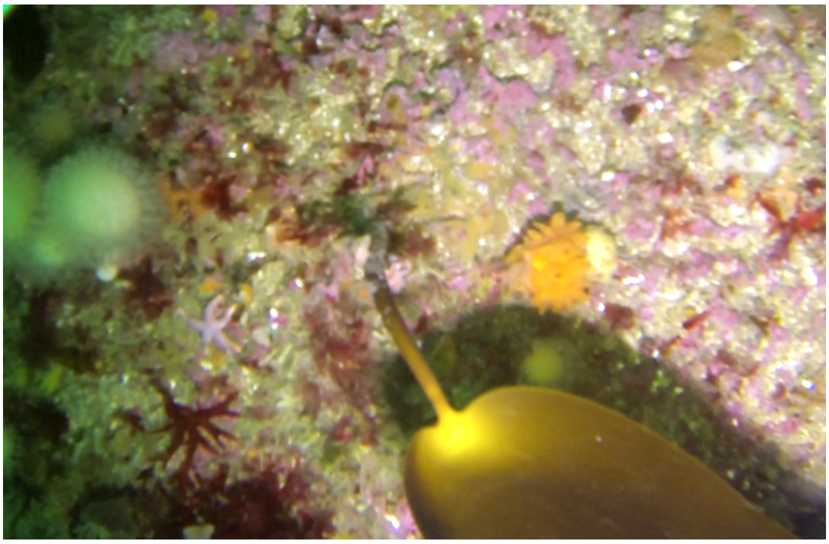
Biotope description: *Laminaria hyperborea* on tide-swept infralittoral mixed substrata.

Biological zone:	Infralittoral
Depth ranges:	0 – 5m, 5 – 10m, 10 – 20m, 20 – 30m
Wave exposure:	Exposed to sheltered
Current exposure:	Strong to weak



Description of community assemblages in Baie ny Carrickey:

Biotope observed at a single location. *Laminaria hyperborea* was observed on bedrock encrusted in Corallinaceae. *Alcyonium digitatum*, foliose red algae, *Henricia* spp. and *Clavelina lepadiformis* were present

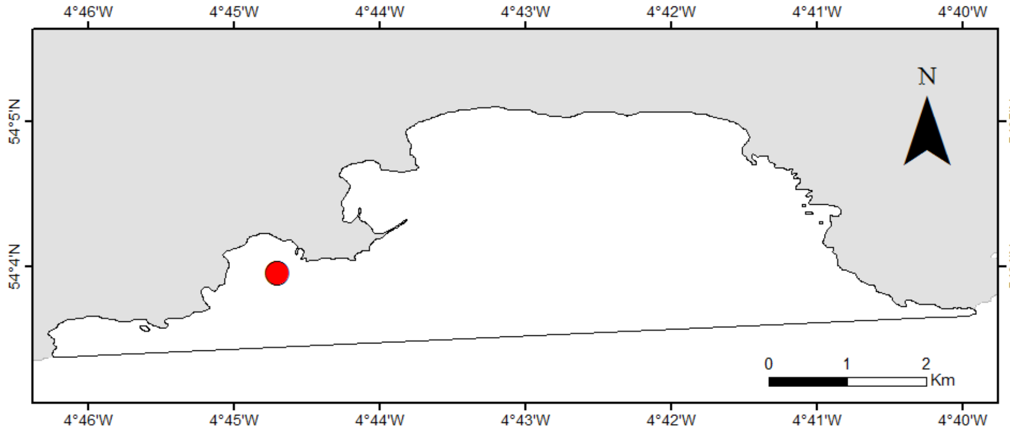


Marine Habitat Classification Scheme for Britain and Ireland

Biotope code: IR.MIR.KT.XKT

Biotope description: Mixed kelp with foliose red seaweeds, sponges and ascidians on sheltered tide-swept infralittoral rock.

Biological zone:	Infralittoral
Depth ranges:	0 – 5m, 5 – 10m
Wave exposure:	Sheltered to extremely sheltered
Current exposure:	Very strong to moderately strong



Description of community assemblages in Baie ny Carrickey:

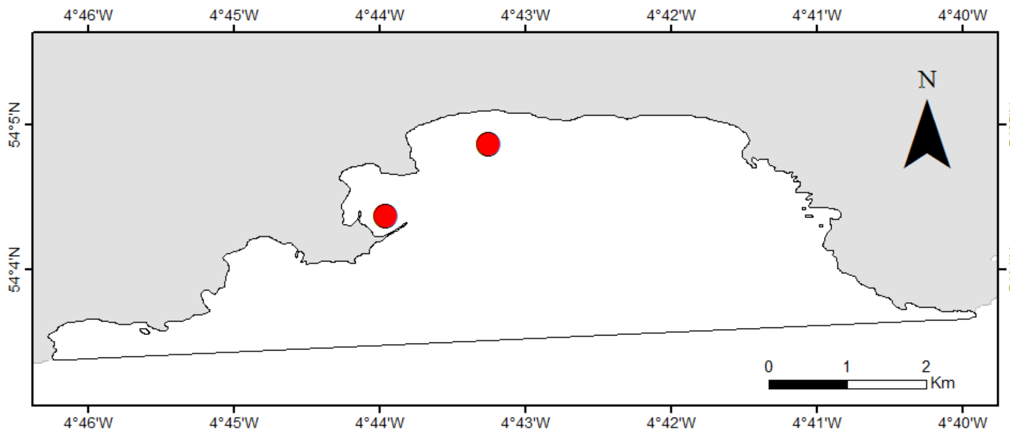
The mixed substratum was comprised of rock, pebbles and sand. *Laminaria hyperborea* and *Saccharina latissima* were observed on rocky outcrops, with *Dictyota dichotoma* and *Halidrys siliquosa* occurring in greater abundances.

Marine Habitat Classification Scheme for Britain and Ireland

Biotope code: SS.SMp.KSwSS.LsacR

Biotope description*:* *Laminaria saccharina* and red seaweeds on infralittoral sediments**.**

Biological zone:	Infralittoral
Depth ranges:	0 – 5m, 5 – 10m, 10 – 20m
Wave exposure:	Exposed to very sheltered
Current exposure:	Moderately strong to very weak



Description of community assemblages in Baie ny Carrickey:

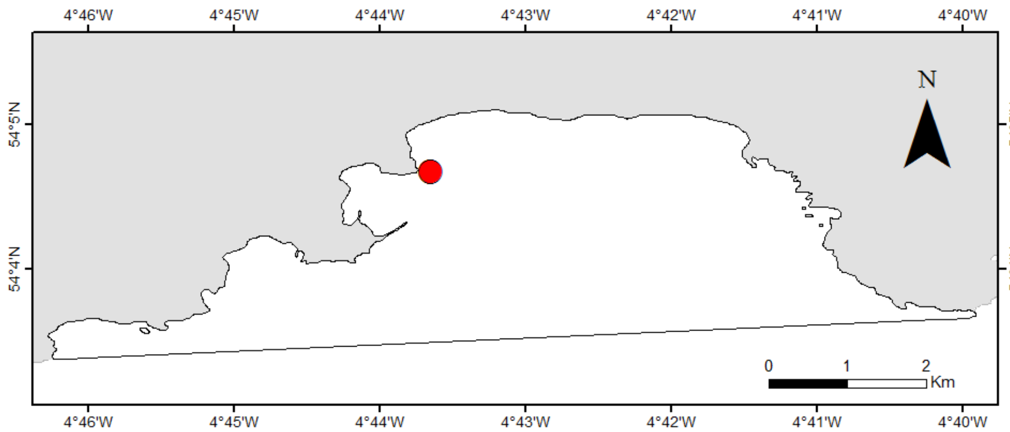
Found in shallow infralittoral sites, communities were characterised by *Saccharina latissima* (formerly *Laminaria saccharina*). Ulva spp., Gibbula spp. and filamentous red algae were also observed. Substratum was mixed, comprising of sand and pebbles

Marine Habitat Classification Scheme for Britain and Ireland

Biotope code: SS.SMp.SSgr.Zmar

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

Biological zone:	Infralittoral
Depth ranges:	0 - 5m, 5 – 10m, lower shore
Wave exposure:	Moderately exposed to extremely sheltered
Current exposure:	Moderately strong to very weak



Description of community assemblages in Baie ny Carrickey:

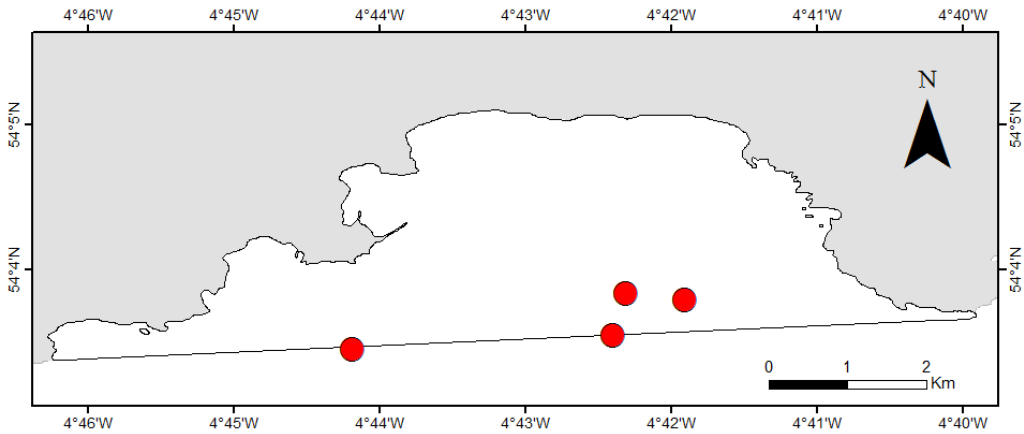
The community was dominated by *Zostera marina* and found on mixed pebbles and sand. Foliose red algae and *Ectocarpus* agg. were also found in low abundances. *Fucus serratus* was also observed in one replicate, marking the edge of the littoral zone.

Marine Habitat Classification Scheme for Britain and Ireland

Biotope code: SS.SMx.CMx.FluHyd

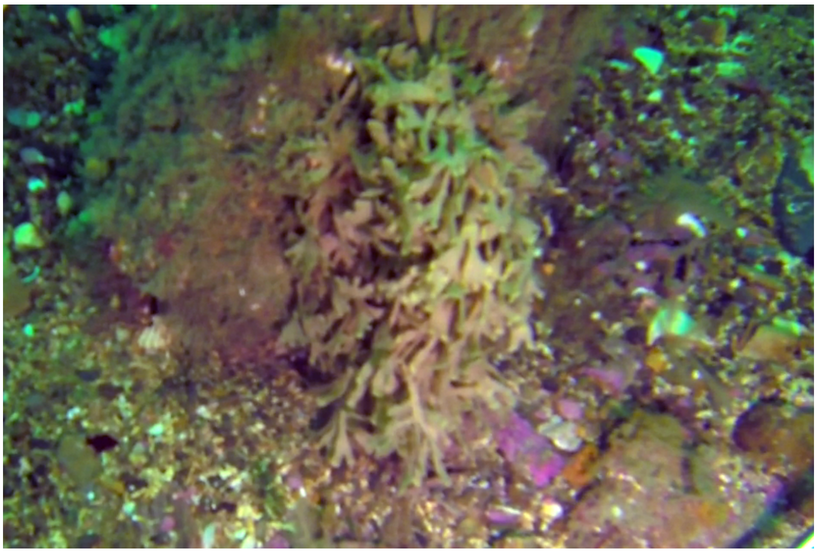
Biotope description: *Flustra foliacea* and *Hydrallmania falcata* on tide-swept circalittoral mixed sediment.

Biological zone:	Circalittoral
Depth ranges:	5 – 10m, 10 – 20m, 20 – 30m, 30 – 50m
Wave exposure:	Exposed to moderately exposed
Current exposure:	Strong to moderately strong



Description of community assemblages in Baie ny Carrickey:

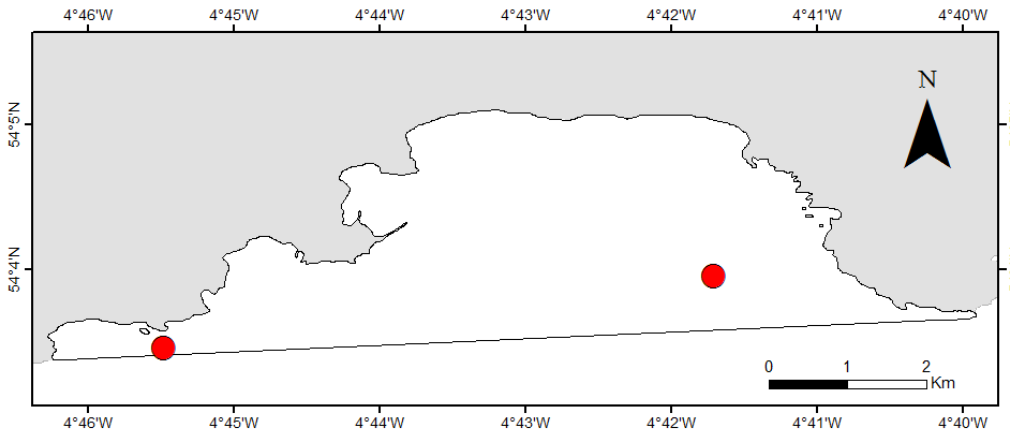
The bryozoan *Flustra foliacea* characterised circalittoral sites on mixed sediment composed of boulders, cobbles and pebbles. *Alcyonium digitatum* and calcareous tube-building polychaetes were observed infrequently



Marine Habitat Classification Scheme for Britain and Ireland
Biotope code: SS.SMx.CMx.OphMx

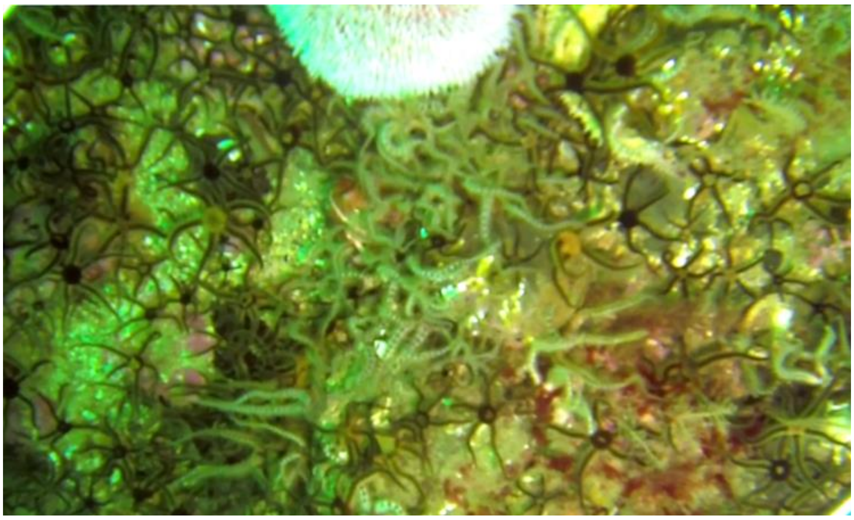
Biotope description: *Ophiothrix fragilis* and/or *Ophiocomina nigra* brittlestar beds on sublittoral mixed sediment.

Biological zone:	Circalittoral
Depth ranges:	5 - 10m, 10 – 20m, 20 – 30m, 30 – 50m
Wave exposure:	Moderately exposed to sheltered
Current exposure:	Strong to weak



Description of community assemblages in Baie ny Carrickey:

Observed at two locations, this biotope was dominated by *Ophiothrix fragilis* and O*phiocomina nigra* on pebble and cobble sediments. The sea urchin *Echinus esculentus*, the common starfish *Asterias rubens* were additionally present

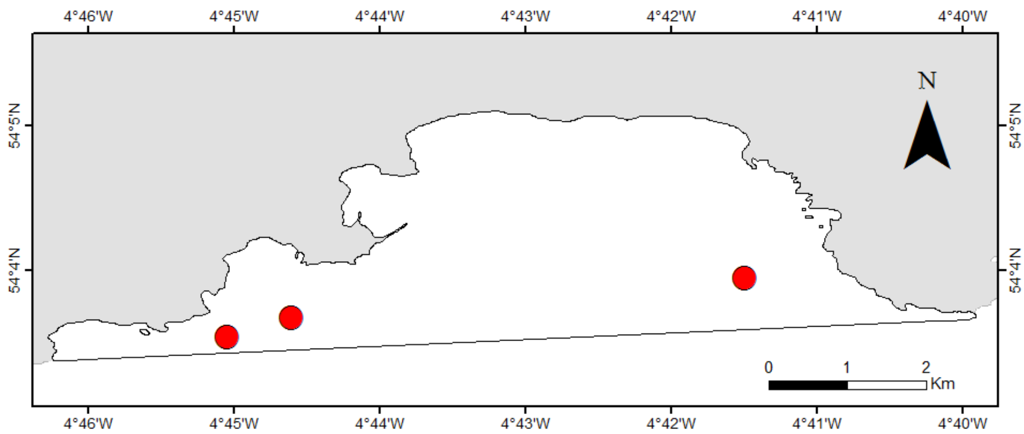


Marine Habitat Classification Scheme for Britain and Ireland

Biotope code: SS.SMx.CMx

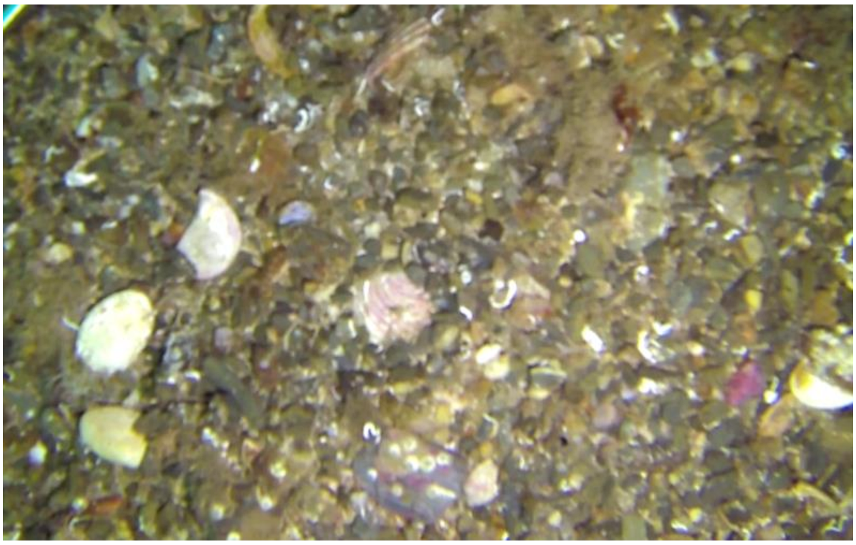
Biotope description: Circalittoral mixed sediment**.**

Biological zone:	Circalittoral
Depth ranges:	5 – 10m, 10 – 20m, 20 – 30m, 30 – 50m
Wave exposure:	Moderately exposed to very sheltered
Current exposure:	Moderately strong to very weak



Description of community assemblages in Baie ny Carrickey:

Mixed sediments containing shells and stones were found at these sites in the circalittoral zone. Biotopes could not be assigned Level 5 biotopes due to the absence of any characterising benthic fauna or flora. Bryozoan turf, Corallinaceae and tube-building polychaetes were observed in low densities.

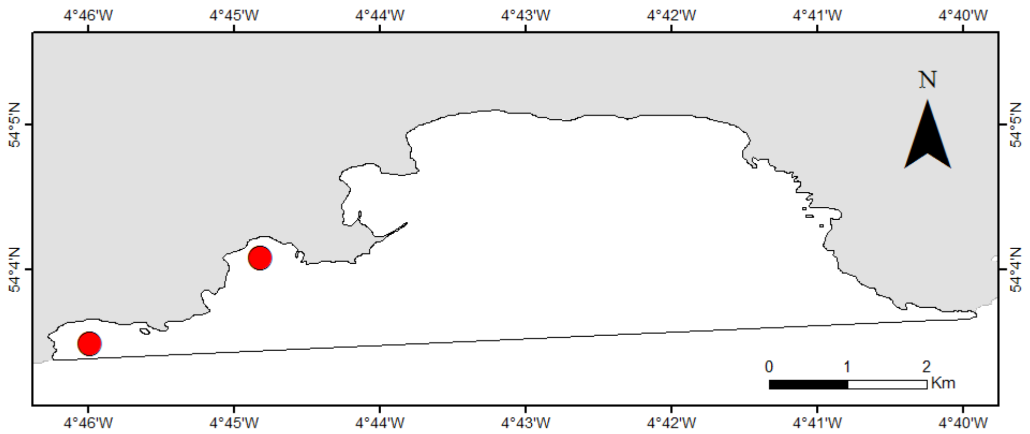


Marine Habitat Classification Scheme for Britain and Ireland

Biotope code: SS.Ssa.IFiSa

Biotope description: Infralittoral fine sand.

Biological zone:	Infralittoral
Depth ranges:	0 – 5m, 5 – 10m, 10 – 20m
Wave exposure:	Exposed to sheltered
Current exposure:	Strong to very weak



Description of community assemblages in Baie ny Carrickey:

Biotopes could not be classified to Level 5 due to any absence of taxa. There was some evidence of bioturbation fauna.