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Assessing the association between scallops, *Pecten Maximus*, and the benthic ecosystem within the Isle of Man marine reserves

A thesis submitted in partial fulfilment of the requirements for the degree of Master of Science (MSc) in Marine Environmental Protection.

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Abstract

The increased threat to the world's marine environment has forced the use of management strategies that encourage resource sustainability like spatial closure and stock replenishment. The success of these strategies are evaluated by assessing the ecosystem health and stock densities, using benthic surveys. This paper aims to investigate king scallop (P*ectin maximus*) population and its associated habitats within Niarbyl Bay (western coast) and Laxey Bay (eastern coast) in the Isle of Man; in order to provide information to the Manx government to help with future management decisions. In June 2016, these reserves were surveyed using video sledge and baited remote underwater video in order to obtain high resolution footage of the seafloor. This data was used to generate biotope maps (top-down and bottom-up approach) with superimposed *P.maximus* densities. This survey found that Laxey Bay encompassed three substrates (sandy, maerl and seagrass), with maerl beds supporting the greatest diversity (2.3-2.9) and a *P.maximus* population. *P.maximus* densities ($0.02m^{-2}$) remained constant over the years, despite reseeding and protection, suggesting that scallops have reached the reserves carrying capacity. The 2009 reseeding was deemed unsuccessful, as stocks did not adhere to the economically viable criteria. It was recommended that Laxey Bay's southern region, encompassing maerl and seagrass, remained closed due to conservation requirements. Niarbyl Bay had a diverse range of habitats including brittlestar beds and a nursery ground. The *P.maximus* in Niarbyl Bay were recorded in a variety of habitats, however the overall density fluctuated yearly. Juveniles (<60mm) were recorded in rocky terrain on the south inshore region of Niarbyl Bay, which was not known for juvenile settlement. Reseeding was also deemed unsuccessful as a stock replenishment agent but it was suspected to benefit recruitment success. It was recommended that Niarbyl Bay remained closed, especially in the southern region as encompasses a nursery ground.

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Glossary of Terms

BRUV – Baited Remote Underwater Video system

DEFA – Department of Environment, Food and Agriculture.

EBM - Ecosystem-based management

IOM – Isle of Man

MLS – Minimum landing size

MPA – marine protected areas

1 Introduction

The world's marine resources and biodiversity are under increasing pressure due to the rise in anthropogenic activities (ie. mining, pollution, commercial fishing) (Thrush, *et al.*, 1995; Cogan, *et al.*, 2009; Brown, *et al.*, 2011). This pressure has forced national and international governments to develop programmes and management strategies (ecosystem-based management) that promote resource sustainability and biodiversity conservation (Halpern and Warner, 2002; Lambert, *et al.*, 2011; White, 2011). However, the success of these programmes is dependent on the availability of scientific information on habitats, species dynamics and community composition (Halpern and Warner, 2002; Lambert, *et al.*, 2011; White, 2011). Therefore, the fishing industries are investing in stock replenishment, biodiversity conservation research and management strategies like spatial closures, which are part of the global initiative called the Conservation on Biological Diversity's initiative (Beukers-Stewart, *et al.*, 2005).

Sustainable fisheries require the implementation of ecosystem-based management (EBM) strategies and supplementary based management strategies. EBM strategies were developed as a more holistic management approach for prioritising protection towards a target species and their associated habitat through the implementation of spatial closures (ie. marine reserves, closed area, and MPA), thus protecting the entire ecosystem from chronic anthropogenic activities (Hiddink, *et al.*, 2006; Sheehan, *et al.*, 2013; Howarth, *et al.*, 2015a); which in turn conserves biodiversity, ecosystem function, and encourages commercial resource restoration on a localised level (Howarth, et al., 2011). Supplementary management strategies include reseeding and translocation of stock which are implemented to replenish depleted stocks or establish new fishing grounds (Borg, 2002). Areas dedicated for stock replenishment are usually intended to be harvested once spat and juveniles have matured and grown to legal minimum landing sizes (Borg, 2002). These supplementary strategies are usually followed by seasonal or temporary spatial closures (Borg, 2002).

The success or failure of the closed areas to conserve the marine ecosystem or stock replenishment is highly dependent on the adequacy of the initial objectives and monitoring strategies implemented (Jordan, *et al.*, 2005; Fleming and Jones, 2012). In order to evaluate the success of a closed area, it is essential to acquire knowledge about that marine ecosystem and native stock density. This information can be obtained through the use of benthic surveying, such as marine habitat mapping, as ecosystem processes are defined by the benthic habitat

composition (Galparsoro, *et al.*, 2015). Therefore, obtaining good scientific knowledge on the seabed habitat distribution, structure, functions, and community diversity gives an indication of the environmental status and the effectiveness of the fisheries management strategies (Galparsoro, *et al.*, 2015). In addition, this benthic information can be used to identify areas that require further protection due to their ecological importance, vulnerability or economic value (Galparsoro, *et al.*, 2015). Thus, it is imperative to use habitat mapping techniques to map the seafloor of the closed area in order to determine the spatial distribution of commercially targeted and important species, identify ecosystem health and ascertain whether the objectives are being fulfilled (Murray, *et al.*, 2009b).

This information is required and utilised by government officials as a conservation tool as the scientific reports provide supporting evidence on the effectiveness of the marine reserve's objectives in order to justify the closures implementation and increase public support (Sheehan, *et al.*, 2013). One scientific technique used to acquire information on the seafloor and provide the required evidence is underwater video footage which can be used to generate habitat maps. Habitat maps provides high resolution benthos data at a low taxonomic level (Jordan, *et al.*, 2005). This method is relatively inexpensive in regards to time and scientific expertise compared to other methods which require taxonomy or equipment specialist (Jordan, *et al.*, 2005).

Habitat maps are visualisation tools that are an important part of the decision making process in EBM and are used as a conservation promotion tool (Cogan, *et al.*, 2009). Habitat maps are also a key tool in identifying the benthos health within marine reserves as they characterise the ecosystem features (shape, size and distribution) based on physical conditions, habitat structure/type and community composition (Cogan, *et al.*, 2009; White, 2011). Benthic habitat mapping (also known as biotope mapping) is a process of "plotting the distribution and extent of habitats to create a map with complete cover of the seabed showing distinct boundaries separating adjacent habitats," (Brown, *et al.*, 2011). A biotope map not only identifies areas of specific interest and concern but it can also be incorporated with species data to identify spatial distribution and habitat preferences which provide crucial information on the likelihood of successful species recruitment and survival within a specific area (Jordan, *et al.*, 2005; Cogan, *et al.*, 2009). Thus, habitat mapping is an essential tool in supporting management and policy decisions for closed area objectives and designs (Jordan, *et al.*, 2005; Cogan, *et al.*, 2009).

The aim of this report is to investigate the spatial distribution and habitat association with key species within two Isle of Man (Manx) closed areas using biotope maps. The integrated approach enables further analysis into the benthic biodiversity and density of the commercially important species especially *Pecten maximus* (king scallop).

1.1 Marine Conservation

Spatial closures are considered to be a vital tool for conservation and fisheries management as it preserves stock resources, ecosystem services and vulnerable habitats into the future (Howarth et al. 2011; Brand, et al., 1991). Spatial closures can be implemented as permanent, temporary or seasonal marine closed areas (marine reserve), which prohibit the use of mobile fishing gears within the area; thus providing a wide range of benefits to the commercial fishing industry, when designed and managed correctly. For spatial management to be successful it must include strict management, and consultation with local and fishing communities, incorporation of multi-habitats, realistic objectives, and an understanding of recovery time associated with the specific life-history strategies of different habitats and species (Jordan, *et al.*, 2005; Blyth-Skyrme, *et al.*, 2006; Gell and Hanley, 2010; Howarth, *et al.*, 2015a). Life history strategies are a key part of marine reserves achieving their objectives as species that are sessile tend to benefit more from area closures compared to mobile species which migrate out of the conservation zone (Beukers-Stewart, *et al.*, 2005). It has also been shown that species that have a slow growing, long lived and late maturation life history, strategies tend to require 5-20 years to recover (some cases no recovery) from anthropogenic disturbance compared to fast growing, short lived species with a high recruitment rate which tend to recover quickly (0-2 years) (Halpern and Warner, 2002; Hinz, *et al.*, 2010; Hinz, *et al.*, 2011; Szostek, *et al.*, 2016).

Long-established marine reserves that adhere to management strategies have been shown to have the greatest benefit to the commercial industry. Strict protection of marine reserves can increase target species biomass, abundance and average size, as well as increase local biodiversity, enhance recruitment (improved juvenile survival) and increase habitat complexity (Roberts, *et al.*, 2001; Blyth, *et al.*, 2004; Blyth-Skyrme, *et al.*, 2006; Howarth, *et al.*, 2011), thus increasing the chance of stock rebuilding (Roberts, *et al.*, 2001). However, a negative impact of marine reserves is the displacement of fishing effort and increased fishing pressure in other areas, which encourages wider and increased intensity of environmental degradation (Hiddink, *et al.*, 2006; Howarth, *et al.*, 2015a).

1.2 Commercial Species

Spatial closures have shown to benefit the commercial fisheries especially in the shellfish industry where the target species are highly valuable and have strong associations to vulnerable biogenic habitats, such as maerl beds, seagrass meadows and mussel beds (Seitz, *et al.*, 2013). The species of major concern to the Manx government is the commercially important shellfish species, scallops, which have shown stock recoveries with strict and regularly enforced spatial closures (Beukers-Stewart, *et al.*, 2005)

Well managed marine reserves that are established to enhance scallop production and are closed for an adequate time period have been successful as the closure prevents any destructive anthropogenic activities; thus reducing turbidity, improving water quality and preserving essential seafloor habitats which are factors crucial for scallop survival (Beukers-Stewart, *et al.*, 2005). Thus, scallop stocks within these marine reserves have been recorded to have an increased density, greater mean age and wider size class range (Beukers-Stewart, et al., 2005; Howarth, et al., 2011); indicating increased recruitment success. This benefit was observed in Georges Bank's Marine Reserve (USA) where scallop biomass had increased by 9-14 times during the space of 4 years (Beukers-Stewart, *et al.*, 2005). Therefore, spatial closures are vital for sustainable fishing as they preserve nursery habitat complexity, enhances spat settlement, thus, ensuring fishery sustainability.

1.3 Scallops

There are seven scallop species within the North Atlantic with *A.opercularis* (queen scallop) and *P. maximus* (king scallop) being harvested within the Isle of Man territorial waters using mobile fishing gear (dredges) (Shumway and Parsons, 2011). These filter feeding bivalves have many metamorphosis stages, and are typically characterised by their jet propulsion predator responses during their free-swimming adult stage (Howarth, *et al.*, 2011). Adult scallops are relatively sedentary, moving less then 30m in 18 months, making their distribution highly predictable and consequently ideal for reseeding into closed areas (Beukers-Stewart, *et al.*, 2005). The reproductive stage of the scallops occurs during the spawning events where gametes are synchronously released (Kamenos, *et al.*, 2004c; Beukers-Stewart, *et al.*, 2005; Howarth, *et al.*, 2011); thus scallops are highly vulnerable to the allele effect (population density are extremely low, individuals are reproductively isolated and recruitment fails) and require high

population density for fertilisation and recruitment to be successful (Howarth, et al., 2011). The larval settlement stage requires hard substrates with structurally complex epifauna like maerl beds, macroalgae (Rhodophyta and Phaeophyta), bryozoans, tubicolous annelida and hydroids which spats attach to (Kamenos, *et al.*, 2004c; Szostek, *et al.*, 2016). Therefore, scallop recruitment success is highly dependent on population density, habitat type and environmental conditions (Howarth, *et al.*, 2011), making scallops an ideal species for management strategies that use temporal and spatial area closures.

In order to maintain the sustainability of this scallop fishery the biology, behavioural traits, abundance and distribution needs to be understood. *P.maximus* is known as the giant or king scallop as it grows to an average of 150mm (length) which is larger than any other scallop species (Shumway and Parsons, 2011). The largest length of *P.maximus* recorded was 210mm in 1978 by Minchin (Shumway and Parsons, 2011). *P. maximus* is a commercially important shellfish species distributed throughout the North Irish Sea, where it is harvested using destructive dredging fishing gear (Beukers-Stewart, *et al.*, 2005). These scallops burrow into the substrate and have a morphology that facilitates with this behaviour. *P.maximus* has an inequivalve morphology with the upper valve being flat and the lower valve being deeply curved. This allows the scallops' upper valve to be level with the sediment surface when they recess into the seabed (Shumway and Parsons, 2011). Recessing is a camouflage behavioural response, which involves scallops dispersing sediment onto their shells in order to increase the difficulty of predator detection. Recessing also reduces the settlement of epifauna onto the shell; epifauna on scallops' shells hinders the swimming performance and increases filter feeding completion (Shumway and Parsons, 2011). *P. maximus* has three disturbance responses: closing of valves, a jumping reaction and more vigorous swimming. The swimming response is observed more readily in juveniles for any disturbance; whereas recessing adults tend to respond to disturbance by closing their valves. As swimming willingness and performance decreases with age, adults tend to only enact the jump or swim response when encountering a starfish threat (Shumway and Parsons, 2011).

1.3.1 Reseeding scallop stocks

The supplementary management tool of reseeding and transplantation/translocation was inspired by Japanese fishermen who adopted a proactive role towards conservation and resource enhancement (Slater, 2006). This method of juvenile (<60mm) cultivation has been highly

beneficial to the Japanese scallop industry as annual landings have increased to over 500,000t (1995) compared to pre-cultivating landings of 9,000t (1960s) (Slater, 2006). The success of this management approach and the high exploitation and decline of scallop stocks in Europe has encouraged European countries to implement scallop cultivation programs (1980's) (Minchin, 2002; Slater, 2006).

These management tools artificially enhance local bivalve's (scallop) densities, increase genetic diversity, generate new fishing grounds, and enhance stock quality (Borg, 2002). Reseeding is a process of transferring a large number of wild or cultured larvae or juveniles into the depleted area (Barbeau, *et al.*, 1998; Borg, 2002; Minchin, 2002; Magnesen and Redmond, 2012). The stocks replenished by the reseeded spat are intended to be harvested after the population densities recover and the reseeded scallop have mature (Barbeau, *et al.*, 1998; Borg, 2002). This management strategy is usually followed by spatial closure which protects the scallop associated habitat and allows for stock recovery until the brood-stocks reaches the minimum landing size (MLS), thus eventually increasing commercial and recreational yield (Borg, 2002).

The success of a reseeding operation is defined by it meeting the predetermined objectives of enhancing scallop brood-stock density (Barbeau, *et al.*, 1998). The reseeding objective is to mass produce juveniles of suitable breeding species which are released in an area to dramatically increase the yield for several fisheries. However, European countries (Ireland, Isle of man, France, Spain, Norway and England) that have implemented reseeding strategies have not observed the same benefits as the Japanese industry (Borg, 2002; Minchin, 2002; Slater, 2006).

These supplementary techniques have several economic and social benefits as reseeding is cheaper compared to fish farms because a minimal amount of infrastructure is required at the reseeding site and no artificial feeding is required; this management tool also has the benefit of re-establishing fishing in depleted stocks after a short period of spat recovery time (2 years of closure from sowing to reach market size); and has a lower environmental impact compared to fish farms (Borg, 2002; Minchin, 2002). The negative impacts of reseeding are: few reliable scallop hatcheries (spat often obtained from the wild), low survival rate (effected by spat quality, and increased predation), no ownership of stock, and imported stocks may alter the gene pool and the areas carrying capacity which may adversely affect the ecosystems, food chain and interspecific competition (Borg, 2002; Minchin, 2002; Slater, 2006). Handling time

(out of the water) and continuous exploitation also drastically effects the reseeding effect (Borg, 2002).

Low survival rate of spat is influenced by high mortality which is effected by the following factors: high levels of predation, habitat structural complexity for spat settlement, stock quality/genetics, environmental physical variables (temperature, currents and salinity) and time spat is exposed to the air during transportation (handling time) (Borg, 2002).

1.3.2 Habitat Association

Scallop distributions are driven by habitat and substrate characteristics as it influences spat settlement, nursery function, food availability and may even alter reaction time of the predator behavioural response (Shumway and Parsons, 2011). The marine seabed in a temperate environment comprising of range of habitats that are grouped into substrate types (sediment based and biogenic reefs). The sediment based habitats are those that predominantly consist of mud, sand, gravel and hard substrate (ie. rocks, boulders and cobble) (Seitz, *et al.*, 2013). The substrate is classified according to the grain size measurement defined on the Wentworth Scale. The community assemblage is unique to different substrate sediment types (Seitz, *et al.*, 2013).

Biogenic reefs are structurally complex habitats that are created by living organisms like coralline algae known as maerl (*Corallinales*), seagrass meadows, brittlestar beds, molluscs (oyster and mussels) and polychaetes (*Sabellaria spp.*) (Seitz, *et al.*, 2013). Biogenic reefs are mostly classified as sensitive habitats as anthropogenic disturbance (like mobile fishing gears) can reduce their complexity, increase sediment resuspension, and remove vital species such as bioturbators, sessile epifauna and structural-building megafauna (Lindholm, *et al.*, 2004; White, 2011; Howarth, *et al.*, 2015a). Complex biogenic habitats are associated with scallop nursery and feeding grounds (Seitz, *et al.*, 2013), and many biogenic habitats are protected under the Habitats Directive (ie. maerl beds) (Maddock, 2008), which means it is important to identify the location of this habitat as it is of conservation interest and legally requires protection.

Maerl beds are a benthic habitat that is formed from a variety of dead and living crust-forming calcareous red algae (Rhodophyta: *Corallinales*) (Hall-Spencer and Moore, 2000; Kamenos, *et al.*, 2004c; White, 2011; Seitz, *et al.*, 2013), which grows as unattached nodules (Maddock, 2008). Maerl beds typically develop in shallow bays or lochs at depths extending from neap

tide level to 40 metres (Maddock, 2008). There are three main maerl bed forming species, however the species predominantly found in the Irish Sea is *Phymatolithon calcareum* (Maddock, 2008). Maerl habitats are important as they support high levels of biodiversity (over 600 species living amongst, on or underneath the habitat) (Barbera, *et al.*, 2003; Gell and Hanley, 2010; Gell and Hanley, 2013). Maerl is highly sensitive to anthropogenic disturbance like scallop dredging due to the fragile branching nature of the maerl species (Maddock, 2008). Mearl habitats are important for *Pecten maximus* recruitment and survival as the maerl emit chemical stimulus that encourage spat settlement and habitat complexity allows juvenile to escape predation (Kamenos, *et al.*, 2004c; Howarth, *et al.*, 2015a). Thus maerl beds are important nursery habitats (Kamenos, *et al.*, 2004c; Gell and Hanley, 2010; Gell and Hanley, 2013). These habitats commercial relevance and vulnerability to anthropogenic disturbance indicates this biogenic reef is an important area for conservation. At present, maerl habitats are legally protected under international conservation legislation and the maerl species is listed under the OSPAR threatened species list (Barbera, *et al.*, 2003; Kamenos, *et al.*, 2004; Gell and Hanley, 2010; Gell and Hanley, 2013).

Habitat composition is not only important for juvenile recruitment and nursery function but can also influence behavioural responses in scallops. The predator swimming response is associated with an increase in swimming frequency with individuals on hard substrate, whereas, individuals on sandy or sand-mud substrate show little to no swimming response and recess into the substrate (Shumway and Parsons, 2011). Therefore, the assumption is that juveniles that actively swim in response to predation will prefer hard substrate habitats compared to adults that recess into the substrates so therefore prefer softer substrate habitats. It has been observed that adults will inhabit a variety of soft sediment, including coarse and fine sands, mixed sediment, mud areas and gravel substrates (Beukers-Stewart and Beukers-Stewart, 2009).

1.3.3 Threats to scallop stocks

All scallops are highly vulnerable to anthropogenic, biological and environmental factors, which increase mortality at juvenile and adult level. The anthropogenic activities include mining, timber harvest, factor waste, urban pollution and commercial fishing (Alaska, 2004). The biological and environmental factors include invasive species, storms, disease and pathogens (scallop larvae are susceptible to *Vibrio pectenicida* and *Vibrio splendidus*), predation pressure as well as interspecies and intraspecies competition (Alaska, 2004;

Kesarcodi-Watson, *et al.*, 2014). These factors increase turbidity, eutrophication levels, harmful toxin and nutrients concentrations, thus inducing stress and reducing population survivability (Alaska, 2004; Kesarcodi-Watson, *et al.*, 2014). However juvenile scallops are extremely susceptible to these induced stress which increases spat mortality when these events occur (Barbeau, *et al.*, 1998). Two major threats to juvenile (<60mm) scallops survival during a reseeding process are predation pressure (mainly crabs and starfish) (Barbeau, *et al.*, 1998); and fishing pressure, especially mobile fishing gear that alters benthic ecosystems (Borg, 2002).

1.3.3.1 Predation

The main predators of the scallop *P.maximus* are *Cancer pagurus*, *liocarcinus puber*, and *Inachus spp.* (crab); *Pagurus spp*. (hermit crab); A*sterias rubens*, *Marthasterias glacialis*, *Parania pulvillus and Crossaster pupposus* (starfish); *Eledone cirrhosa* (octopus); *Anthopleura balli* (sea anemone); *Calionymus lyra*, *Triglidae* and other fish species (Veale, *et al.*, 2000a; Shumway and Parsons, 2011). Starfish and crabs have the largest predator impact on reseeded *P.maximus* (Magnesen and Redmond, 2012). The natural daily predation rate of *P.maximus* is from zero to three scallops per day, which increases during initial reseeding and is variable depending on season and temperature (Minchin, 2002; Magnesen and Redmond, 2012). Predation is a major limiting factor on scallop survival and dispersal during reseeding (Barbeau and Scheibling, 1994b). Reseeding management strategy causes a dense aggregation of scallops which results in changes in the predators through short and long term behavioural responses (Barbeau, *et al.*, 1998). The short term response is an increase in prey consumption rates of individual predators whilst the long term response is increased predator density in an area (Barbeau, *et al.*, 1998). Therefore predation pressure is a major factor reducing scallops survivability especially immediately after reseeding (Barbeau, *et al.*, 1998).

The starfish-scallop interaction occurs predominately during dense aggregations of newly reseeded scallops (Barbeau and Scheibling, 1994b). Starfish have been recorded feeding on scallops that are low in quality, are still recovering from handling and transport, damaged, or smaller than 37mm (juvenile) (Barbeau and Scheibling, 1994a; Magnesen and Redmond, 2012). Starfish are non-visual hunters that move slowly and search for prey using chemoreception and chance encounters; therefore higher encounter rates result in greater mortality rates (Barbeau and Scheibling, 1994b). The scallops defensive behavioural response to a starfish threat is to swim or jump to escape predation, which is less well-developed in cultured scallops compared to wild scallops (Barbeau and Scheibling, 1994a; Magnesen and

Redmond, 2012). This swimming behavioural response increases in intensity with age, thus smaller scallops are more vulnerable (Magnesen and Redmond, 2012). The major starfish predators are *Asterias rubens* and *Marthasteria glacialis*, which hunt in shallow waters inducing a high mortality rate to juvenile *P.maximus* as larger scallops are to energetically costly to predate upon (Barbeau and Scheibling, 1994a).

In crab-scallop interactions, encounter rates appear to be a major factor determining predation rates, however this predators effectiveness is size dependent (Barbeau and Scheibling, 1994a; Grefsrud, *et al.*, 2003). Crabs are fast moving predators that detect prey through visual, chemical and tactile stimuli (Barbeau and Scheibling, 1994b). Scallop defence behavioural response to crabs are to close their valves which lowers survivability as captured scallops are consumed (Barbeau and Scheibling, 1994a). Thus crabs are a primary cause of scallop mortality as they feed on undamaged adult scallops. The main species known to consume adult scallops are *Cancer pagurus (*edible crab*)* (Grefsrud, *et al.*, 2003), however *Liocarcinus spp* (swimming crab) and *Pagurus spp* (hermit crab) have been recorded preying on small adults (Jenkins, *et al.*, 2004). *C.Pagurus* has the most efficient predation on *P. maximus* due to their large powerful claws with blunt, broad molars which are specialised in breaking hard–shelled bivalves (easily break and crush valves <50mm, however larger crabs do consume adult scallops >70mm) (Grefsrud, *et al.*, 2003).

1.3.3.2 Fisheries

One variable that influences scallop survival rate is the use of mobile fishing gear. Scallops are harvested using mobile fishing gears (dredging and trawling) which target species that live within and on the seafloor (i.e. *P. maximus*), resulting in physical alteration to the seafloor (Howarth, *et al.*, 2015a). Mobile fishing gear can also be advantageous to the immediate environment as it provides additional food for scavengers and reduces interspecific competition (Hinz, *et al.*, 2009). However, overall this gear has a negative effect on the benthos as it alters the community assemblage and niche function by reducing habitat complexity, biodiversity (loss of 40%), biomass (reduced by 72%), abundance and productivity (Hall-Spencer and Moore, 2000; Kaiser, *et al.*, 2000; Howarth, *et al.*, 2015a). The intensity of the fishing pressure can even reduce scallop stock to uneconomically viable levels within a year (Brand, *et al.*, 1991). It has also been shown that a single towing event causes major alterations to the benthos community composition and habitat complexity (Hall-Spencer and Moore, 2000); and prolonged chronic disturbance results in permanent community regime shifts (Veale, *et al.*,

2000b). Chronic disturbance alters disturbance sensitive habitats such as live maerl beds as it reduces the habitat's complexity and kills off living maerl causing a loss in nursery function (Hall-Spencer and Moore, 2000; Lambert, *et al.*, 2011). Thus, the loss of important nursery, feeding and breeding habitat can impact recruitment success and scallop survival within the immediate area (Lambert, *et al.*, 2011). However, this is not the case for all habitats as disturbance tolerant ecosystems display high levels of species survival and fast recovery (Thrush, *et al.*, 1995). Resilient habitats are typically dominated by encrusting biogenic (encrusting algae) and sandy substrate (Alexander, *et al.*, 2009).

Overall, mobile fishing gear has detrimental effects to benthic communities, and may inevitably prevent fisheries sustainability. Therefore it is essential that mobile fishing gear is prohibited near or within newly reseeded areas, as damaged scallops have an increased risk and vulnerability to predation. Thus, spatial closures around reseeded areas and around less resilient habitats are needed to safeguard these important ecosystems (nursery and breeding) (Murray, *et al.*, 2009a; Howarth, *et al.*, 2015a), and encourage reseeding success, which will lead to future sustainability within the scallop industry.

1.4 Rational

1.4.1 Isle of Man

The Isle of Man (Manx) is situated in the centre of the Irish Sea between England, Ireland, Scotland and Wales. In 2009, the Manx government established two replenishment zones in Niarbyl Bay (western coast) and Laxey Bay (eastern coast). These were reseeded with juvenile king scallops in order to re-build depleted scallop stocks (Slater, 2006). In order to encourage stock replenishment within overexploited areas, marine reserves were created to close off an area to mobile fishing gears to protect the existing and reseeding scallop populations as well as to protect their habitats. These marine reserves not only protect scallop stocks but also provide protection to over 2300 other Manx fauna (Gell, *et al.*, 2013)

1.4.2 Rational

In 2016, DEFA (Department of Environment, Fishing and Agriculture), and the School of Ocean Science at Bangor University conducted a habitat survey, with focus on the commercially important king scallop (*P.maximus*), their associated habitats and conservation important habitats. The survey was undertaken as the current health and distribution of marine

habitats and species within the Manx marine reserves was uncertain, which hampers fisheries management decisions. Thus, in order to make informed management decisions, the Manx government required a comprehensive assessment on the benthic habitat and scallop stocks within both marine reserves (Laxey Bay and Niarbyl Bay). This information will provide supporting evidence for defining whether the objectives of increased scallop densities was met and decide whether the reserves should be reopened to mobile fishing activates.

This thesis aims to investigate the benthic environment with a focus on sensitive habitats and scallop population density within two closed areas in the Manx territorial water, in order to provide information to the Manx government to help with future environmental management decisions on their marine reserves.

1.4.3 Objectives

Objective 1: Generate a biotope map of the benthos within the marine reserves Laxey and Niarbyl Bays.

Objective 2: Identify the distribution of valuable habitats and species within the marine reserves, i.e. those vulnerable to chronic fishing disturbance, important for commercial species recruitment (nursery areas) and legally protected under legislation like the Habitat Directive and Wildlife Act, 2004.

Objective 3: Identify mobile scavengers within the marine reserves.

Objective 4: Identify community biodiversity within the marine reserve and within different substrate types.

Objective 5: Estimate the scallop (*Pecten maximus*) population density, size-frequency and distribution within Laxey and Niarbyl Bays marine reserves for 2016, encompassing a temporal comparison on scallop density.

Objective 6: Estimate the density and distribution of *P. maximus* predators within Laxey and Niarbyl Bays marine reserves.

Objective 7: Assess the substrate/ habitat preference of commercially important shellfish species.

1.4.4 Hypothesis

H 1: Biogenic reefs will have a greater biodiversity compared to sandy or mud substrates (unvegetated habitats) within the reserves.

H 2: The scallop population within Laxey Bay, will have a higher density in 2016 compared to historical densities (2014) during the time of protection.

H 3: The scallop population within Niarbyl Bay, will have a higher density in 2016 compared to historical densities (2011 and 2012) during the time of protection.

H 4: The size-frequency of the scallop population will be similar to historical sample as zero fishing pressure occurs within the reserve.

H 5: High density of scallops will occur in regions with low density of predators.

H 6: Greater density of scallops will be recorded in areas with a higher percentage cover of habitat structural complexity compared to habitat with no structural complexity.

2 Methods

2.1.1 Isle of Man

The Isle of Man economy is predominantly based on the commercial fishing industry, with the shellfish industry being the most financially important (scallops, brown crab, lobster and whelk), providing an annual income of £13 million (Hanley, *et al.*, 2013). The scallop industry is the most valuable fishery as in 2014 it provided 59% of the fisheries' yearly income (DEFA, 2016); however harvesting scallops can be extremely destructive to benthos, as dredging gear penetrates the substrate (Brand, *et al.*, 1991). Therefore, to prevent alterations to important habitat strategies with good scientific backing and effective management need to be implemented in order to conserve future stocks. It has long been recognised that stocks are limited, the Manx government has implemented six inshore and four offshore marine closed areas (DEFA, 2015). Management strategies like cultivating, restocking combined with rotational closure, and well-managed closed areas have shown to result in scallop stock recovery and increase recruitment (Brand, *et al.*, 1991). The Manx government has implemented supplementary (reseeding) and spatial closure management techniques within Laxey Bay and Niarbyl Bay to replenish depleted scallop stocks.

2.2 Description of study area

This study focuses on two closed areas (marine reserves) around the Isle of Man terrestrial waters, one on the eastern coast (Laxey Bay) and the other on the western coast (Niarbyl Bay) (Figure: 1). These areas are protected by the Sea Fisheries Byelaw, which prohibits mobile gear fishing within the closed area (DEFA, unpublished).

Following the success of Port Erin marine reserve. The DEFA outlined a proposal for two reseeding area closures in 2007-2008 DEFA business plan, and the closure of Laxey and Niarbyl Bays was proposed in March 2008. These bays were selected and agreed for closure after extensive consultation with the Manx Fish Producers Organisation (MFPO). Niarbyl Bay was the most practical choice as MFPO was not willing to consider closures in Ramsey Bay at the time. The closure of Laxey and Niarbyl Bays protects the benthic community within these restricted areas, where trawling/mobile fishing gear is not permitted. The main goal of the closure was "to ensure that a reliable supply of scallop spat is exported to adjacent scallop fishing grounds" (Bloor, 2016), although conservation benefits may also occur. The benthic

habitat and scallop stock within the area were assessed after 6 year of closure by Bangor University with the collaboration of DEFA.

The eastern marine reserve, Laxey Bay was closed in 2009 to protect the potential seeding grounds for *P. maximus*. Laxey Bay is approximately 4km^2 with a depth 0-15m. The closure boundary restriction from headland (Carrick Roayrt 54° 14.40' N, 004° 21.95' W) to headland (Clay Head 54° 11.80' N, 004° 23.20' W) (Figure2a). The area was reseeded in autumn of 2009 with one hundred thousand juvenile scallops (1-2 year old) from Mulroy Bay Scallop Farm, Ireland, in order to replenish native stocks (Kennington, 2009). Two locations with a suspected maerl substrate was selected for the reseeding, one was located in the centre of the bay and the second was in the south of the bay (approximately 10m depth) (Kennington, 2009). Laxey Bay's preliminary study indicated that the substrate was predominantly finer substrate with low algal coverage (Kennington, 2009).

The western marine reserve, Niarbyl Bay was closed in 2009 to protect another potential seeding group for *P. maximus*. It had an area approximately 6km^2 and a depth ranging from 0m to 25m. The boarders of this closed area are defined by two markers; Elby Point (54° 09.75' N, 004° 44.56' W) and Fleshwick Bay (54° 06.54' N, 004° 45.67' W) (Figure2b) (DEFA, unpublished). In 2009, the area was reseeded with 5,000 wild caught scallops from local fishing grounds around the west of the Isle of Man (Kennington, 2009). The wild caught scallops were a range of sizes (69mm to 158mm) however the dominant cohort was 3year old scallops (100mm-120mm) (Kennington, 2009). The location of the re-laid scallops was the south western sector of the bay, as the benthic habitat comprised gravel substrate at a depth of approximately 15m which was indicated during a preliminary Van-Veen grab survey (Kennington, 2009). The preliminary survey indicated that Niarbyl Bay had high local *P.maximus* density and location of the bay means that it is exposed to westerly gales (Kennington, 2009). This initial reseeding was followed up with a second transfer in late October, where approximately 110,000 wild scallops were re-laid (Kennington, 2009).

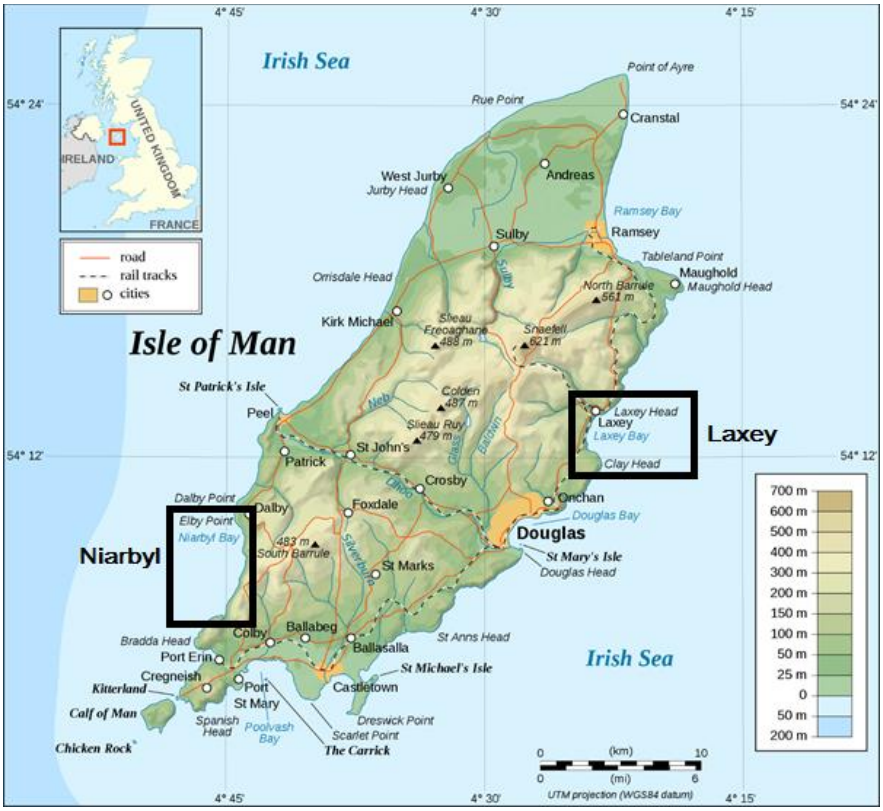

Figure 1: This map of the Isle of Man within the Irish Sea with black boxes indicating the two marine reserves Niarbyl Bay on the western coast and Laxey Bay on the eastern coast © Eric Gaba.

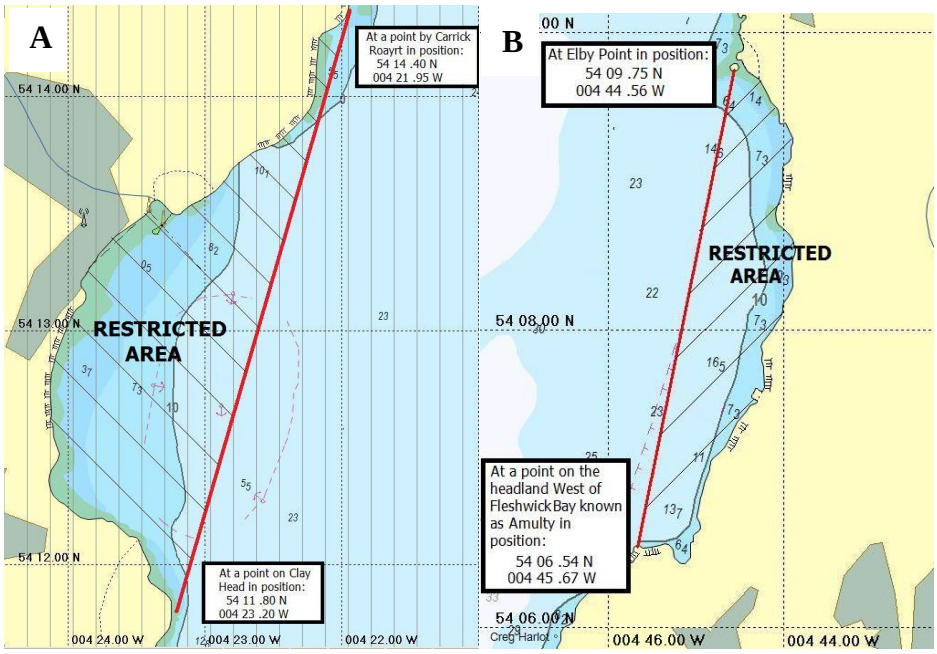

Figure 2: The navigation maps of Laxey Bay (Left, A) and Niarbyl Bay (right, B) with the redline depictions the boarders of the closed area (DEFA, unpublished).

2.3 Survey Design and Data Collection Method

The marine reserve seabed was surveyed using a video sledge which is a low impact and non-invasive sampling technique that obtains high resolution images of the benthos over a large spatial scale, over a short time period. The video sledge comprises a live video feed, a mounted camera with flash (Canon EOS 400Dl: 1080dp and 60 frames per second), a high resolution GoPro Hero 3 (1080HD) and two underwater lights on the front (Figure 3a). The mobile scavenger species within the marine reserves were surveyed using a baited remote underwater video system (BRUV) (Figure 3b). The BRUV was a demeshed lobster-pot with bait, GoPro Hero 3 and underwater light attached to the frame.

Laxey and Niarbyl Bays were surveyed from the 13th June 2016 to 25th June 2016. The benthos was surveyed using the non-invasive video sledge technique deployed off the back of the government enforcement vessel, FPV Barrule. Due to boat movability and draft restrictions the video sledge could not be deployed at depth shallower than 5m or in areas where static fishing pots were present.

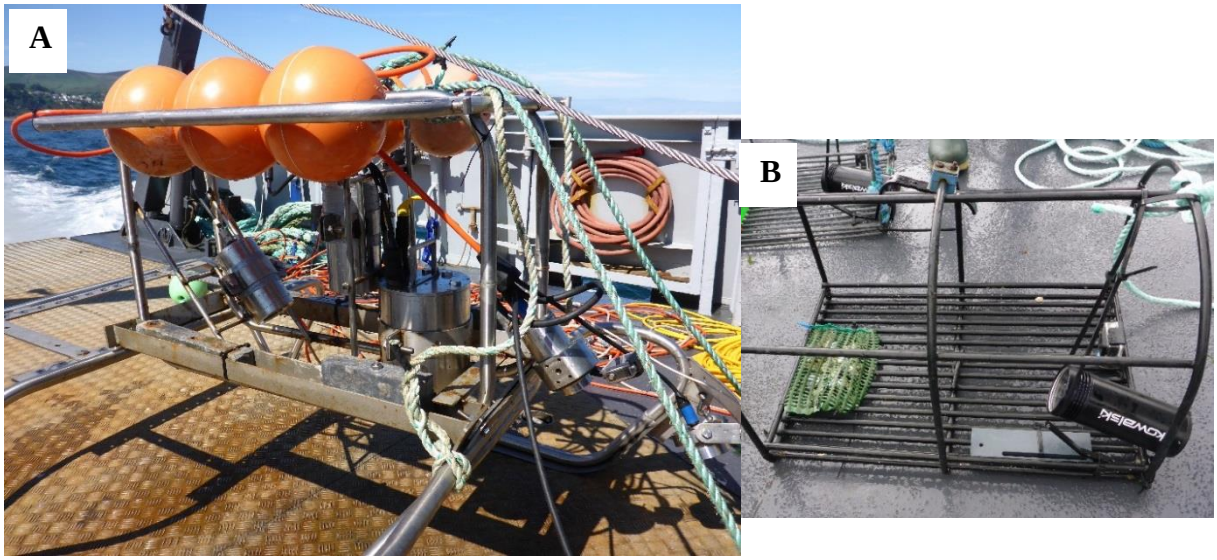

Figure 3: The equipment used in the benthic survey of the two marine reserves. Image A (left) is video sledge with live video feed (front of the sledge) (right) and the still image camera and light (centre of the sledge, position horizontally to the seafloor). Image B (right) is baited remote underwater video (BRUV) system with the bait on the left and camera with a light on the right.

2.4 Video Sledge

The benthic ecosystem was surveyed using a video sledge that was towed along predefined transects that incorporate all depths ranges across the closed area. The still video camera attached to the sledge frame was set to take a photograph every ten seconds. The start point of each transect was set as when the sledge touched the seafloor and the live video feed was clear enough to see detail in the benthos, which occurred at a speed of 0.3knots. The end point of each transect was when the sledge lifted off the seafloor or the boat speed increased to >1.5knots.

The Laxey Bay survey comprised six transects which covered all sections of the bay (Figure 4a). The video sledge was towed along each transect for 1 hour, producing six 10 minute segments. Laxey Bay covers a smaller area, thus long tows were used to obtain fine scale information on the benthic composition. After recovery of the video sledge, a 1 hour video (GoPro Hero 3) and 360 still images (Canon EOS 400D camera) were collected and stored on two hard drives for each transect.

Niarbyl Bay was surveyed slightly differently due to the larger area and inshore fishing pots. Therefore, to cover the larger area in the same time frame, 27 short transect were set across the bay all measuring approximately 200m apart (Figure 4b). The video sledge was towed along the seafloor for 10 minutes at each transect, however to save time the video sledge was not removed from the water after each transect, instead the video sledge was towed in the water column until the next transect predefined start location was reached. Thus, the transects equate to six 1 hour video tows. After recovery of the video sledge a 1 hour video and 360 still images were recovered, however only a maximum of 50 minutes could be used in any one tow as recording occurred during deployment and recovery.

During each video tow, the GPS coordinates (latitude, longitude), time and date were recorded every 30 seconds using tracker software aboard the ship. However, depth was only recorded every 5 minutes. The GPS coordinates, time and date were also recorded manually every 5 minutes as a backup in case the software crashed. These videos and still imagery data with the tracking data were then used to generate biotope maps and provide population estimates.

Due to the complexity of the method used a simplified version of the method procedure was displayed in a flow chart, located at the end of the method section (Figure 7).

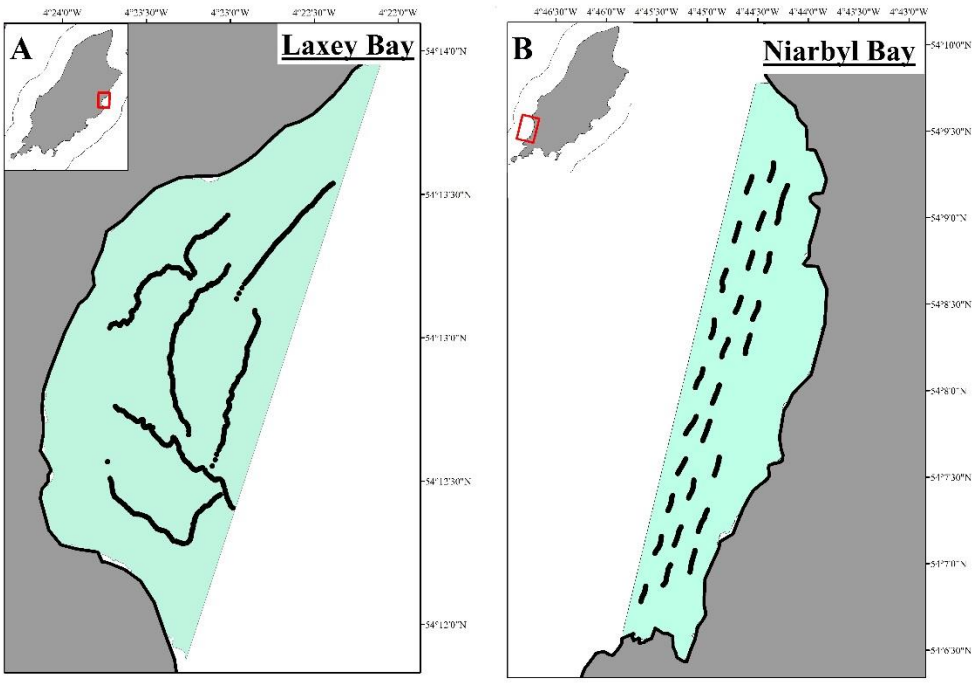

Figure 4: A map of the video sledge transect used in the benthic survey. Black lines indicate the tows and the light turquoise indicated the marine reserve. Map A (left) is Laxey Bay, and map B (right) is Niarbyl Bay.

2.4.1 Video Sledge: Data Processing

2.4.1.1 Still Imagery Processing

The still images were taken every 10 seconds and the GPS co-ordinates were recorded automatically every 30 seconds. The images were then separated into 30 seconds sections, comprising of 3 images per coordinate. An inspection of each image was conducted before analysis using a criteria table (Table: 1) which assessed the image based on visibility and quality (Hannah and Blume, 2012). If the image scored zero in any of the two categories within the criteria table the image was rejected. This resulted in a single image per coordinate with a high criteria score being using for further investigation. The images were imported into ImageJ where the stack function was used to enhance the same level of brightness and colour contrast to all the images.

The habitat types were determined by overlaying a 12 point grid in ImageJ. The overlaid grid was set to have intersecting lines 800,000 pixel^2 apart. This created 12 markers on the still image. At each marker the surface substrate was identified according to its visual appearance, as well as based on measured grain size which was used to classify the sediment from the Wentworth scale (Table: 2). However, sediment smaller than 0.25mm could not be measured using ImageJ, thus the classification "sand" includes clays, silts, mud, fine sand, medium sand and coarse sand. The habitats were identified as biogenic or macroalgae substrate, which included maerl bed, seagrass meadows, and brittlestar beds (biogenic reef), as well as *Laminaria* spp., Rhodophyta (red algae) and other macroalgae substrates. A percentage cover of the substrate type was estimated based on the 12 markers for each image.

All sessile and mobile epifauna present in the images were identified to lowest taxonomic level. If species identification was not possible, or potentially inaccurate, the species were given an identification code based on their phylum. This coding process was essential for algae, bryozoans and hydroid species especially with highly similar species that required microscopic analysis. The algae, bryozoans and hydroid species were marked as either present or absent, whereas sessile and mobile species were recorded as individual counts.

Table 1: Criteria table used to either rejected or accepted photographs from analysis. The criteria table was based on the visibility and quality of the images field of view (Hannah and Blume, 2012)

Category	Score	Criteria
Visibility	0	View is totally obscured by suspended substrate (turbidity) or image is unfocused or lens is foggy
	1	View is partially (<40%) obscured by turbidity or low lighting (limited visibility)
	2	Clear view in light area
Quality	0	Camera is at an angle, looking up into the water column or >70% of the image is covered with close up rock or kelp.
	1	Camera is at the correct angle, close flora is blocking <70%
	2	Camera is at the correct angle, and unobstructed view

Table 2: Wentworth scale table used to define the measured sediments within each photograph. As grain size determines sediment type (Wentworth, 1922).

Measurement (mm)	Wentworth size class	Labelled
>256	Boulder	Rock
64 - 256	Cobble	Pebble/cobble
8 - 64	Pebble	Pebble/cobble
8 - 4	Fine Gravel	Gravel
2 - 4	Very fine gravel	Gravel
1 – 2	Very Coarse sand	Sand
0.5 - 1	Coarse sand	Sand
0.25 – 0.5	Medium sand	Sand
< 0.25	Fine sand and muds	Sand

2.4.1.2 Video Processing

The video data was used to estimate scallop density and habitat verification as well as to identify any less common/large mobile and sessile species. The GoPro video footage was viewed using VLC media player and images of scallops and rare species were extracted using the VLC screen-shot function. All video images were identified to a minimum of genus level and this information was integrated with the still image species abundance database. All scallop photographs were processed using ImageJ as this allowed each scallop to be measured. These measurements were used to estimate the scallop size-frequency within each of the closed areas. However, due to camera movement and the scallop positioning within the frame, the measurements have a minimum error of ±4mm.

2.4.2 Habitat Mapping

The biotope maps were generated in ArcGIS using two different approaches, the bottom-up approach and the top-down approach as this gives more detail on the benthic community composition (May, 2015). The bottom-up approach is a biotope mapping method that utilises the congregation of different community assemblages and environmental factors to determine different habitat types within the closed area. The top-down approach is a biotope map that is based on strictly defined habitat classifications that are internationally recognised. The full databases were then further pooled into similar habitat and dominant species assemblage, to reduce the sample size, for the statistical analysis software. After statistical analysis the pooled database was deconstructed back to GPS point level for the Biotope maps to be created.

2.4.2.1 Top-Down Approach

The top-down approach was based on the Joint Nature Conservation Committee (JNCC) Marine Habitat Classification for Britain and Ireland (MHCBI) (Connor, *et al.*, 2004). The JNCC MHCBI provides a management tool for conserving marine benthic habitat as it categorised all habitats based on a comprehensive classification system with a hierarchical format (Connor, *et al.*, 2003; May, 2015). The JNCC classification uses a common reference to allow for spatial and temporal comparisons as habitat class was based on predefined criteria (Galparsoro, *et al.*, 2015). This common reference was essential for conservation programs and monitoring schemes (Galparsoro, *et al.*, 2015). The hierarchical formation are based on levels associated with depth zone, substrate composition, key species and overall species composition. Each still image was classified using JNCC MHCBI which was based on the percentage cover of each identified habitat. However, some habitats could only be identified to level 2 like the rocky habitats which require environmental conditions to be known before proceeding to the species composition level (Table: 3). Thus, each GPS point had a resultant habitat category.

The 30 seconds interval points with the JNCC classifications were imported into ArcGIS 10.3, to create the biotope map using an algorithm called inverse distance weighted function (IDW). IDW extrapolated the habitat types between the points, providing the basis of the habitat boundaries. For IDW to work the JNCC habitats were given a number from 1 to 12 (Table: 4). The algorithm then determined the likely habitat code around each point to create a biotope raster in ArcMap. This coding however did result in habitat codes occurring that were not actually present. Therefore, IDW was used to define habitat boundaries around each point, then polygons were created for each habitats classed by the point's JNCC MHCBI.

The pooled database was used in PRIMER v.6, a multivariate analysis (Clarke and Gorley, 2006). Perm-ANOVA in PRIMER v.6 was undertaken in order to determine the significant differences between the community compositions of the different JNCC classified habitats. A SIMPER analysis was also undertaken to identify species that contributed most to habitat dissimilarity in species composition, as well as species similarity within the habitat.

Table 3: The JNCC Marine Habitat Classification for Britain and Irish Seas used to determine the habitats within the marine reserves. Habitat were classified based on JNCC hierarchical system, that has a description with it corresponding codes for each level (Connor, et al., 2004).

Level	Description	JNCC Classification	Code
Level 1	Environment (marine)	Sublittoral sediment	SS
Level 2	Broad habitat type	Sublittoral macrophyte-dominate communities on sediment	SS.SMp
Level 3	Habitat Complex	Maerl beds	SS.SMp.Mrl
Level 4	Biotope Complex	*Phymatolithon calcareum* maerl beds in infralittoral clean gravel or coarse sand	SS.SMp.Mrl.Pcal
Level 5 & 6	Sub-biotope	*Phymatolithon calcareum* maerl beds with red seaweeds in shallow infralittoral clean gravel or coarse sand	SS.SMp.Mrl.Pcal.R

Table 4: The JNCC MHCBI that were occurred within the marine reserves; with the JNCC code, descriptions and code number for all habitat displayed in ArcGIS maps (Connor, et al.*, 2004).*

JNCC Habitat	Description	Code
SS.Smp.SSgr.Zmar	Zostera beds in full salinity infralittoral sediments	1
SS.SSa.IFiSa	Infralittoral fine sand	2
SS.SSa.CFiSa	Circalittoral fine sand	3
SS.SMx.IMx	Infralittoral mixed sediments	5
SS.SMX.CMx	Circalittoral mixed sediments	4
SS.SCS.ICS	Infralittoral coarse/gravel sediment	6
SS.SCS.CCS	Circalittoral coarse/gravel sediment	7
SS.SMp.Mrl	*Phymatolithon calcareum* maerl beds in infralittoral clean gravel or coarse sand	8
CR.MCR	Atlantic and Mediterranean moderate energy circalittoral rock	9
CR.MCR.EcCr	Echinoderms and crustose communities on circalittoral rock	10
CR.SMp.KWsSS	*Laminaria saccharina* and red seaweeds on infralittoral sediments	11
SS.SBR	Sublittoral biogenic reefs	12

2.4.2.2 Bottom-Up Approach

The pooled database was used in the bottom-up analysis in PRIMER v.6 (Clarke and Gorley, 2006). This multivariate analysis was used to determine the significant changes in the benthic community composition, which identified cluster groups which were used to generate a bottom-up biotope map.

The grouped benthic dataset in PRIMER was transformed using a square root transformation, in order to reduce influence of rare or dominant taxa. A Bray-Curtis similarity coefficient matrix was then generated. A CLUSTER analysis was performed on the pooled dataset to identify significant groupings in order to distinguish and classify the benthos. A SIMPROF (similarity test for an a priori design) was incorporated into the cluster analysis to create clustered groupings factors, one was based on the environmental variables and a second factor was based on the species assemblage. The grouped dataset was deconstructed into the GPS co-ordinate points with the defined cluster groups factors attached. These defined points were used to generate a biotope map in ArcGIS. The method used to generate the biotope was the same procedure as the top-down mapping process.

The grouped benthic resemblance matrix in PRIMER was used to generate a MDS plot (Non-metric Multi-dimensional scaling) which provided visual representatives of community composition. The SIMPER function was undertaken with the factors obtained from the cluster analysis. This was undertaken in order to determine which species contribute most to similarity within the cluster groupings and dissimilarity between the cluster groupings. The cluster groupings were statistically analysed using the PermANOVA analysis. The relationship between the environmental variables (average depth (m) and percentage cover of substrate) and community composition was analysed using BEST analysis with BIO-ENV function. A draftsman's plot was also conducted on the environmental data.

2.4.3 Species diversity

The full database was aggregated into the 10 minutes tow time, in order to get a diversity index for the marine reserves. The diversity indices were obtained using the DIVERSE function in PRIMER v.6. The species richness and Shannon-Wiener index were displayed graphically on ArcGIS. The species database was also used to calculate the diversity indices for each JNCC habitat type and overall closed area. This was undertaken using the DIVERSE function in

PRIMER, which generated outputs for: total species (S), total individuals (N), Pielou's evenness (J´), and Shannon-Wiener (H'(loge)) (Clarke and Gorley, 2006). Shannon-Wiener index is a measure of biodiversity, the greater the value the more diverse the community (Khan, 2006). These diversity indexes were analysed for any significant difference between habitats and overall closed areas using ANOVA in SPSS statistic software package. The diversity indexes per 10 minutes was superimposed on to the biotope maps generated by the top-down approach.

2.5 Baited Remote Underwater Video (BRUV)

The BRUV was designed to record the relative occurrence frequency of mobile scavengers that were attracted to an odour plume caused by the oily fish bait. The BRUV comprises of a "D" shaped lobster pot frame with no mesh; a mounted GoPro Hero 3 camera which was fitted to one end; and a plastic bait holder on the other end (Figure:3b). The GoPro was set to wide frame (1080dp and 60 frames per second). An underwater light with a diffuser attached to the lens (reducing the lights deterrent effect and thus allowing the entire video frame to be evenly lit) was placed beside the video camera. The lobster pots were attached to a 30m rope with two buoys. One of the buoys was attached slightly further down the rope, to reduce the potential of the rope falling in front of the camera. The BRUV was positioned horizontally on the seafloor capturing information on the species attracted to the oily fish bait. The bait consisted of 1.5 to 2 herrings that were still frozen and freshly cut; this was to prevent the loss of oils that attract the mobile scavengers.

BRUVs were deployed randomly across all depth ranges and at each site between the hours 08:00–20:00. The time, date, latitude, longitude and depth was recorded for each BRUV. The BRUVs were left on the seabed for a minimum of 60 minutes based on the recommendations from Willis and Babcock (2000) and Watson et al. (2005) studies. After 60minutes, the BRUV was hauled back onto the boat and video data was collected from the SD cards. The SD cards were wiped and the BRUVs were redeployed. BRUVs were deployed from the FPV Barrule and a local fishing vessel (FV Manx Cat). On the FPV Barrule the BRUVs were deployed at the same time as the video sledge tows were conducted. Unfortunately no replicates within the various habitat type and depths was undertaken due to time constraints; therefore the BRUV only give an indication of the variety of species within the immediate area.

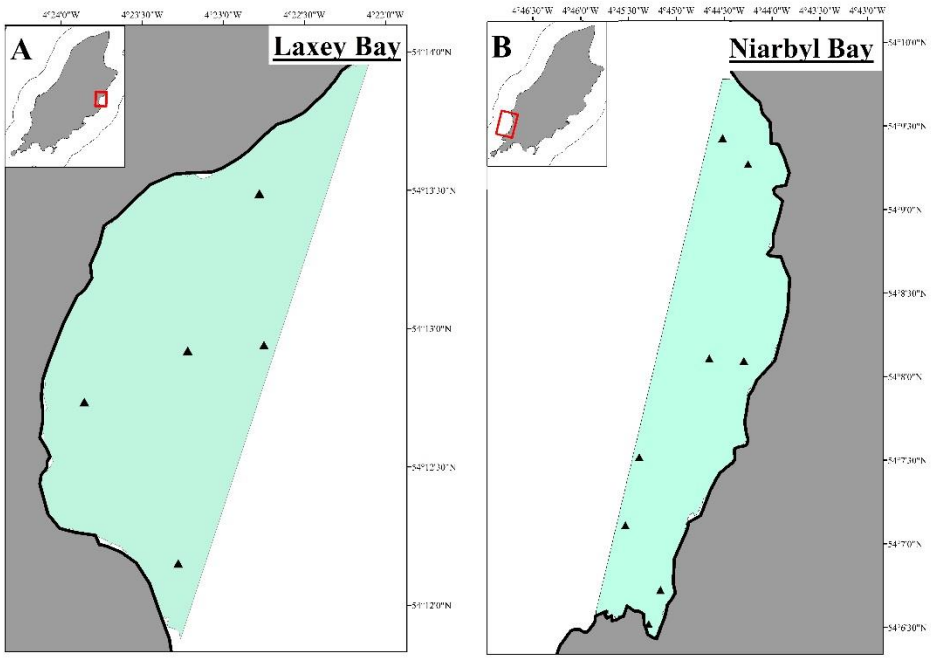

Figure 5: A map of the Baited Remote Underwater Video system (BRUV) deployed in the benthic survey. The black lines indicate the BRUV locations and the light turquoise indicated the area closure. Map A (left) is Laxey Bay and map B (right) is Niarbyl Bay.

2.5.1 Data Processing

BRUV data was analysed using Windows Media player or VLC player. These videos provided information on species, abundance, arrival time to bait and behavioural responses of individuals. The habitat type according to the MHCBI was identified for each BRUV deployed. BRUV data was separated into 5 minute intervals, with all species observed in the video frame being identified to a minimum of genus level. The abundance of each species was recorded using the methodology described by Cappo, *et al.* (2004). The abundance was recorded by counting the number of individuals for each species seen in a single frame at a single point in time. The maximum number of individuals (MaxN) for each species was recorded for each five minutes. The exact time at which MaxN occurs and the time at which the first individual of each species arrives (time of arrival, TA) at the bait was recorded for each BRUV.

2.5.2 Statistics Analysis

The species and abundance data was used to identify the mobile scavengers in each of the two marine reserves. The MaxN data was added into the PRIMER V.6 analysis and used in investigating the differences between the diversity indices (Diversity Function on PRIMER)

between habitat types and closed areas. The patterns of diversity within the marine reserves are displayed in ArcGIS.

2.6 Scallop Density

After the marine reserves establishment, the juvenile scallops were reseeded into the bays in 2009. The *P. maximus* juveniles reseeded into Laxey Bay were 2 year old (mean of 51.2mm) and Niarbyl Bay were 3 year old (mean 107mm). In order to monitor the stock levels and the long term survival and growth rate of the tagged scallops, an annual dredging survey has been undertaken within the marine reserves. Therefore, the government historical database contains information on the scallop stock density within the predefined grids (Figure: 6a; 6b). The scallops recorded by the video sledge was used to estimate population densities within each historical grid (Figure: 6a; 6b). The density of scallops was converted into scallop per m^2 to allow for comparison with historical data.

The scallop density was calculated using the equation:

Density = No. Scallops per tow / Area Swept by video tow.

Area swept by the video sledge was calculated using the below calculation. The distance of transect was measured in ArcGIS after all sampling was undertaken.

Area Swept = width of camera frame (m) X distance of transect (m)

The historical density within each marine reserve was statistically analysed using ANOVA in SPSS.

The size-frequency analysis required the measurement of the scallops' width to the nearest mm. All scallops recorded in the benthic survey were measured except for partial scallops. The measurements were undertaken in ImageJ which had an accuracy ±4mm. The historical and 2016 scallop measurements were used to generate size-frequency plots, which were used to illustrate the temporal change in size distribution within the marine reserves. The reseeding population was identified in each year by estimating the potential average size based on Mason (1957) growth rate and second estimate was produced by calculating the growth rate of the populations based on the historical age with size data.

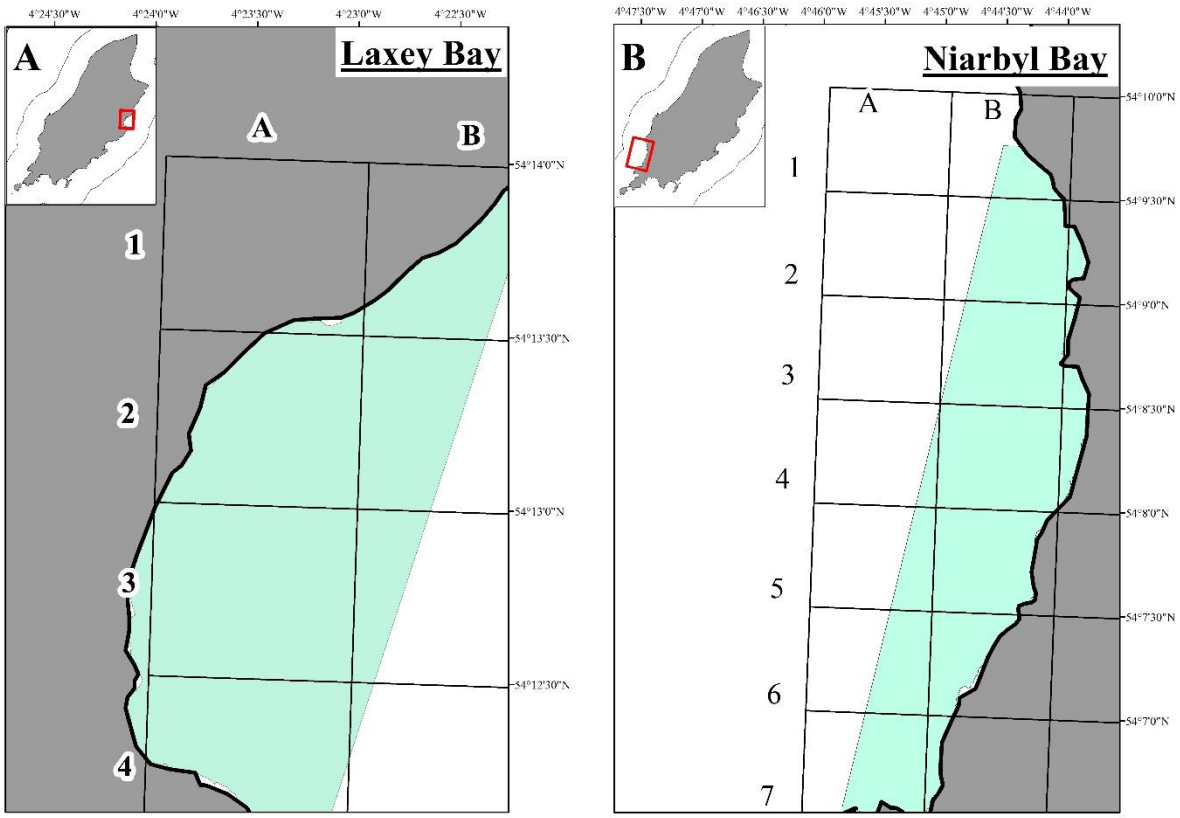

Figure 6: A map of the historical grid used to estimate scallop density per m². The black lines indicate the grid defined by the Isle of Man government department (DEFA) and the light turquoise indicated the closed area. Map A (left) is Laxey Bay and map B (right) is Niarbyl Bay.

2.7 Predation Pressure

The predator pressure on *P.maximus* was assessed by measuring their predator density. The predator species were identified from both the video sledge footage and BRUV data within Laxey and Niarbyl Bays marine reserves. The density within each historical grid was estimated using the video sledge data to allow for comparisons between the scallop density and their predator density. The density of scallop predators was estimated within each historical grid to give a visual indication of predation pressure to scallops. The density estimation for predators was carried out in the same way as the methodology for estimating scallop densities. The BRUV footage and video sledge footage was used to indicate the predator species within the reserves.

2.8 Habitat association

The aggregated tow data was used to analyse the relationship between the commercial species density and habitat complexity's percentage cover. The abundance data for king scallops (*P.*

maximus) and edible crabs (*C. pagurus*) was converted into density per tow. The habitat complexity percentage cover per tow was estimated, based on the groupings of habitat that were classed as complex. Habitats that were classified as complex are rocky, maerl beds, seagrass meadow, gravel, pebbles, and macroalgae habitats. The non-complex habitats were sandy, muddy and turf algae habitats.

The relationship between habitats complexity and the species *P.maxiums* and *C.pagurus* was analysed statistically using a quantile regression in R-statistics, which assesses the polygonal relationship rather than a simple linear relationship (Hiddink and Kaiser, 2005). The relationship with depth was also associated using a quantile regression. The quantile regression is a statistical tool that describes the relationship between the abundance and the limiting environmental factor, when other limiting factors occur simultaneously (Cade, *et al.*, 1999; Hiddink and Kaiser, 2005). The 50th quantile is equivalent to the linear regression. The 80th quantile was used to estimate the population limitation, the species abundance was limited by this environmental factor (Hiddink and Kaiser, 2005).

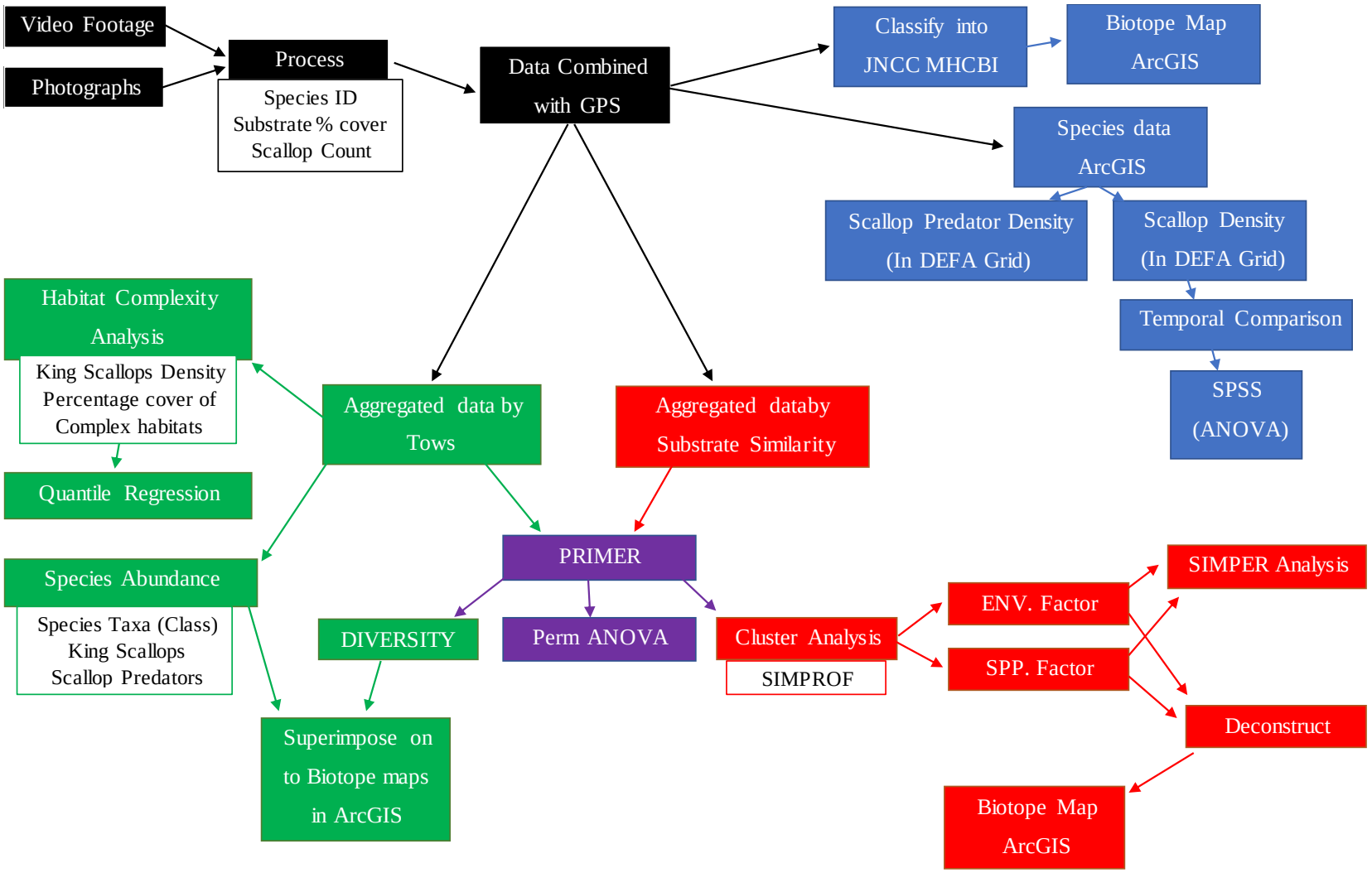

Figure 7: Method flow chart explaining the procedure and analysis used in the benthic survey. Blue indicates the process for the data that was not aggregated (top-down biotope map). Green indicates the process for the data that was aggregated by tow. Red indicates the process for the data that was aggregated by substrate similarity within each tow (Bottom-up biotope maps).

3 Results

3.1 Biotope Maps

The benthic survey was undertaken between 5m to 25m below chart datum (Figure:7), a total of six tows with 5 ten minute segments were taken for each marine reserve, however due to camera failure and the sledge getting stuck on a ghost fishing pot, one of the 1 hour video tows only acquired 20min of data. A total of 236 species were identified from the still images and video footages, and 19 mobile scavengers were identified from the BRUV footage in Laxey and Niarbyl Bays. The benthic habitat within the marine reserves was determined using the JNCC classification, as well as by using defining benthic community assemblage based on the results from a habitat analysis. The top-down biotope map was based on the JNCC MHCBI and the bottom-up biotope map was based on the PRIMER cluster groupings.

In Laxey Bay, the general distribution trend was recorded for the dominant class taxa within the marine reserve (Figure 8). *Polychaeta* had the greatest abundance and distribution throughout the bay (Figure 8). The most dominant *Polychaeta* was *Arenicola marina* which was distributed throughout with sandy substrate. *Malacostraca* had a wide distribution throughout the bay; with the hermit crab (*Pagurus spp*.) and swimming crabs (*Liocarcinus spp*.) being the most predominant species. *Asteroidea* had a small distribution and was only present in the centre of the bay at depths of 15m (Figure: 7 & 8); and the species most commonly observed was *Asterias rubens.*

In Niarbyl Bay, the general distribution trend of the dominant class taxa was recorded within the marine reserve (Figure 9). *Malacostraca* had a wide distribution throughout, with a large variability of species, the most common species observed were *Inachus dorsetensis*, *Cancer pagurus*, *Liocarcinus spp.* and *Necora puber*. *Asteroidea* were widely distributed below the depth 10m throughout the bay, but the most common species observed was *Marthasterias glacialis.* *Gastropods* and *Porifera* had a greater abundance on the southern side of the bay (Figure 9). *Phaeophyceae* and *Rhodophyta* had a greater abundance and a variety of species were observed in the most northern and southern part of the bay.

The species assemblage, abundance and distribution was different between the two marine reserves (Figure 8 & 9). Comparing Niarbyl Bay to Laxey Bay, indicated that Niarbyl Bay had a greater abundance of *Gastropods* and *Porifera* as well as a greater variety of algae phyla,

Phaeophyceae and *Rhodophyta* (Figure: 8; 9) and wider distribution with greater abundance of bivalves (Figure 8 & 9), however all the bivalves occurred within the 10 – 22m depth range (Figure 7).

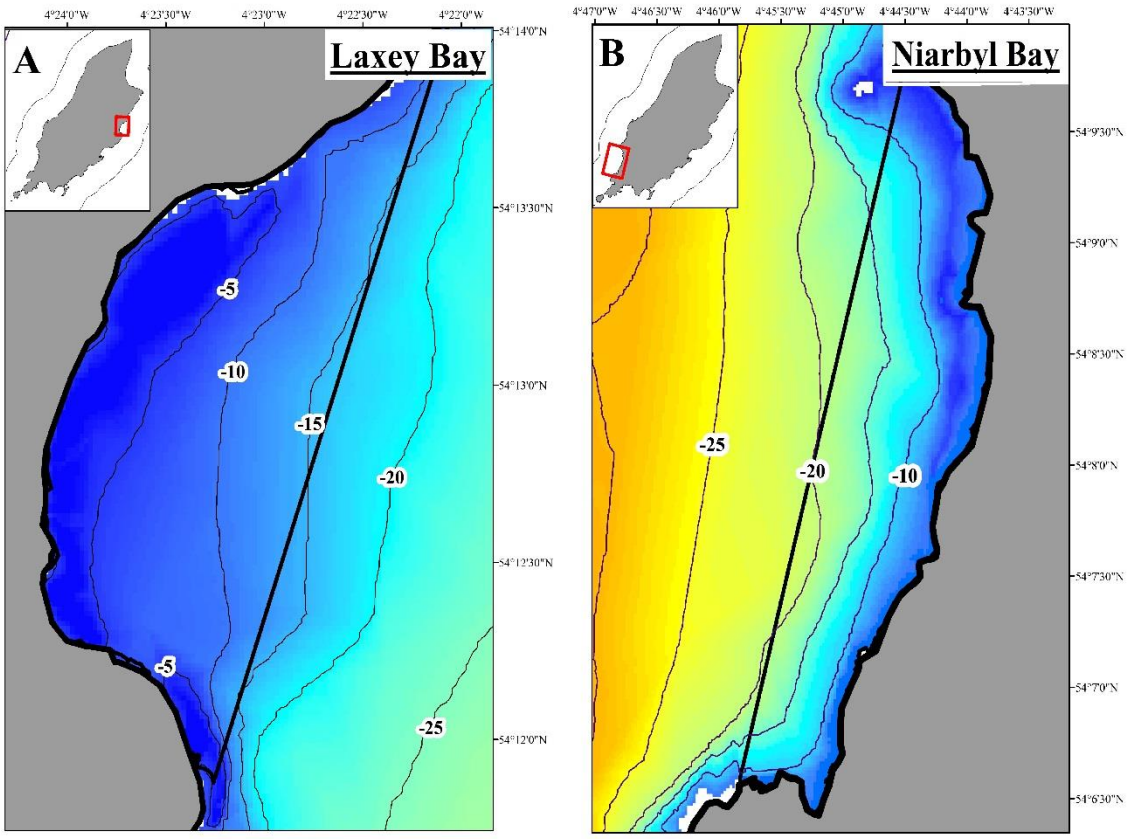

Figure 8: The bathymetry with depth contours for both marine reserves. The bathymetry background changes from dark blue (shallow water) to light orange (deep water). The thick black lines indicate the closed area borders. Map A (left) is Laxey Bays and map B (right) is Niarbyl Bay (Digimap, 2013).

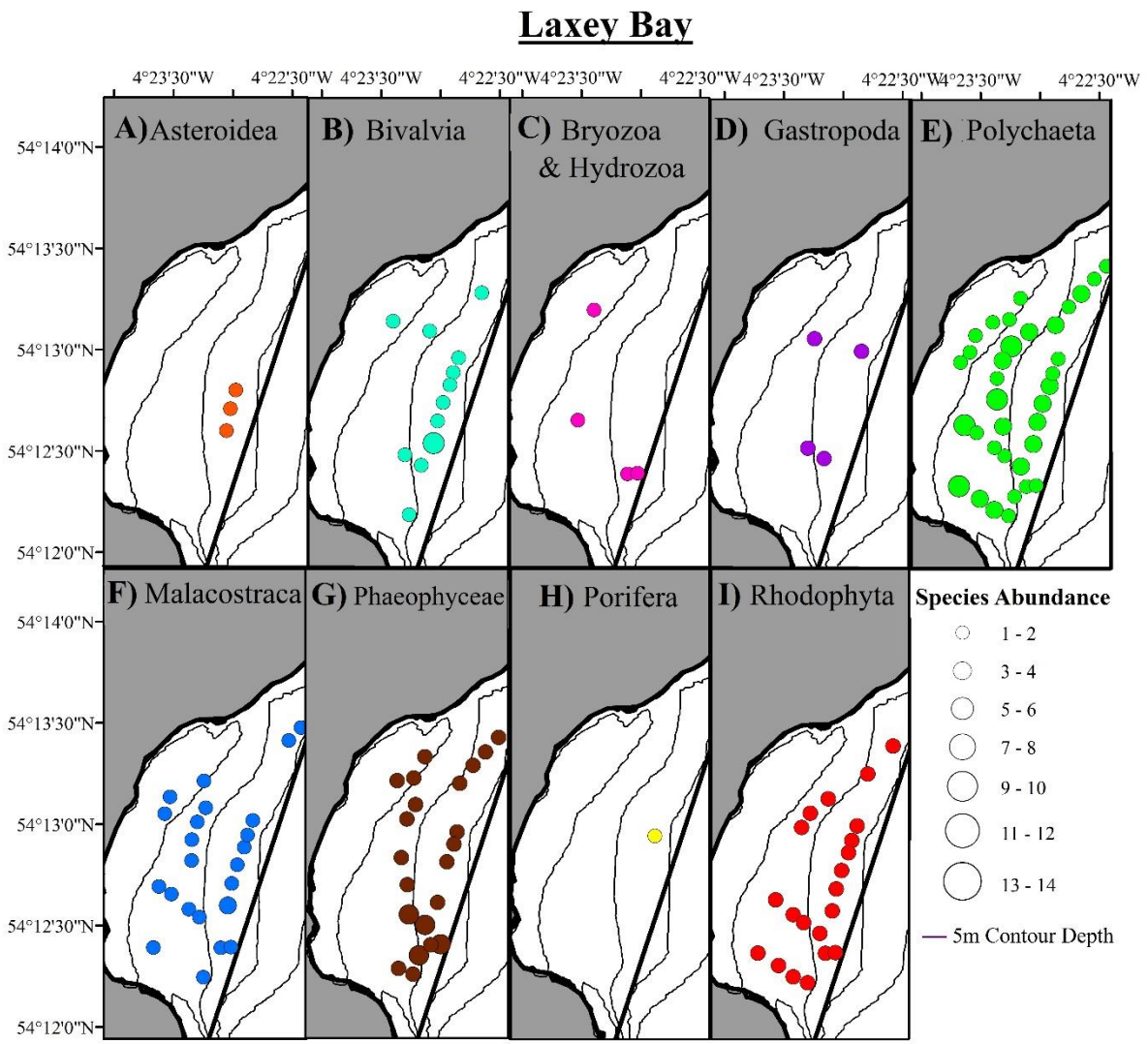

Figure 9: The abundance of the common taxonomy classes within Laxey Bay marine reserve. The abundance relates to the size of the circle. The thick black lines indicate the border closed area and the 5m depth contours are thin black line (starting 5m depth). The taxonomy classes are: A) Asteroidea (starfish); B) Bivalvia; C) Bryozoans and hydroids; D) Gastropoda; E)Polychaeta; F) Malacostraca (crabs and lobster); G)Phaeophyceae (brown algae); H) Porifera (sponges); I) Rhodophyta (red algae).

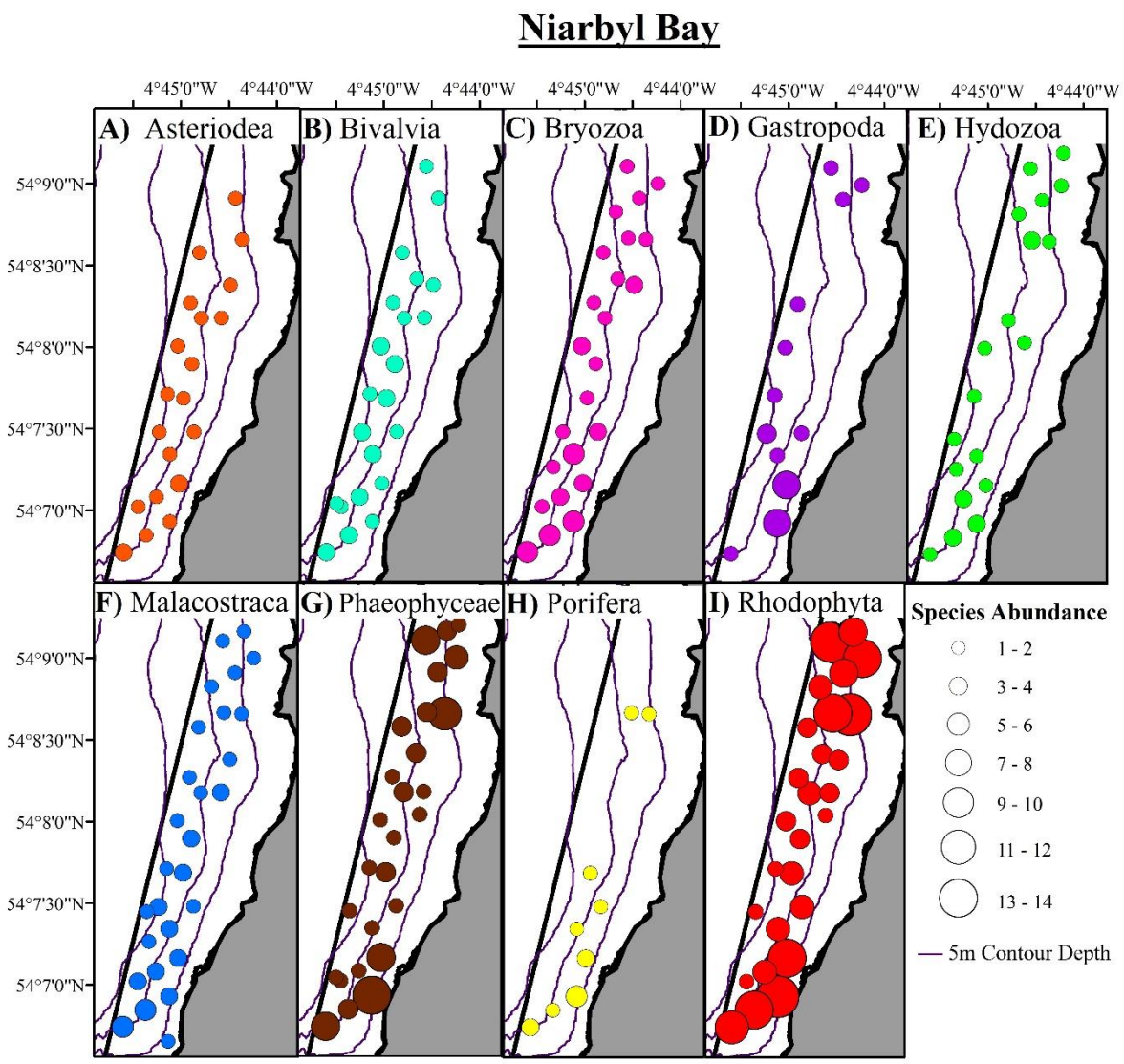

Figure 10: The abundance of common taxonomy classes within Niarbyl Bay marine reserve. The abundance related to the size of the circle. The thick black lines indicate the border of closed area and the 5m depth contours are thin black line (starting at 10m depth). The taxonomy classes are: A) Asteroidea (starfish); B) Bivalvia; C) Bryozoans; D) Gastropoda; E) Hydroid; F) Malacostraca (crabs and lobster); G) Phaeophyceae (brown algae); H) Porifera (sponges); I) Rhodophyta (Red algae).

3.1.1 Top-Down Approach

The JNCC biotope map generated in ArcGIS displays the distribution of the habitat within Laxey Bay and Niarbyl Bay (Figure 12a; 12b). Laxey Bay's benthic habitat comprised predominantly of sandy substrate with patches of two biogenic habitats (classified as SS.SMp.SSgr.Zmar and SS.SMp.Mrl) which are of conservation importance. SS.SMp.Mrl incorporates living and dead maerl. This biogenic classification was located in the centre of the bay at depths of 10-15m (Figure 12a). SS.SMp.SSgr.Zmar incorporates the eelgrass species *Zostera marina*. This habitat was located inshore at depth <8m on the southern side of the bay, which was away from the local town and public beaches (Figure 12a)

Niarbyl Bay had a diverse range of habitat types classified under the JNCC MHCBI (Figure: 12b). The area was dominated by rocky habitat (CR.MCR) and kelp forests (SS.SMp.KSwSS) in the shallow inshore (eastern) part of the bay. The areas classified as SS.SMp.KSwSS were predominantly dominated by *Rhodophyta* species and *Laminaria spp*. The central part of the bay was predominantly coarse substrate (SS.SCS), this classification includes stone, pebble, cobble and gravel substrate types. Whereas, the deeper parts of the bay were classified as either gravel sediment or brittlestar bed (SS. SBR). Niarbyl Bay benthos had two brittlestar biogenic habitats. The first and most common type of brittlestar bed occurred in the rocky substrate close inshore southern region of the bay. This habitat was classed as CR.MCR.EcCr (dark blue), which was a small brittlestar bed that comprises *Ophiothrix fragilis* and *Ophiocomina nigra* (Figure: 12b). The second brittlestar biogenic habitat was at a depth >15m in the south western part of the bay. This unique biogenic habitat comprised *Acrocnida brachiata* legs in sandy substrate and was classified as SS.SBR (pink) by the JNCC MHCBI (Figure: 12b).

The benthic species community assemblage was significantly different from the JNCC MHCBI across both marine reserves (PermANOVA: Pseudo-$F_{(11, 139)} = 3.623$; $p \leq 0.001$). The SIMPER analysis indicated that the *Spirorbis spirorbis* and *Arenicola marina* contributed the most to species dissimilarity between the classifications after taking into account those species that define specific biogenic reefs (*Acrocnida brachiata*; *Ophiothrix fragilis; Phymatolithon calcareum* and *Zostera marina).* The SIMPER analysis also indicated the most common epifauna species within each JNCC classification (Table: 5). This indicates that the commercially important species *Cancer pagurus* was a species that commonly occurred in gravel sediment shallower than 13m depth (SS.SCS.CCS). The SIMPER analysis also indicated

that *Pecten maximus* contributed to the similarity between the community composition within mixed substrate (SS.SMx.CMx) and gravel substrate (SS.SCS.CCS) (Table:5) at depths greater than 13m. *P.maximus* was also common within the communities associated with maerl habitat.

The species composition was significantly different (ANOSIM: Global R = 0.473; p = 0.01) between the marine reserves. Laxey Bay had an overall lower biodiversity and the greatest diversity occurred within its SS.SMp.Mrl habitat (2.3-2.9) (Figure: 13). Whereas, Niarbyl Bay had the highest diversity overall, with the greatest diversity occurring within the southern region where the habitat encompassed CR.MCR and CR.MCR.EcCr. The lowest diversity in Niarbyl Bay occurred in the centre of the bay at depth >15m (Figure: 14).

The habitat classified in the JNCC MHCBI system from both marine reserves were grouped for the biodiversity comparison; which indicated that diversity indices were significantly different (ANOVA: $F_{(11, 1363)} = 47.904$; $p = 0.000$) between habitat catagories. The habitat categories as CR.MCR and SS.SMp.KWSS had the greatest mean diversity (1.9±0.1 CR.MCR and 2.2 ±0.1 SS.SMp.KWSS) (Figure: 10). These two habitat categories had the greater species richness (9.6±0.8 CR.MCR and 12.3 ±1.2 SS.SMp.KWSS) compared to other habitat categories which was significantly lower (1- 6) (Figure 11). Species richness was significantly different (ANOVA: $F_{(11,1363)} = 34.695$; $p = 0.000$) between JNCC habitats.

Table 5: The species that contributed the most to the JNCC MHCBI categories similarity for both Laxey and Niarbyl Bay's marine reserves. The species were identified from the SIMPER results (contributed >4%).

JNCC MHCBI	Species	JNCC MHCBI	Species
SS.SMp.SSgr.Zmar	*Arenicola marina* *Zosteria marina*	**SS.SBR**	*Acronida brachiata*
SS.SSa.IFiSa	*Arenicola marina* Tube's	**SS.SSa.CFiSa**	*Arenicola marina*
SS.SMx.IMx	*Arenicola marina* *Lagis koreni* Tubes	**SS.SMx.CMx**	*Spirorbis spirorbis* *Turf* *Pecten maximus* *Rhodophyta spp.*
SS.SCS.ICS	*Rhodophyta spp.* *Cancer pagurus* *Cerianthus lloydii*	**SS.SCS.CCS**	*Spirorbis spirorbis* *Turf* *Thin Rhodophyta spp.* *Phymatolithon calcareum* *Cerianthus lloydii* *Pectin maximus*
SS.SMp.Mrl	*Phymatolithon calcareum* *Hydrobia spp* *Pagurus spp.* *Pecten maximus*	**SS.SMp.KWsSS**	*Spirorbis spirorbis* *Saccharina latissima* *Rhodophyta spp.* *Coralline encrusting*
CR.MCR	*Spirorbis spirorbis* Coralline encrusting *Thin Rhodophyta spp.* Encrusting brown algae	**CR.MCR.EcCr**	*Ophiothrix fragilis* *Spirorbis spirorbis* Coralline encrusting Small *gastropoda*

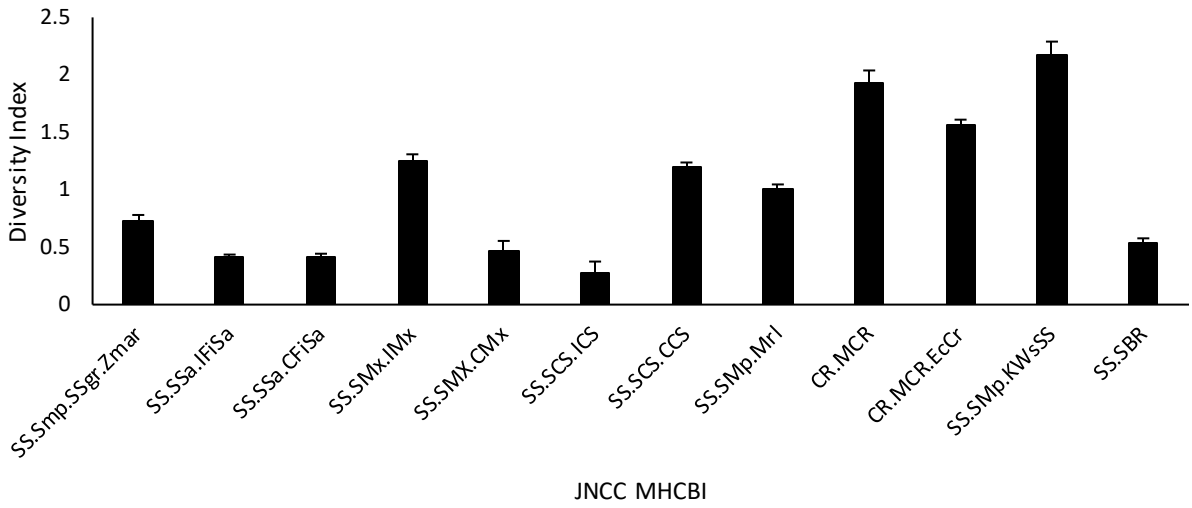

Figure 11: Mean diversity index (Shannon-Wiener) for JNCC habitat categories, for combined data of Laxey and Niarbyl Bay (IOM). The greater the Shannon-Wiener value the more diversity the habitat.

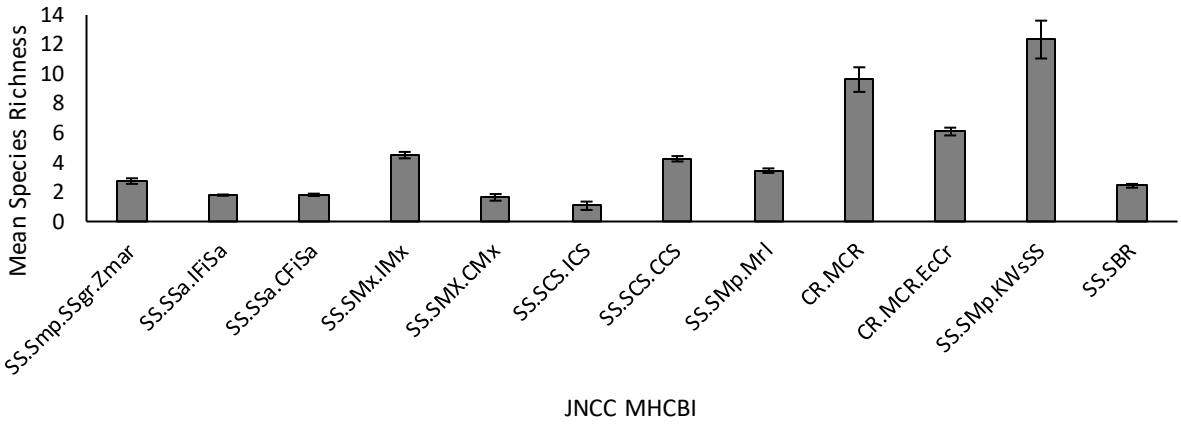

Figure 12: Mean species richness value for JNCC habitat categories for combined data of Laxey Bay and Niarbyl Bay (IOM).

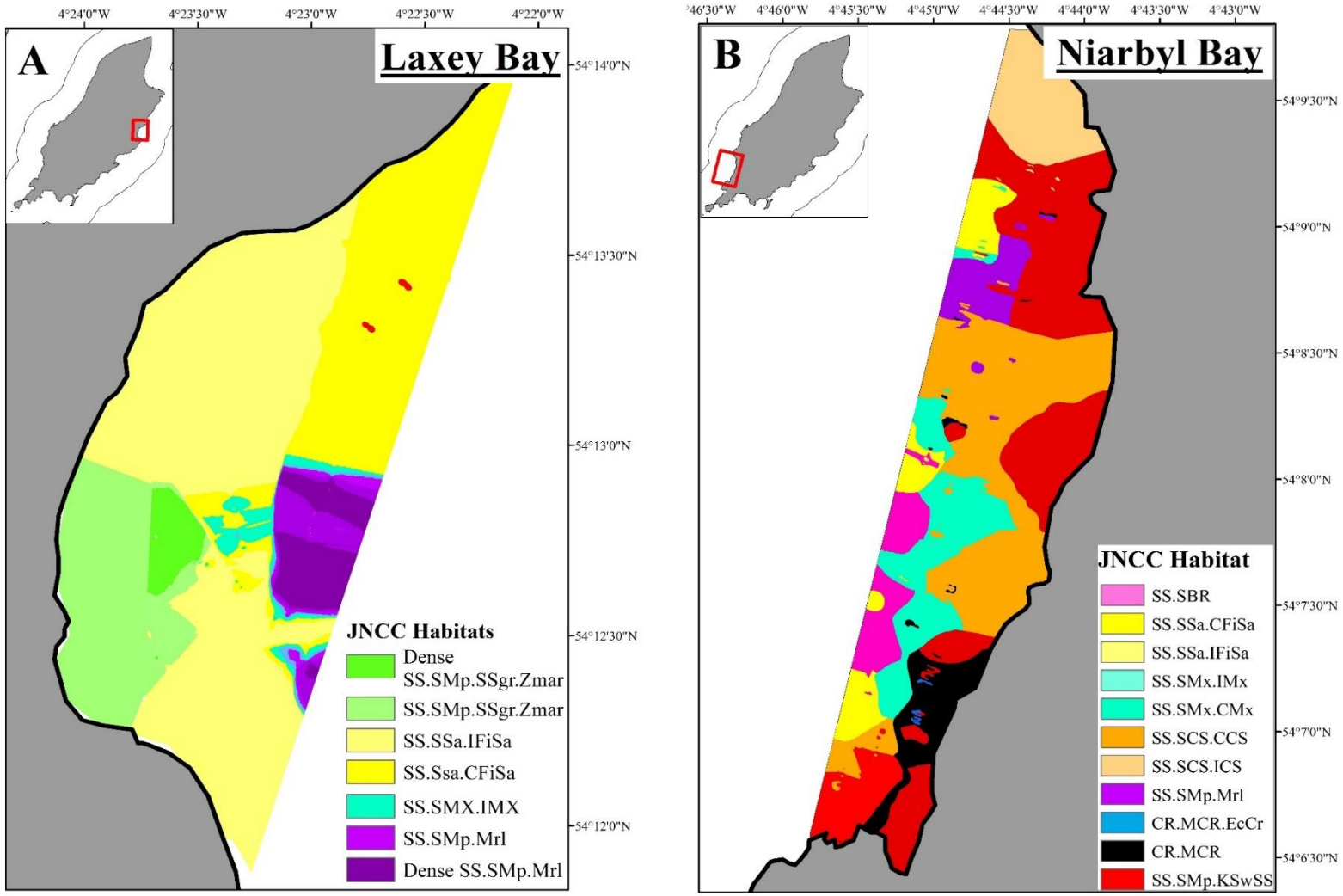

Figure 13: Biotope map of the two marine reserves in the Isle of Man territorial waters. The biotope maps were generated according to the JNCC habitat categories in ArcGIS. Map A (left) indicates the biotope map for Laxey Bay marine reserve. Map B (right) indicates the biotope map for Niarbyl Bay Marine reserve.

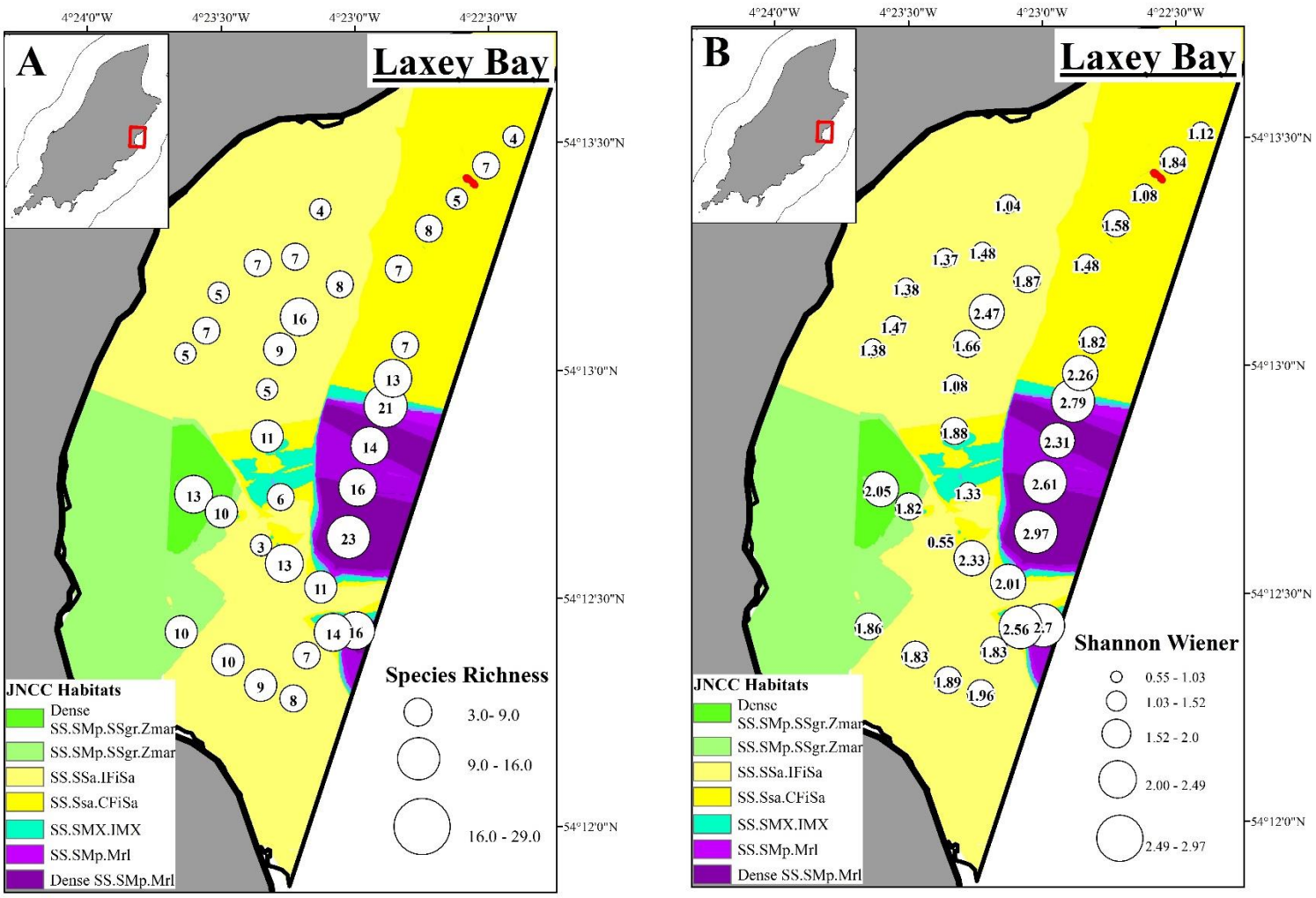

Figure 14: Diversity indices for the 10 minute tows were superimposed onto the JNCC Biotope map for marine reserve of Laxey Bay in the IOM territorial waters. Map A (left) indicates the spatial distribution of species richness. Map B (right) indicates the spatial distribution of diversity index.

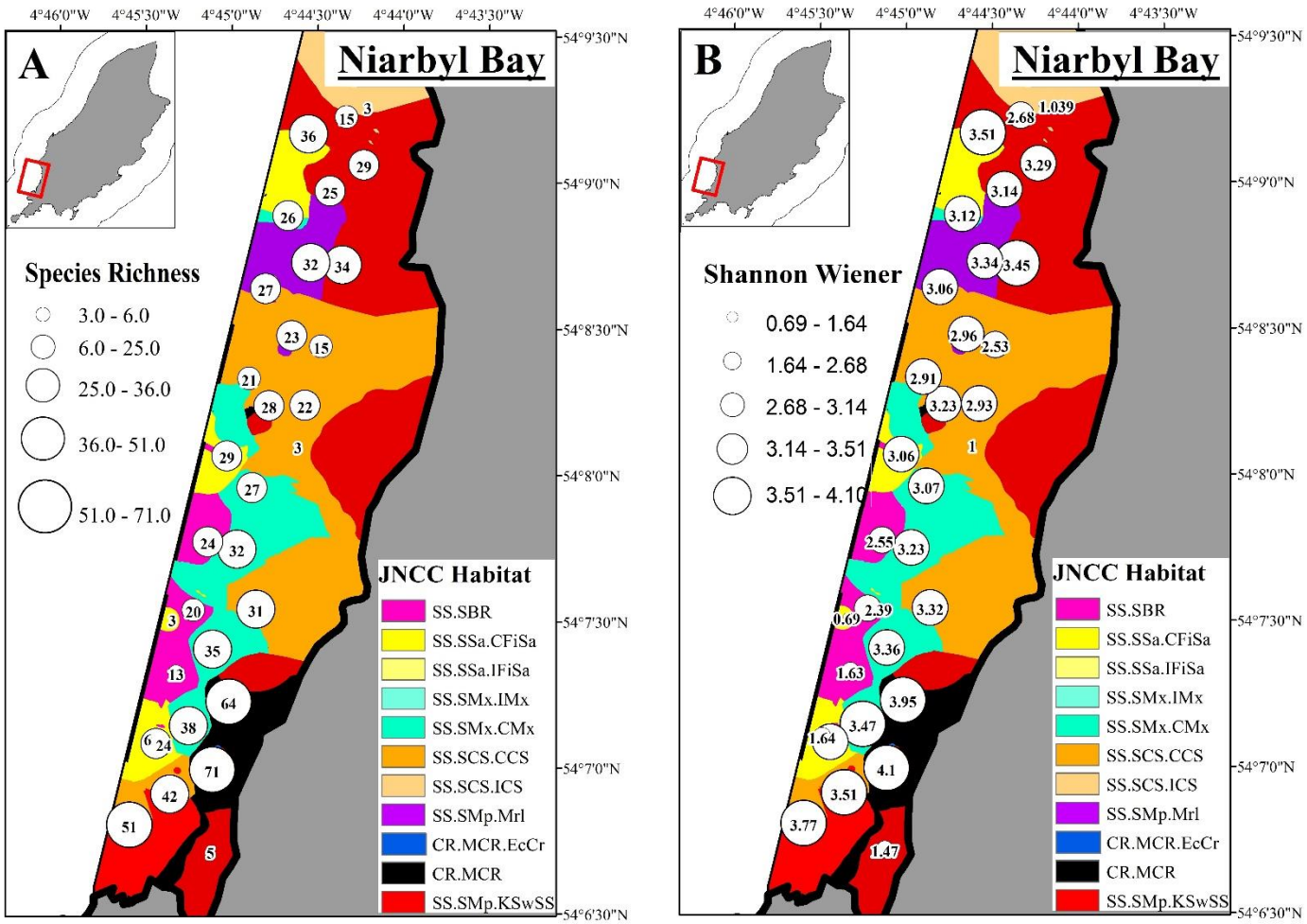

Figure 15: Diversity indices for the 10 minute tows were superimposed onto the JNCC Biotope map for the Niarbyl Bay marine reserve in the IOM territorial waters. Map A (left) indicates the spatial distribution of species richness. Map B (right) indicates the spatial distribution of diversity index.

3.1.2 Bottom-up Approach

The biotopes maps were generated for the bottom-up approach based on the outputs created by the PRIMER function cluster and SIMPROF factor creator. Two cluster groupings were created during the cluster analysis, resulting in cluster factors being identified. The first cluster grouping was based on the environmental variables (Figure: 16) and the second was based on the community assemblages (Figure: 18). The PRIMER function BEST indicated a significant correlation (BEST: Rho = 0.485; p = 0.01) between species community composition and the environmental variable (particularly: gravel and sandy sediment, maerl bed, *Zostera* meadow and depth). There was no autocorrelation with the environmental data. The cluster grouped factors were used to generate biotope maps in ArcGIS.

The benthic community assemblage associated with environmental variables of depth and substrate type was significantly different between the environmental cluster factors created (Env. Factor) (PermANOVA: Pseudo-$F_{(17, 133)} = 7.889$; $p \leq 0.001$). The biotope map of these clusters indicated that the most prominent factor occurring was "K" in Laxey Bay and "P" in Niarbyl Bay (Figure: 17). The biotope map of Laxey Bay displayed a greater range of habitat types compared to the JNCC classification, with the environmental factors indicating that a different habitat community "F" occurs in inshore areas (western centre) (Figure: 17a). In Niarbyl Bay, there were fewer differences between the varieties of habitats that were classified when comparing the different approaches (top-down and bottom-up). As Env. bottom-up approach indicated that Niarbyl Bay was predominantly classed as "L", "N", "P", "Q" (Figure: 17b). Habitat "N" and "Q" occurred in the northern part of the bay; "L" occurred at depths greater than 15m near the outer edge of the marine reserve (Figure: 17). The PCA indicated that "K" and "F" were predominantly associated with the environmental variables of sandy, *Zostera* meadow and maerl based substrate (Figure: 15); thus the differences between these habitats were associated with community composition. The PCA plot indicates that the major habitats in Niarbyl Bay classed as "P" were predominantly pulled by pebble/cobble substrate and depth (Figure: 15). Habitat "L" and "Q" in the PCA plot were associated with the environmental substrates of sand, gravel sediment, and brittlestar beds (Figure: 15). Habitat "N" was associated with substrates that comprised *Laminaria spp* and *Rhodophyta spp*. (Figure: 15). The SIMPER analysis for this cluster factor (Env. Factor) indicates which species contributed most to the similarity within the community of each factor type (Table: 6). The commercially important shellfish species *P. maximus* was identified to be a similar species in the communities sampled in the Env. Factor "L" and "P" which occurred throughout Niarbyl Bay (Figure: 17 &

Table: 6). In Laxey Bay *P.maximus* occupied areas classed as "R", "J" and "I", which all comprised maerl and coarse sediment. *C. pagurus* was identified as a SIMPER species for the Env. Factor "I" which occurred in very small patches around Laxey and Niarbyl Bays (Figure: 17).

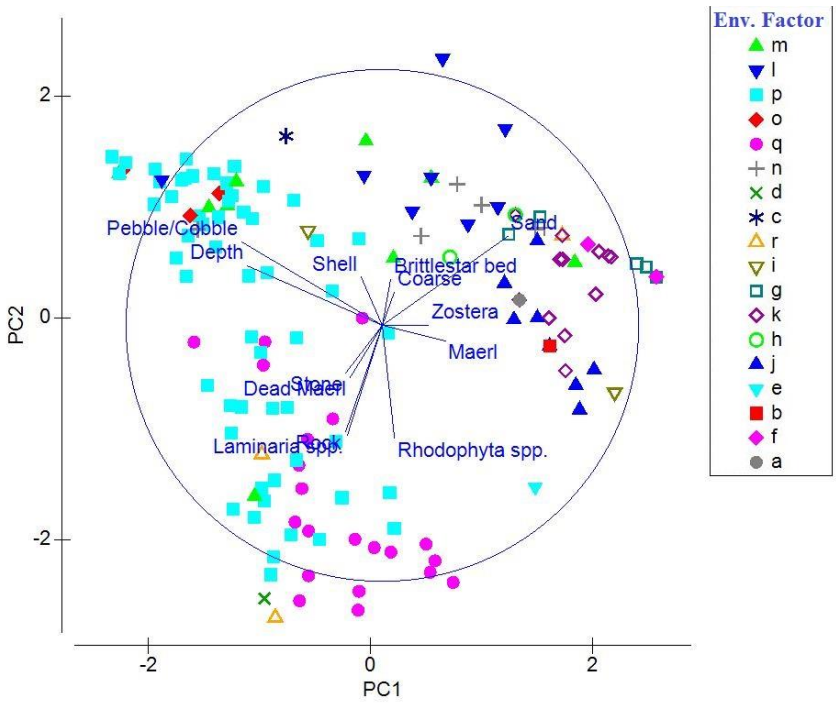

Figure 16: PCA plot illustrates the distribution of the Env. Factor according to their environmental variable.

Table 6: The species that contributed the most to the similarity within Env. Factor categories for Laxey and Niarbyl Bays marine reserves. These species were identified from PRIMER v.6 SIMPER results (contributed >4%).

Env. Factor	Similarity species	Env. Factor	Similarity species
"B"	*Hydroid spp.*	**"L"**	*Acronida branchiate* *Arenicola marina* *Cerianthus lloydii* *Pecten maximus*
"F"	*Tube's*	**"M"**	*Turf* *Coralline encrusting*
"G"	*Arenicola marina* *Zosteria marina*	**"N"**	*Clavelina lepadiformis* *Rhodophyta spp.*
"H"	*Pagurus spp.*	**"O"**	*Sponge spp.* *Turf* *Pagurus* *Spirorbis spirorbis* *Bryozoans*
"I"	*Cerianthus lloydii* *Cancer pagurus* *Phymatolithon calcareum*	**"P"**	*Spirorbis spirorbis* *Coralline crust* *Turf* *Pectin maximus* *Phymatolithon calcareum*
"J"	*Phymatolithon calcareum* *Hydroid spp.* *Turf spp.*	**"Q"**	*Rhodophyta (Red V)* *Saccharina latissima* *Coralline encrusting* *Electra pilosa*
"K"	*Arenicola marina* *Tube's* *Pagurus spp.*	**"R"**	*Phymatolithon calcareum* *Rhodophyta spp.* *Ophiura ophiura*

The benthic community assemblage within Laxey and Niarbyl Bays marine reserves was significantly different between the generated cluster factor (Spp. Factor) which was based on the species composition (PermANOVA: Pseudo-F $_{(27, 123)}$ = 6.8189; p ≤0.001). The pairwise comparison indicated that species factors (Spp. Factor) were significantly different, except for those Spp. Factors that had low replication of the same community composition (i.e. "Y", "T", "S", "N" and "J") (Appendix:3). The biotope map of the Spp. Factors indicated that the benthos in Laxey Bay was predominantly classed as "L" habitat (Figure: 19). Whereas the benthos in Niarbyl Bay was predominantly "R", however Niarbyl Bay had a greater diversity of Spp. Factor. The SIMPER results displayed the species and environmental variable that contributed to the most similarity between the samples for each factor (Table: 7). The cluster Spp. Factor indicates that Laxey Bay had unique community assemblages, classed as "F", in the sandy substrate area at depths of <5m at chart datum. The cluster Spp. Factor for Laxey Bay that comprised of maerl beds was "K", and "I". The factor that comprised mostly of *Zostera* (seagrass meadow) was classed as "G", located on the shallow southern part of the Bay.

Niarbyl Bay had a variety of habitat distributed throughout the bay, in the north part Spp. Factors "X", "AA" and "P" are most prominent (Figure: 19). In the centre of the bay the most prominent Spp. Factors are "R", "M" and "X", whereas in the south the prominent Spp. Factors are "R", "T", "U", "V", and "M"(Figure: 19). The area classed as "M" had a unique brittlestar benthos which comprised small *A.brachiata* legs with the species *Cerianthus lloydii* (SIMPER: Table: 7). The area classed "R" comprises of gravel sediment with a community of *Rhodophta* and S*pirobis spirobis* (SIMPER: Table: 7). The area classed as "U" was relatively small with a rocky substrate that had a community containing several juvenile scallops (*P. maximus* and *A. opercularis* were observed).

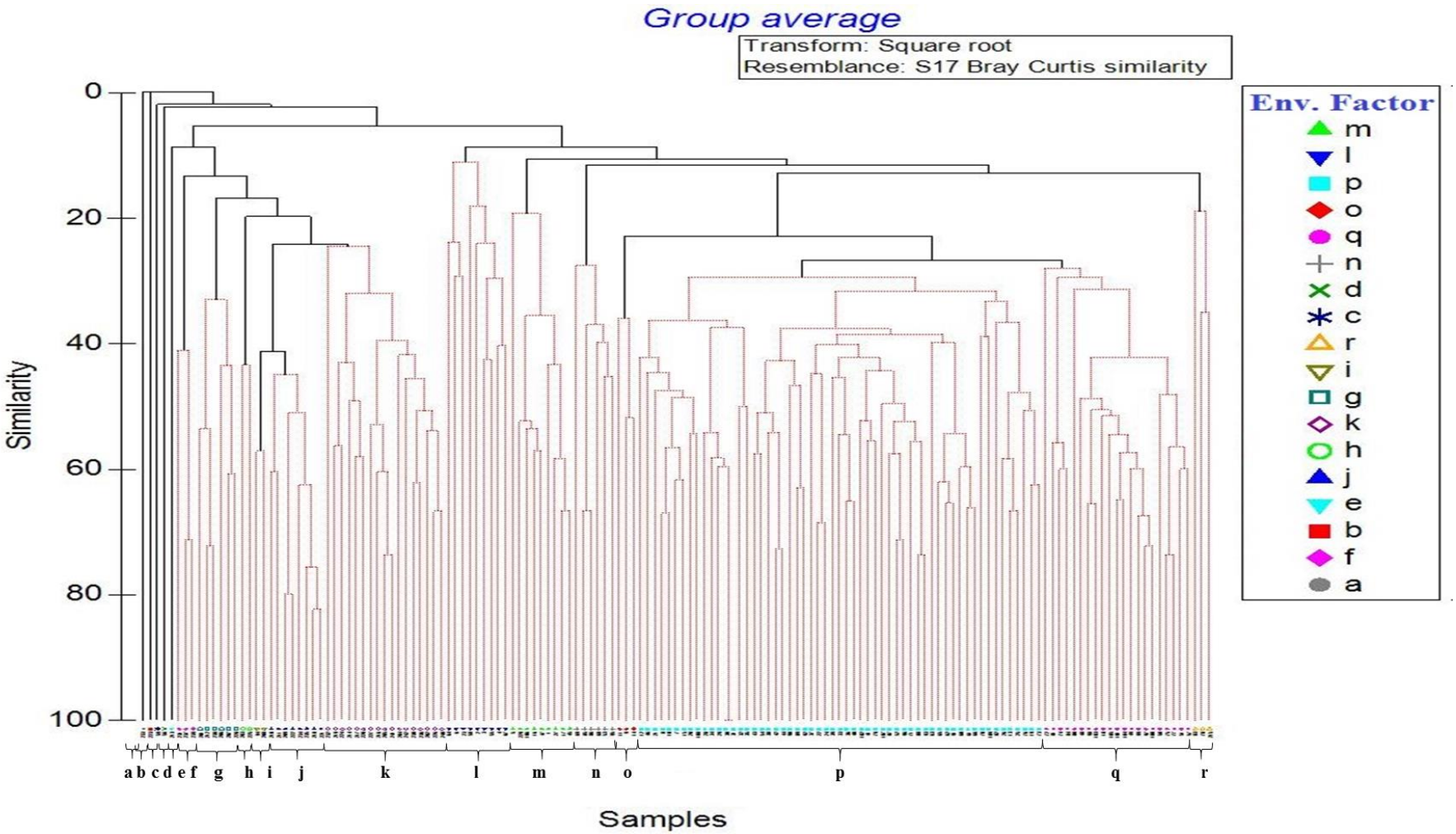

Figure 17: The cluster chart for all the species identified within Laxey and Niarbyl Bays. The cluster represents the groupings based on the benthic species assemblages with the categories based on the Env. Factors which was determined by the SIMPROF analysis of the environmental variables (substrate and depth. These Env. Factors are indicated at the bottom on the cluster chart.

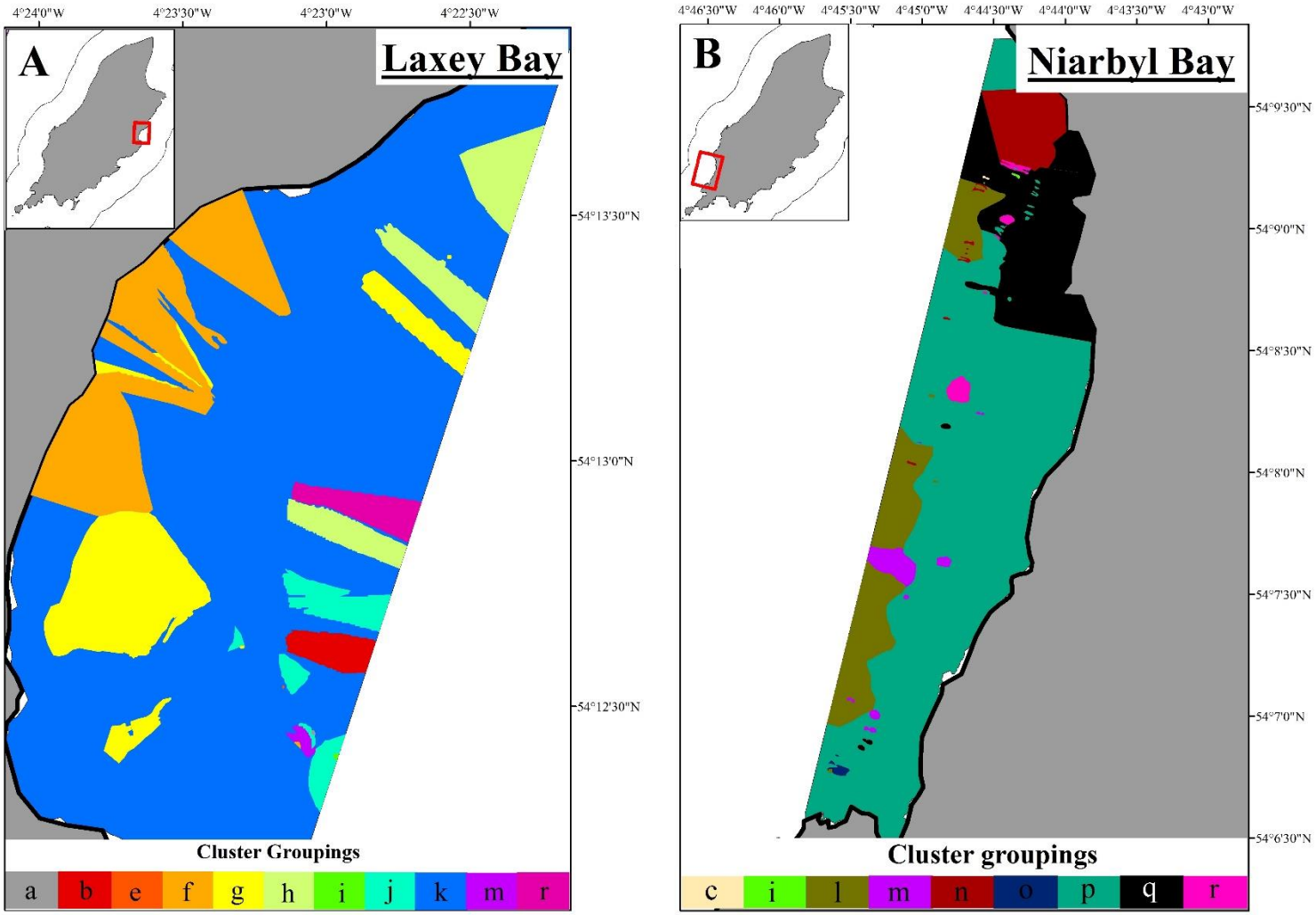

Figure 18: ArcGIS biotope map of Env. Factor in two marine reserves in the IOM territorial waters. Map A (left) indicates the spatial distribution of Env. Factor within Laxey Bay marine reserve. Map B (right) indicates the spatial distribution of the Env. Factor within Niarbyl Bay marine reserve.

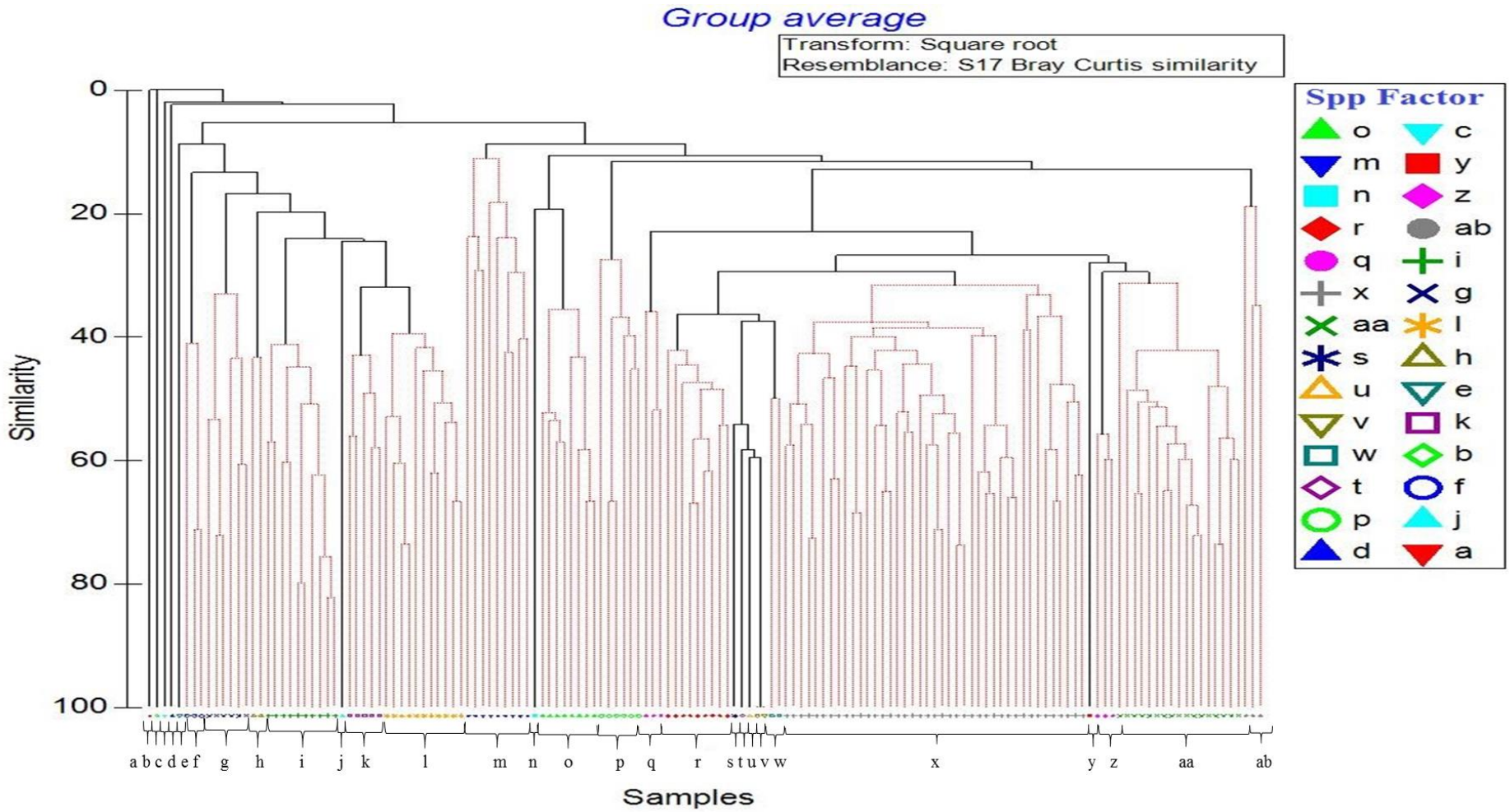

Figure 19: The cluster chart of all the species identified within Laxey and Niarbyl Bays. The cluster represents the groupings based on the benthic species assemblage with the categories based on the Spp. Factors which was determined by the SIMPROF analysis on the benthic species. The Spp. Factors defined by the SIMPROF analysis on the species assemblage are indicated at the bottom on the cluster chart.

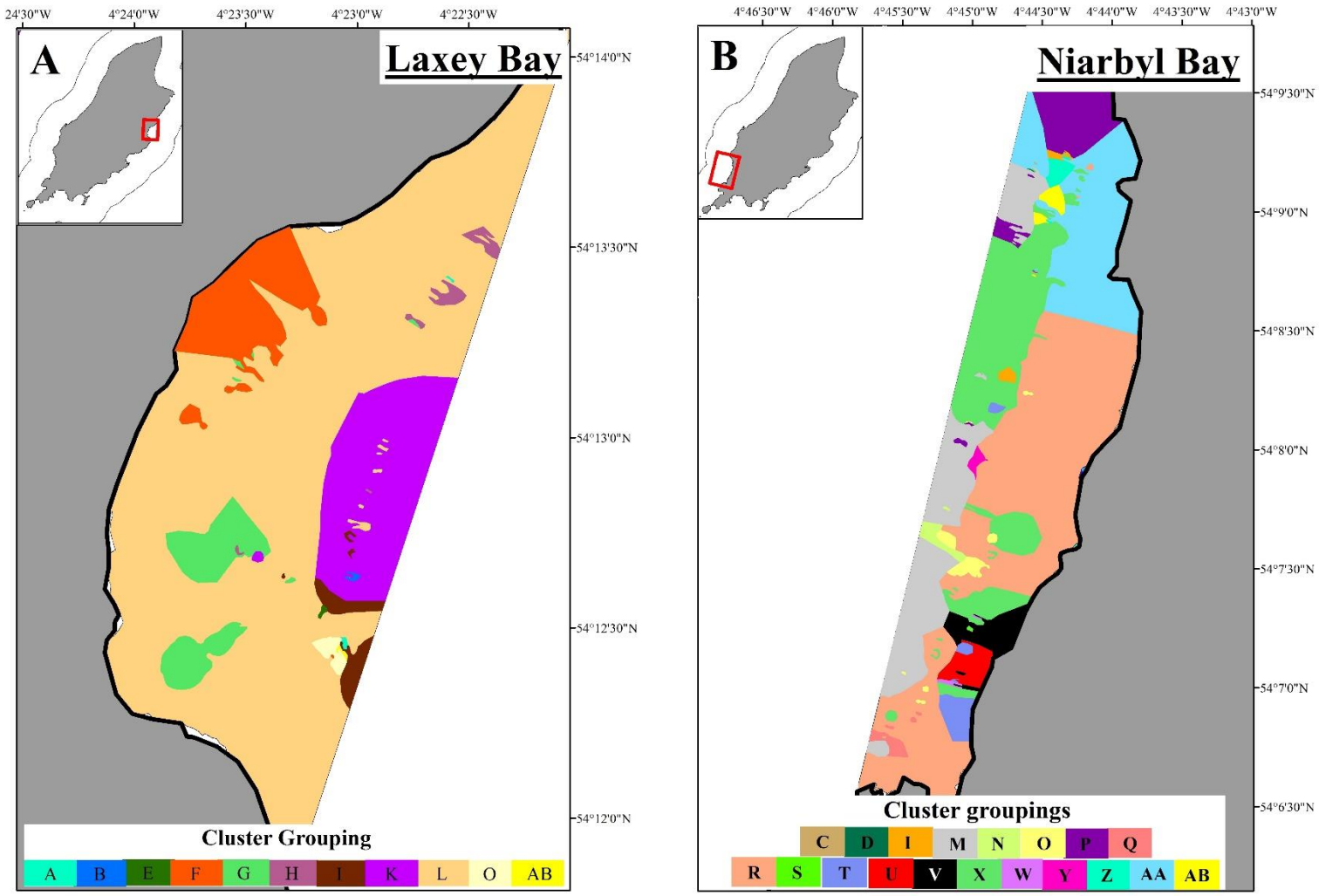

Figure 20: ArcGIS biotope map of the Spp. Factor categories within the two marine reserves in the IOM territorial waters. Map A (left) indicates the spatial distribution of Spp. Factor within Laxey Bay marine reserve. Map B (right) indicates the spatial distribution of the Spp. Factor within Niarbyl Bay marine reserve

Table 7: The species and environmental variables that contributed to the highest similarity between the Spp. Factor category defined by the SIMPROF analysis for both Laxey and Niarbyl Bays marine reserves. The species and environment were identified to contributed >4% to similarity within the groups.

Cluster Group	Species	Environmental variable
Group a	Section within sandy habitat (L)	
Group b	Section within Maerl (K)	
Group c	Section within rocky habitat (AA)	
Group d	Section between sandy brittlestar bed (M) and rocky (AA)	
Group e	Section between sand (L) and mixed sediment (I)	
Group f	Tube's	Shell
	Zostera marina	Shallow Depth
Group g	*Arenicola marina*	Eelgrass bed (*Zostera*)
	Pagurus spp.	
	Zostera marina	
Group h	*Pagurus spp.*	Gravel sediment
		Sandy sediment
Group i	*Phymatolithon calcareum*	Maerl beds
	Hydrobia	Gravel sediment
	Turf Brown	
Group k	*Pagurus spp.*	Maerl beds
	Ophiura ophiura	
	Hydrobia	Sandy sediment
	Phymatolithon calcareum	
Group l	Tube's	Depth <20m
	Lagis koreni	
	Hydrobia	Low Gravel sediment
	Arenicola marina	

Cluster Group	Species	Environmental variable
Group m	*Cerianthus lloydii*	Brittlestar beds (*A.brachiata*)
	Acrocnida brachiata	
	Arenicola marina	
Group n	Between two brittlestar beds (M)	
Group o	Coralline encrusting	Stone benthos
	Turf Brown	Depth <20m
Group p	*Clavelina lepadiformis*	Gravel sediment
	Thin Red I	Low sandy sediment
Group q	Sponge I	Rocky benthos
	Turf Brown	Pebble/cobble
	Bryozoan I	Low shell
	Thin Brown I	Seaweed
	Spirorbis spp.	
Group r	*Spirorbis spp.*	Gravel sediment
	Encrusting brown	Stones
	Red I	Depth <20m
	Thin Brown	
Group s	Within rocky and brittlestar region	
Group t	Brittlestar: *Ophiothrix fragilis* and *Ophiocomina nigra*	
Group u	Rocky habitat: juvenile scallop community	
Group v	*Spirorbis spp.*	Rocky benthos
	Gastropoda I	
	Bryozoan I	

Table 8 Continue: The table illustrated the species and environmental variables that contributed the most to the similarity between the Spp. Factor categories within both Laxey and Niarbyl Bays marine reserves. The species and environment were identified by the PRIMER v.6 SIMPER results (contributed >4%).

Cluster Group	***Species***	***Environmental variable***
Group w	Encrusting brown	Stone benthos
	Gibbula cineraria	
	Red I	
	Small gastropoda	
	Thin Brown I	
	Turf Brown	
	Unknown V	
Group x	*Spirorbis spp.*	Dead Maerl
	Coralline crust	Stoney/Cobble/Pebble benthos
	Thin Red II	Rocky benthos
Group y	Between brittlestar bed (M) and gravel sand (R)	
\Group z	Red IV	Seaweed
	Red V	Dead Maerl
	coralline crust	Gravel Sediment
	Thin Red I	
Group aa	*Saccharina latissima*	Rocky Benthos
	Electra pilosa	*Laminaria* spp.
	Red V	
	coralline crust	Seaweed
	Spirorbis spp.	
Group ab	*Phymatolithon calcareum*	Stone
	Ophiura ophiura	
	Red I	Dead Maerl
	Red V	*Laminaria* spp.

3.2 BRUV

Seven BRUV's were deployed within each marine reserve but only five BRUV's per site had video footage that adhered to the recommended 60minute. The ten BRUV's were used to calculate the diversity indices within PRIMER v.6. However, all BRUV footage collected regardless of recording time were used to superimpose the mobile species presence within each marine reserve (Figure: 20). In Laxey Bay the most abundant mobile scavenger present was *Pagurus spp*. (hermit crab), and the most common hermit crab species was *Pagurus bernhardus*, as *Pagurus prideaux* was only recorded three times. *Scyliorhinus canicula* was observed in every BRUV deployed within Laxey Bay. *Buccinum undatum* was observed within the bay at a range of sizes. The greatest diversity of mobile scavengers (1.68) occurred in the sandy substrate near the northern perimeter of the bay (Figure: 21).

The mobile scavenger population within Nairbyl Bay varied throughout the bay (Figure: 20). The northern part of the bay had a mobile community that comprised *Scyliorhinus canicula*, *Cancer pagurus* (edible crab) and *Pagurus spp*.. Whereas the southern part of the bay comprised *Ophiura spp*. (brittlestar) and bony fish with a few *Pagurus spp*. being observed (Figure: 20). The diversity within the bay was greater in sandy substrate (1.64) on the perimeter of the southern region (Figure: 22).

Overall Laxey Bay had the greater abundant of *Pagurus spp*. population compared to Niarbyl Bay. Niarbyl bay had the greater abundance of bony fish and *Ophiura spp*. The greatest mobile scavenger diversity occurred in the sandy substrate in both marine reserves. The other habitat that had relatively high diversity and species richness were maerl (1.62), *Zostera* meadow (1.28) and shallow rocky habitats (1.47) (Figure: 21 & 22)

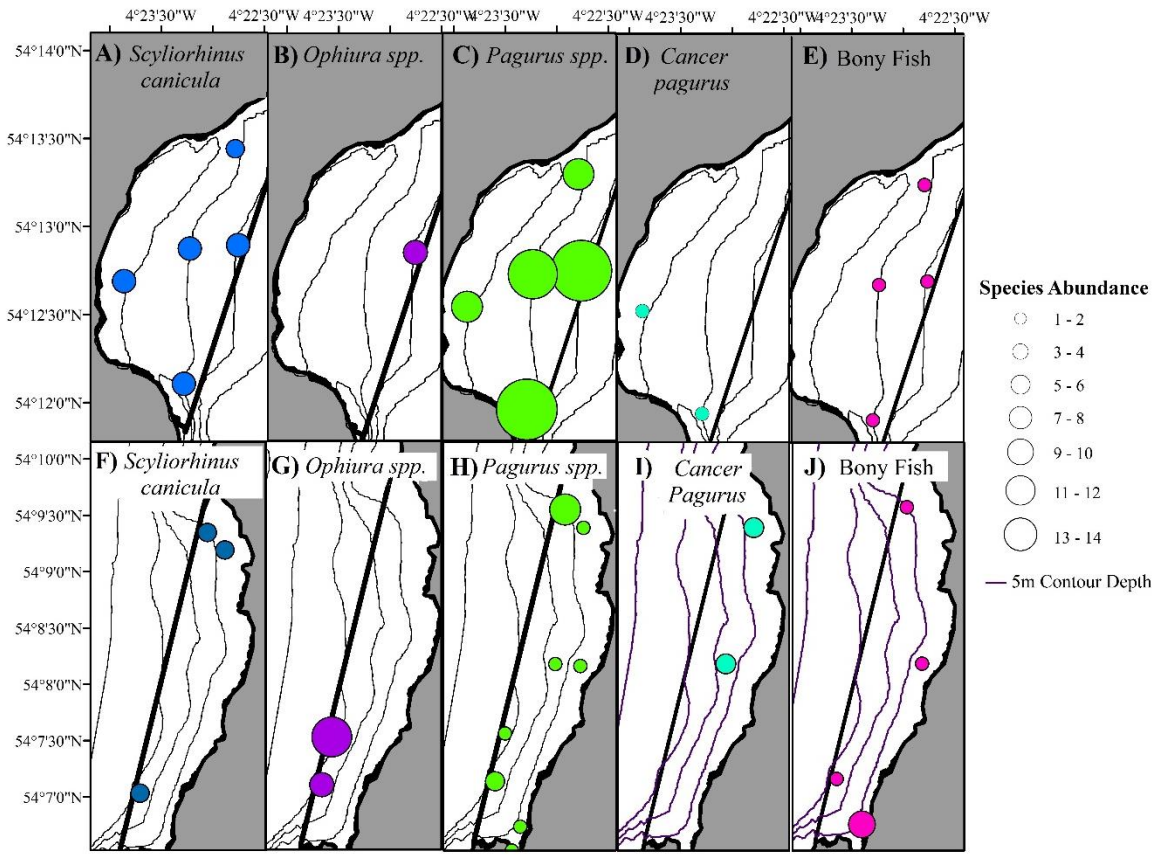

Figure 21: The abundance of common taxonomy classes recorded with the two marine reserves. The abundance (MaxN observed in a single point in time) relates to the size of the circle. Maps A to E are in Laxey Bay and maps F to J are in Niarbyl Bay. The thick black lines indicate the border of the closed areas and the thin black line 5m depth contours (start 5m for Laxey Bay and 10m for Niarbyl Bay). The taxonomy classes are: A & F) Scyliorhinus canicula (Common catshark); B & G) Ophiura spp. (brittlestar); C & H) Pagurus spp. (hermit crab); D & I) Cancer pagurus (Edible crab); E & J) Bony fish (pelagic and demersal fish species).

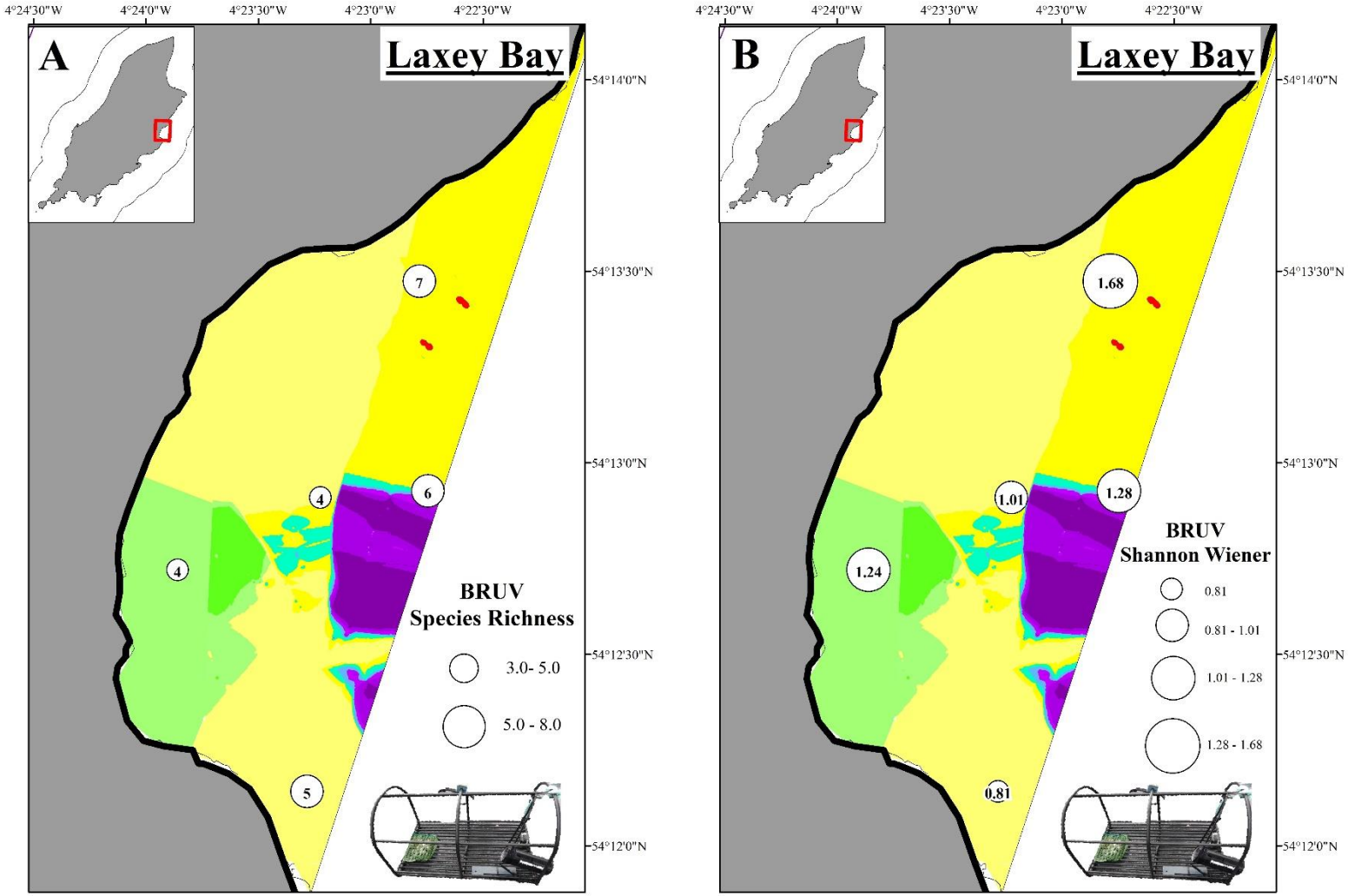

Figure 22: Diversity indices from the BRUV video footage was superimposed onto the ArcGIS JNCC biotope map for Laxey Bay marine reserve in the IOM territorial waters. Map A (left) indicates the spatial distribution of species richness. Map B (right) indicates the spatial distribution of diversity index.

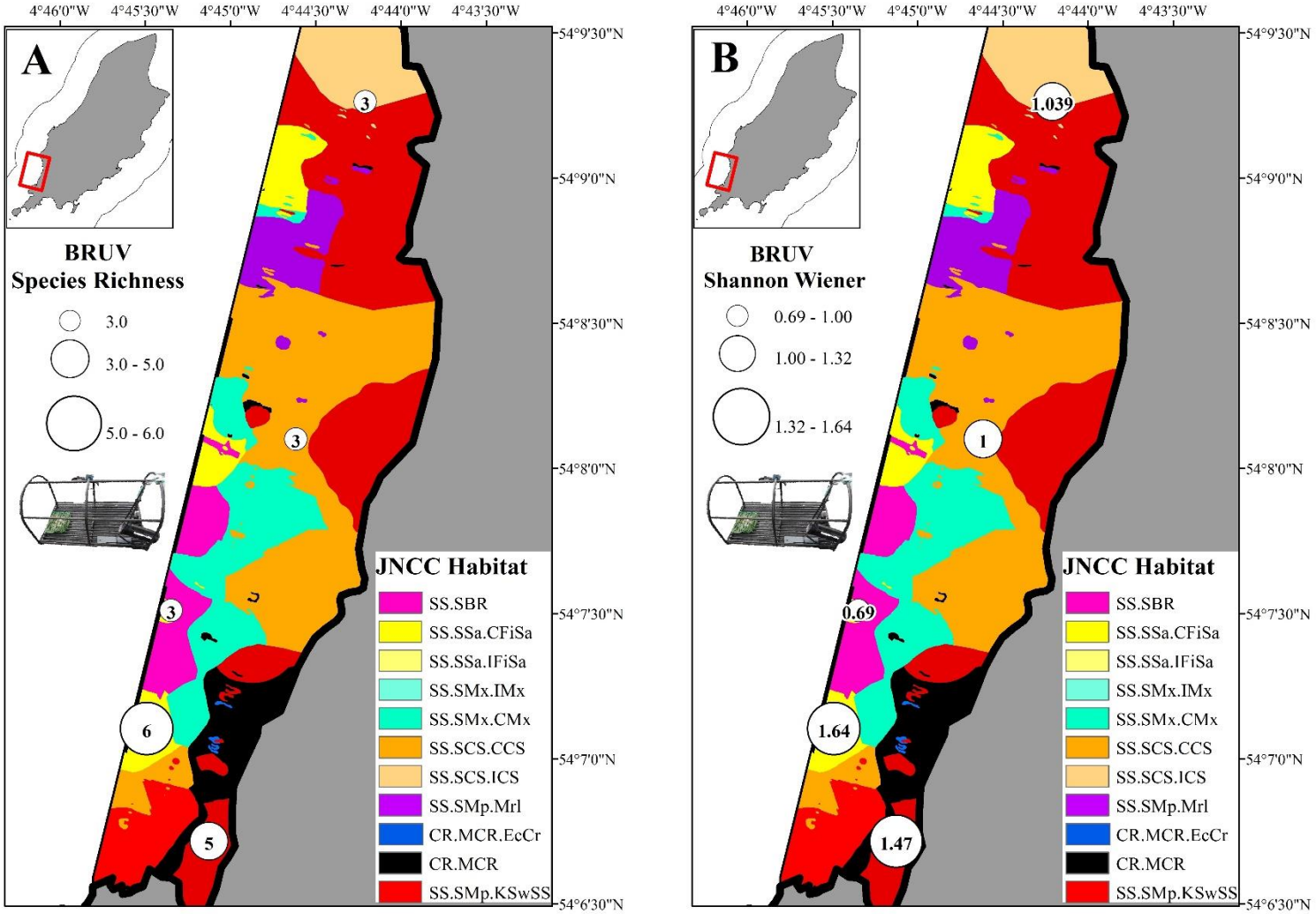

Figure 23: Diversity indices from the BRUV video footage was superimposed onto the ArcGIS JNCC biotope map for Niarbyl Bay marine reserve in the IOM territorial waters. Map A (left) indicates the spatial distribution of species richness. Map B (right) indicates the spatial distribution of diversity index.

3.3 Commercially Important Shellfish Species

All the commercially important shellfish were observed within at least one of the marine reserves, however the most abundant species observed was the scallop, *P. maximus* and the edible crab, *C. pagurus*. The distribution and size pattern of *P. maximus* was described below, however due to the cryptic nature of these species the abundance estimates may be much lower than the existing population within the reserves.

3.3.1 Scallop Distribution

In Laxey Bay, the observed population of *P. maximus* population was relatively small, with only 22 individuals being recorded. This population congregated in the centre of the bay at depths of approximately 15m within substrate comprising of maerl and gravel. The biotope maps indicated that scallops were present in the habitat classed as SS.SMp.Mrl (JNCC classification) (Figure: 23a) and "K" (cluster Spp. factor) (Figure: 23b).

In Niarbyl Bay, the observed population of *P. maximus* had larger and wider dispersion throughout the bay, with 123 individuals being recorded (Figure: 24). The population seemed to aggregate at depth >10m and in habitats with a coarser substrate. Recessing *P. maximus* occurred in gravel, pebble, cobble and maerl substrates, whereas juvenile scallops were present in rocky habitats. The Niarbyl Bay population were present in the habitat classified by the JNCC MHCBI as SS.SCS.CCS, CR.MCR, SS.SSa.IMx, SS.SMp.Mrl, and CR.MCR.EcCr (Figure: 24a). These same populations were classified in "R", "V", "U" and "X" under the bottom-up approach (Spp. Factor) (Figure: 24b).

During the survey 11 juveniles *P. maximus* were observed in the southern shallower areas of Niarbyl Bay (Figure: 26). This area comprised of rocky habitat classed in JNCC MHCBI (CR.MCR, CR.MCR.EcCr and SS.SMp.KSwSS (rocky – *Laminaria spp*. and Rhodophyta)) (Figure: 26). The juveniles were found in an area with the highest biodiversity that has a community assemblage comprising of *Ophiothrix fragilis*, *Ophiocomina nigra*, diverse Rhodophyta, bryozoans, gastropods, *Spirorbis spirorbis*, and *Porifera*. It was also noted from visual observations that juveniles occurred near coralline encrusting algae (Figure: 25).

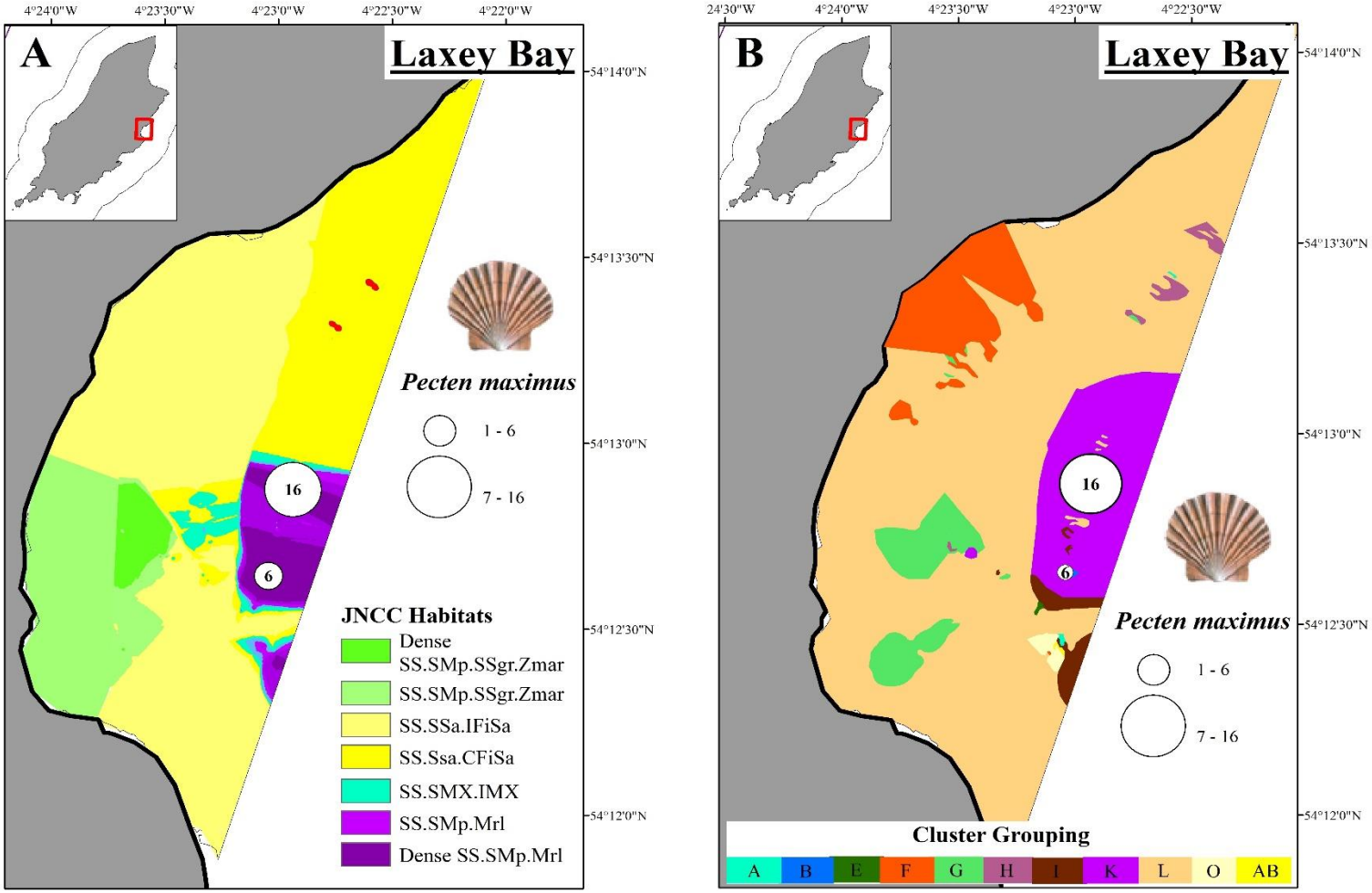

Figure 24: Pecten maximus (king scallop) abundance from each 10 minute tows was superimposed onto the ArcGIS Biotope map for Laxey Bay marine reserve in the IOM territorial waters. Map A (left) indicates the spatial distribution of Pecten maximus superimposed on the JNCC biotope map. Map B (right) indicates the spatial distribution of Pecten maximus superimposed on the Spp. Factor biotope map. The scallop image © McCartney, 2016

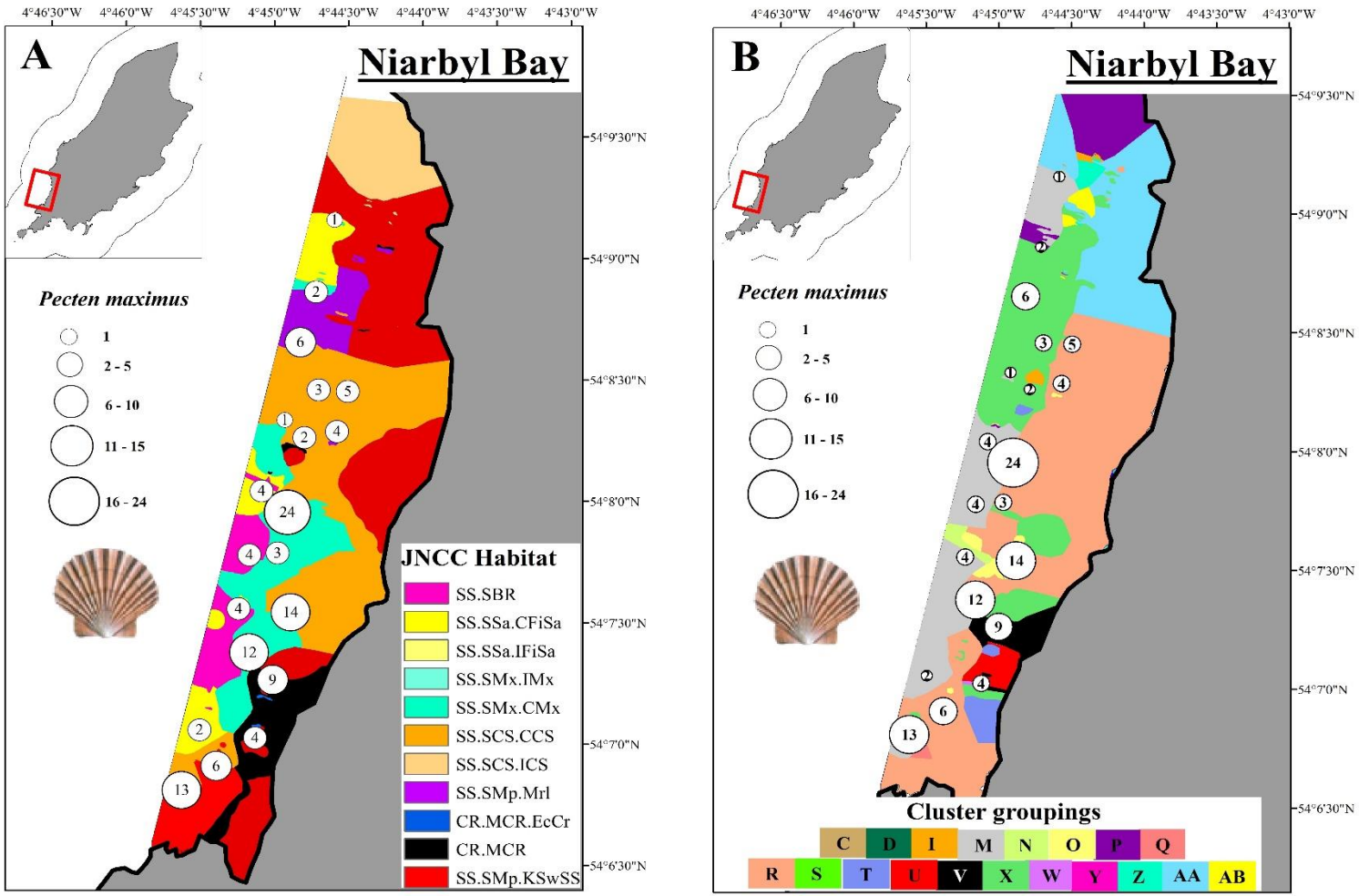

Figure 25: Pecten maximus (king scallop) abundance from each 10 minute tows was superimposed onto the ArcGIS biotope map for Niarbyl Bay marine reserve in the Isle of Man territorial waters. Map A (left) indicates the spatial distribution of Pecten maximus superimposed on the JNCC biotope map. Map B (right) indicates the spatial distribution of Pecten maximus superimposed on the Spp. Factor biotope map. The scallop image © McCartney, 2016

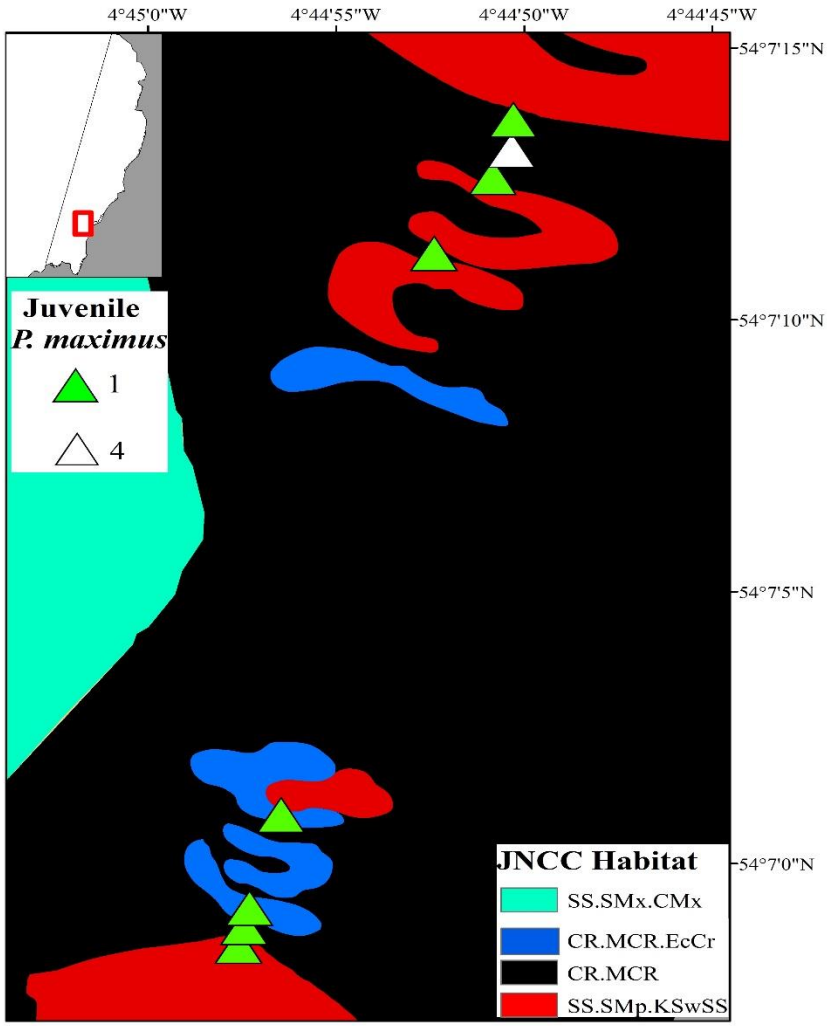

Figure 27: Juvenile Pecten maximus (<60mm) recorded were superimposed onto the JNCC Biotope map displaying the distribution of juvenile king scallops (observed in each 30 second interval of the benthic survey), as well as indicates juvenile associated habitat within Niarbyl Bay marine reserve, IOM.

Figure 26: Photograph of a juvenile scallops (Pecten maximus) taken from the video sledge footage recorded during the benthic survey in Niarbyl Bay marine reserve, IOM.

3.3.2 Scallop Density

The scallop density and size-frequency were compared to historical data that was collected within each grid using a dredge fishing technique (comprised king and queen dredge bars). The king dredge selected for larger *P.maximus* (MLS *110mm*) whereas the queens dredge selected for *P.maximus* under MLS. However, it is suspected that size selectivity still occurs with the dredging methodology, as it was noted that the smaller scallops were not collected in the historical collection. Whereas the video sledge technique recorded a range of sized individuals, with more observed of smaller sized scallops (Figure: 29 & 32). Overall Laxey Bay scallop density was considerably smaller compared to Niarbyl Bay (Figure: 28 & 31).

3.3.2.1 Laxey Bay

In Laxey Bay, the greater density estimates occurred in grid block B3 (0.0659m^{-2}), with all the other blocks having no recording (zero scallops), except block A3 (Figure: 30a). In 2014, the results was similar to this finding except scallops were also recorded in block B2. These results suggest that scallops congregated in single area and did not spread throughout the bay. The historical *P. maximus* density for 2014 was not significantly different ($\chi^2 = 0.368$; p=0.544) to the density estimated in 2016 (Figure: 28). Overall there was a greater density estimated was in 2016 (0.02m^{-2}) but the error bars are three times larger than that calculated in 2014 (Figure: 28) Thus, population density remained constant around 0.02 m^{-2} over the years.

In Laxey Bay, *P. maximus* was not recorded at sizes greater than >140mm ±4mm in 2016, whereas in 2014 seven individual were recorded at size of 140-160mm (Figure: 29). In 2016, a greater number of smaller juvenile scallops <60mm were observed, with the greatest proportion occurring in the 60-80mm size class (Figure: 29b). Whereas in 2014, the greatest number of scallops within the 120-140mm size class (Figure: 29a).

In 2009, Laxey Bay was reseeded with 100,000 two year old king scallops, measuring 51.2mm. Based on the growth rate estimate of 0.0394 (calculated from the mean size for each age group) the seeded population was estimated to measured 98.76mm (2014) and 106.70mm (2016). However, based on Mason (1957) measurements the seeded population measured approximately 104mm (2014) and 118mm (2016). Therefore the expected reseeding population measures 107mm to 118mm (indicated in red in Figure: 28a &28). This suggests that only 2 out of 150 individuals recorded in 2014 were from the reseeding population (Figure: 28a).

Whereas, in 2016 it is suggested that only 1 out of 16 individuals recorded were from the reseeding population (Figure: 28b).

3.3.2.2 Niarbyl Bay

In Niarbyl Bay, the greatest density estimate occurred in grid block B5 (0.1213 m^{-2} ± 0.0556 m^{-2}) (Figure: 30b). Block B6 contained juveniles (measuring 27mm to 69mm) and had the second largest density estimate (0.1022 m^{-2} ± 0.0524m^{-2}) (Figure:30b) The overall density estimate was 0.05 m^{-2} (Figure: 30b). Overall the historical density estimates recorded in 2011 and 2012 were significantly different (χ^2 = 8.673; p=0.013) from the 2016 density estimates. The highest overall density occurred in 2012 (0.188m^{-2} ±0.040m^{-2}), and the lowest density occurred in 2011 (0.025m^{-2} ±0.004m^{-2}) (Figure: 31).

The *P. maximus* size ranged from 27mm to 186mm (±4mm) (Figure: 32). In 2012, 74% of scallops were recorded in the 120mm - 140mm size class (Figure: 32b). In 2011, the highest frequency (46%) occurred in size class 100mm – 120mm (Figure: 32a). In 2016, the highest frequency (33.7%) occurred within 120mm - 140mm, however the size-frequencies range had increased compared to temporal data (Figure: 32c). 2016 survey had a greater proportion of juveniles recorded in the smaller size classes (20mm to 80mm) compared to previous years (Figure:32c).

In 2009, Niarbyl Bay was first reseeded with 5000 scallops measuring a mean of 107mm (3 years). Based on the growth rate estimate of 0.058 (calculated from the mean size for each age group, obtained from 2011 and 2012 data), the seeded population was predicted to measure 114mm in 2011; 124mm in 2012 and 151mm in 2016. A second prediction of the reseeded population measurement was undertaken using Mason (1957) growth rate estimate which predicted that the reseeded population would potentially measure 127mm in 2011; 134mm in 2012 and 162mm in 2016. Therefore the predicted reseeding population was indicated in red (Figure: 32). This result indicates that the seeding population decreased with time (Figure: 32).

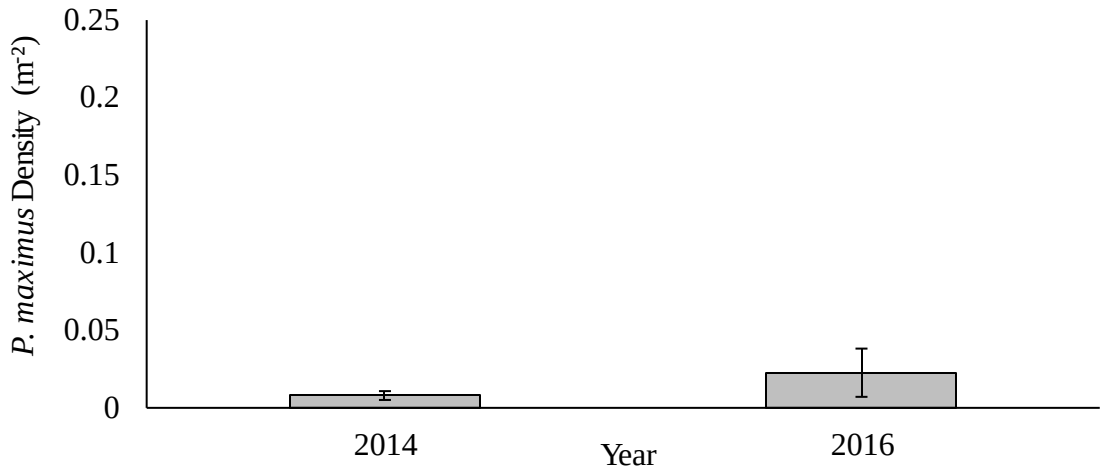

Figure 28: P.maximus (m^{-2}) density recorded within Laxey Bay marine reserve, IOM for 2016 and 2014. The densities were recorded during a dredging survey in 2014 and during a benthic video sledge survey in 2016.

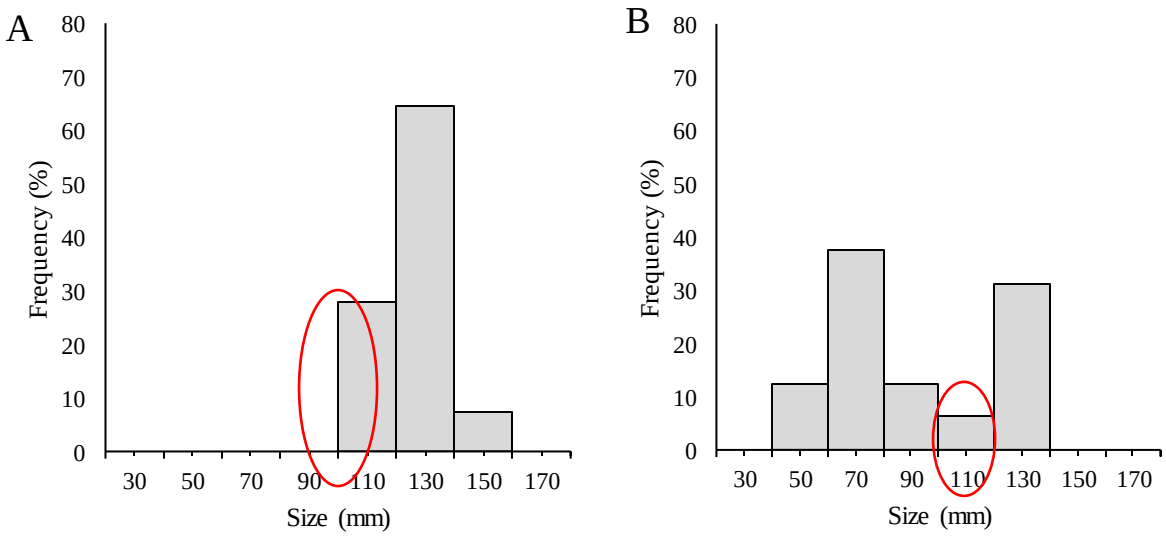

Figure 29: The size-frequency of P.maximus recorded within Laxey Bay marine reserve IOM. Graph A (left) are the size-frequency recorded in 2014 (total 150 individuals) during a dredging survey. Graph B (right) are the size-frequency recorded in 2016 (total 16 individuals) during a benthic video sledge survey. The red marker indicates the predicted size of the seeded population transferred to the marine reserve in 2009.

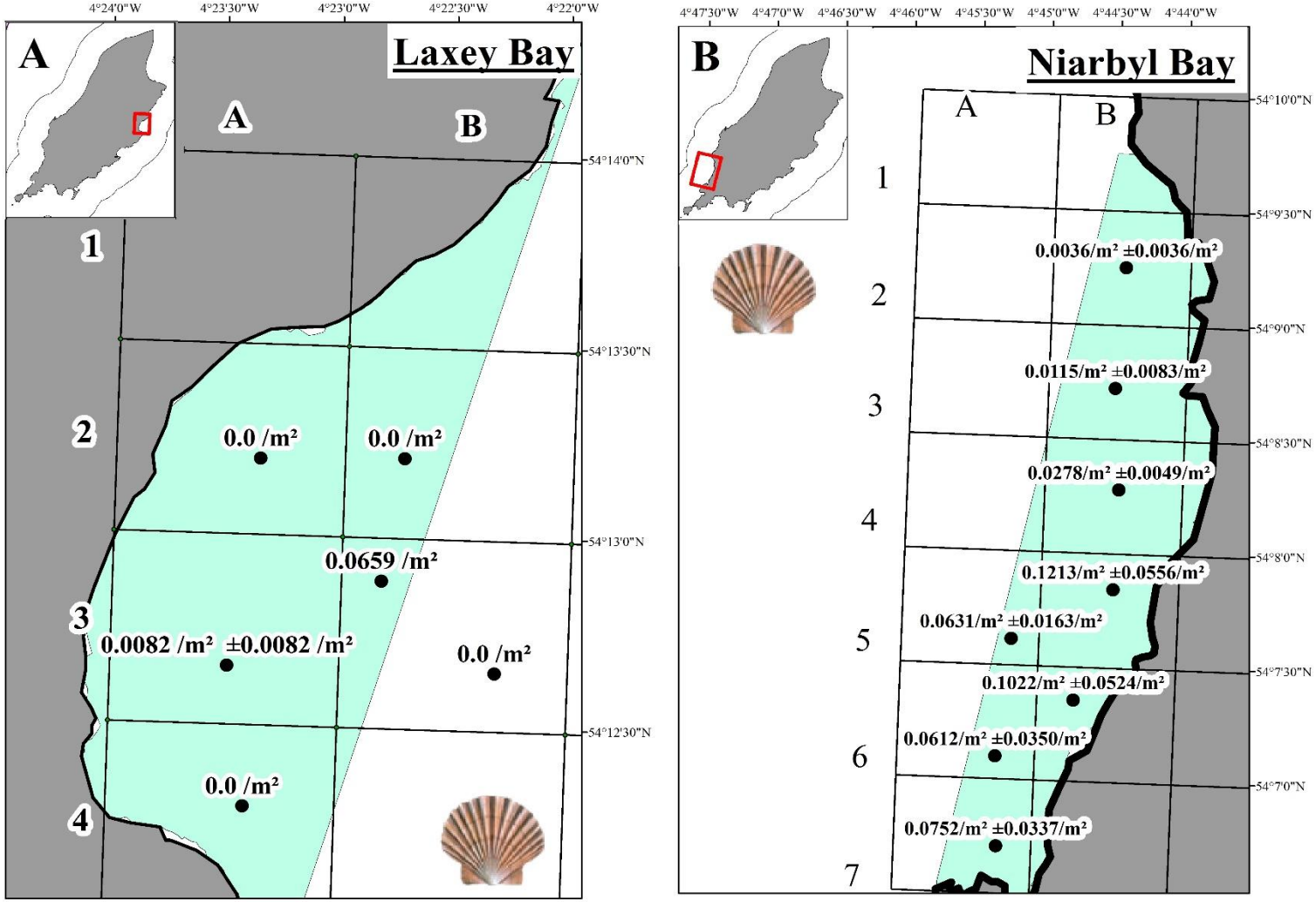

Figure 30: The density of P.maximus (m^{-2}) recorded within each historical grid layout over two marine reserves, IOM. Map A (left) indicates the P.maximus density within Laxey Bay marine reserve grid for the 2016 benthic survey. Map B (right) indicates the P.maximus density within Niarbyl Bay marine reserve grid for the 2016 benthic survey. The scallop image © McCartney, 2016.

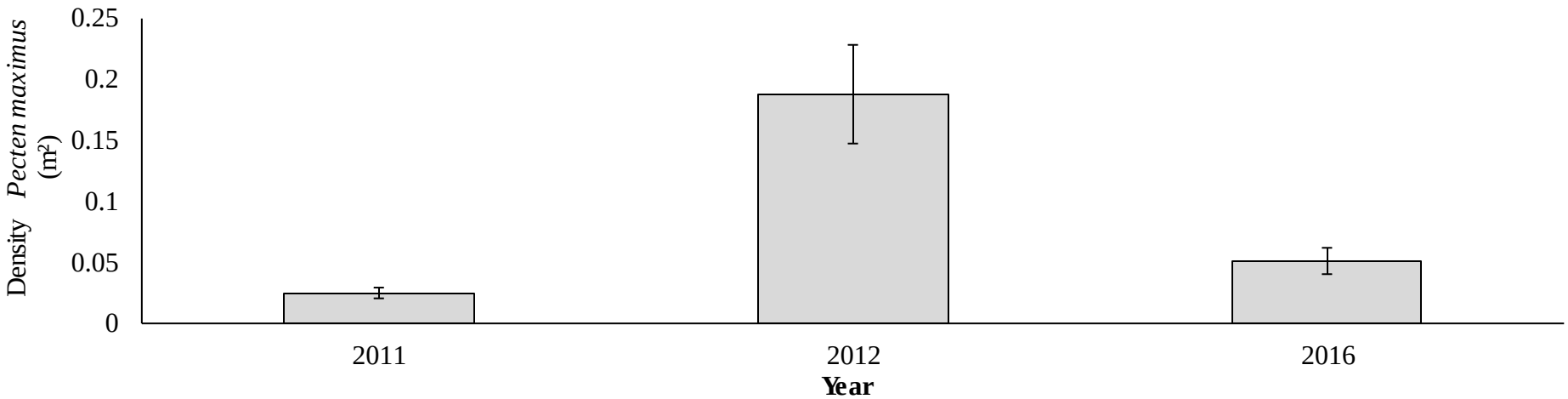

Figure 31: The density of P.maximus (m^{-2}) recorded within Niarbyl Bay marine reserve, IOM. The densities were recorded in 2011 and 2012 were during a dredging survey and 2016 was during a benthic video sledge survey.

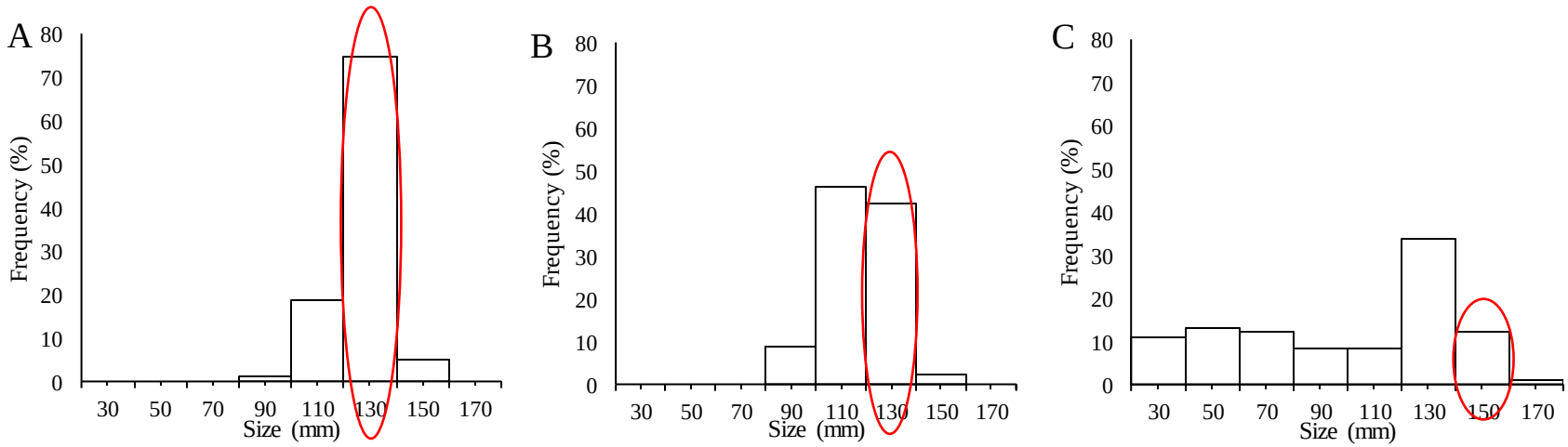

Figure 32: The size-frequency of P.maximus recorded within Niarbyl Bay marine reserve, IOM. Graph A (left) are the size-frequency recorded in 2011 (dredging survey). Graph B (centre) size-frequency recorded in 2012 (dredging survey). Graph C (right) are the size-frequency recorded in 2016 (benthic video sledge survey). The red marker indicates the predicted size of the reseeded population transferred to the marine reserve in 2009.

3.3.3 Predators of *P.maximus*

This section covers the distribution and density of predators that consume king scallops (*P.maximus*) within the marine reserves. In Laxey Bay the predators observed were *Cancer pagurus, Liocarcinus spp. Pagurus spp., Scliorhinus canicula* and *Asterias rubens* (Figure: 33a), with *Pagurus spp.* being the most abundant. The highest density of predators occurred in grid block B2 and B3 which were in the deepest part of the bay (Figure: 34a). Block B3 had the greatest density of scallops and predators. The density comparison indicated that overall the area had higher predation pressure compared to scallop stock population (Figure: 34b).

Niarbyl Bay marine reserve supports a variety of starfish, crabs, lobsters, octopus and elasmobranchs predators throughout the bay (Figure: 33b). *Pagurus spp*. was most abundant in the southern section (Grid: A7, A6, B6) (Figure: 33b). There was a high abundance of *Cancer pagurus* and *Marthasterias glaciallis* (spiny starfish) (Figure: 33b). The densities predator region occurred in grid A7 in the southern part of the Niarbyl Bay and the lowest predator density occurred in the northern part of the bay (Grid: B2, B3) (Figure: 35a). In the northern region (Grid: B2, B3), there was a higher predation pressure compared to scallop stocks (Figure: 35b). The middle region had a higher density of scallops compared to predators (indicated in green; Figure: 35b). Grid B6 had a population of juvenile scallop and had a lower density of predators compared to scallop densities; potentially an indication of low predation pressure (Figure: 35b).

One of *P.maximus* is *Cancer pagurus* which is commercially harvested within both marine reserves (Appendix:4). This species was recorded in both BRUV and sledge footage displaying behavioural traits of slow defensive approaches to bait on the BRUV footage and burrowing behaviour in the sledge video footage (personal observations).

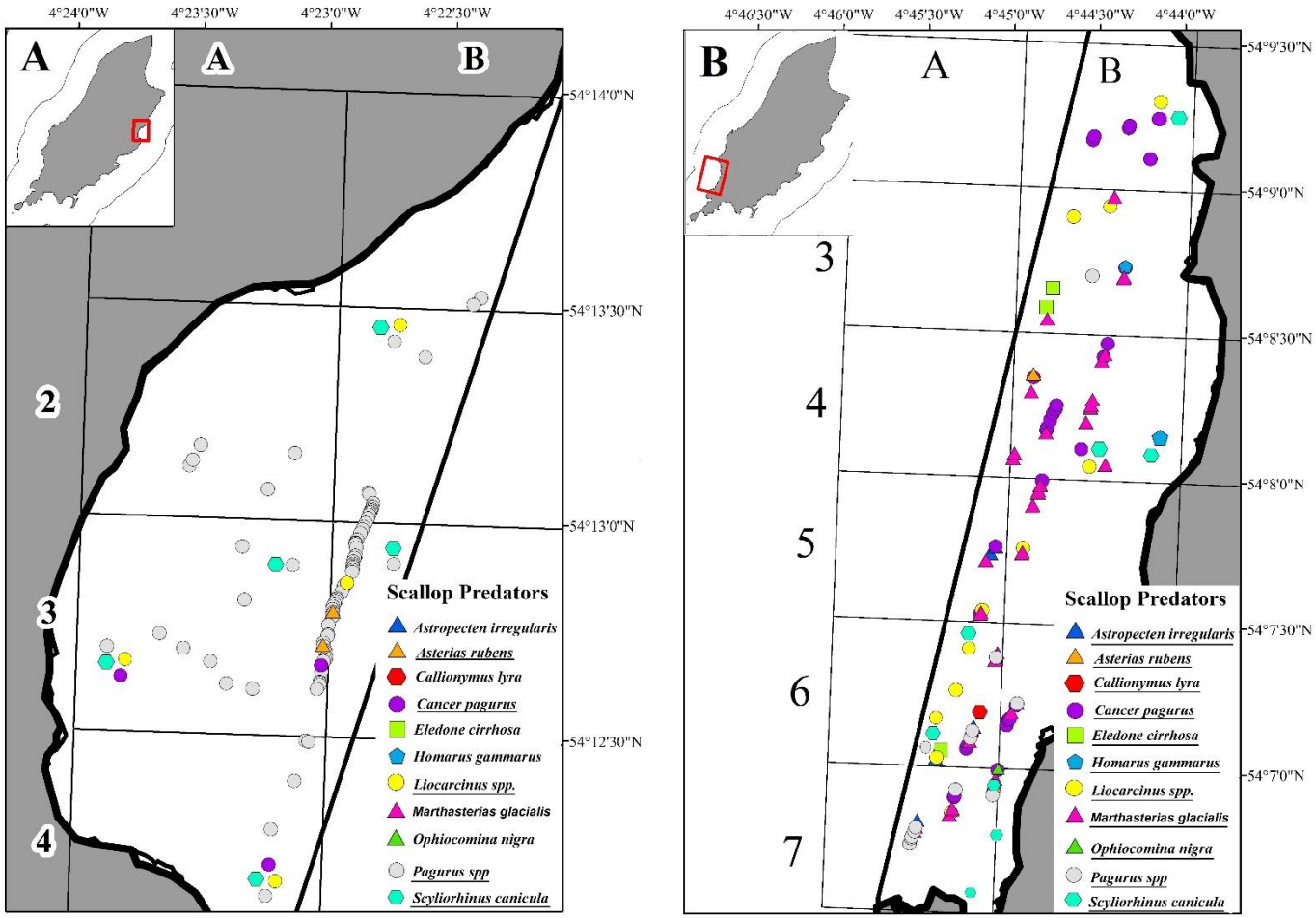

Figure 33: The distribution of Pecten maximus predators within the two marine reserve recorded during the 10 minute video sledge tows and BRUV footage. Map A (left) indicates the spatial distribution of predators within Laxey Bay. Map B (right) indicates the spatial distribution of predators within Niarbyl Bay. The underlined species name are the predators observed in the area. The shapes illustrate the different species classes: triangles - Asteroidea (starfish); hexagon - Elasmobranch and bony fish; circles (crabs) and pentagon *(lobster)- Malacostraca; and square - octopus.*

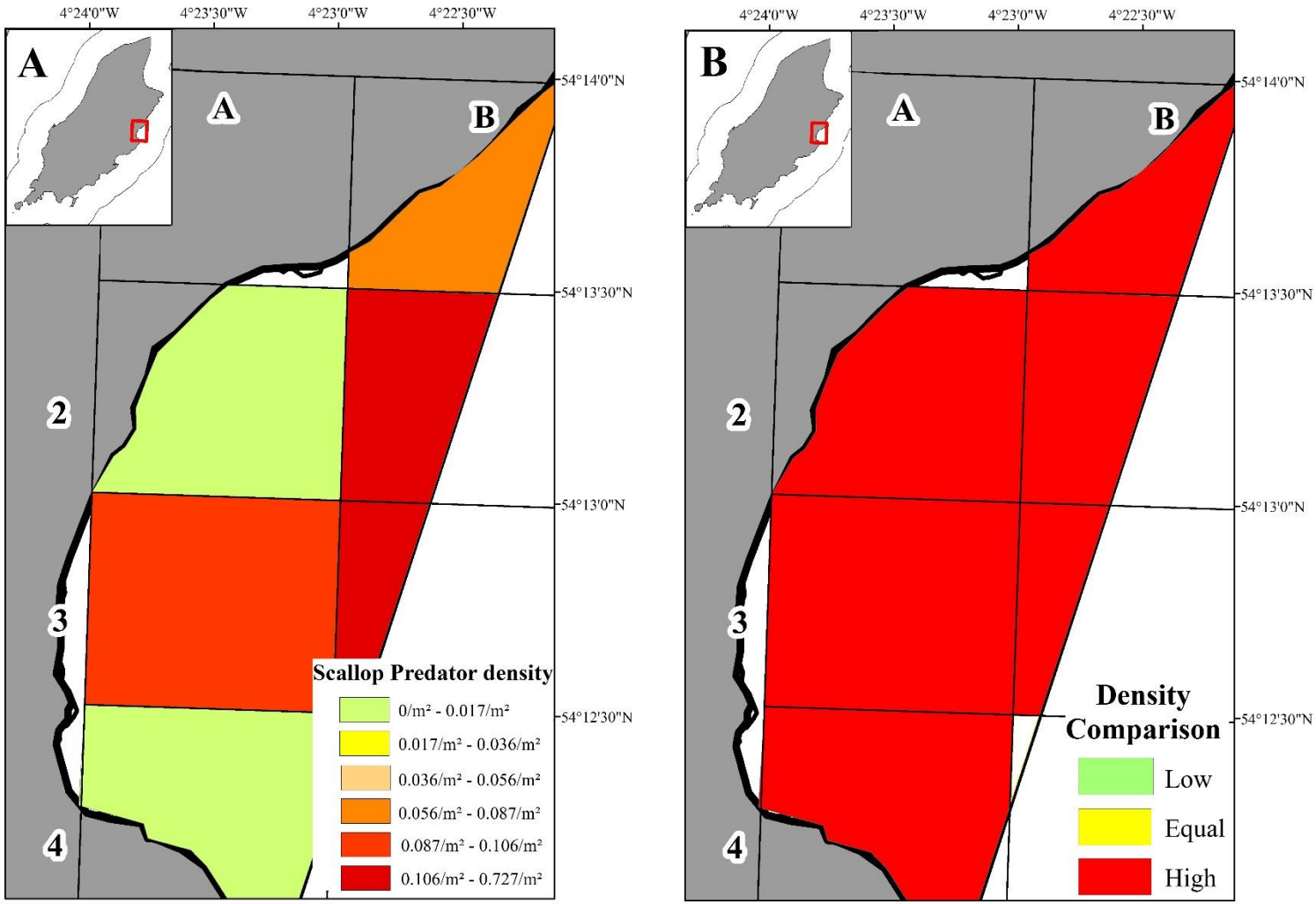

Figure 34: The density of Pecten maximus predators (m^{-2}) recorded within each historical grid layout over Laxey Bay marine reserve IOM. Map A (left) indicates the predator density within grid block. Map B (right) indicates whether the density of predators was greater, equal or less than P.maximus density within each grid block.

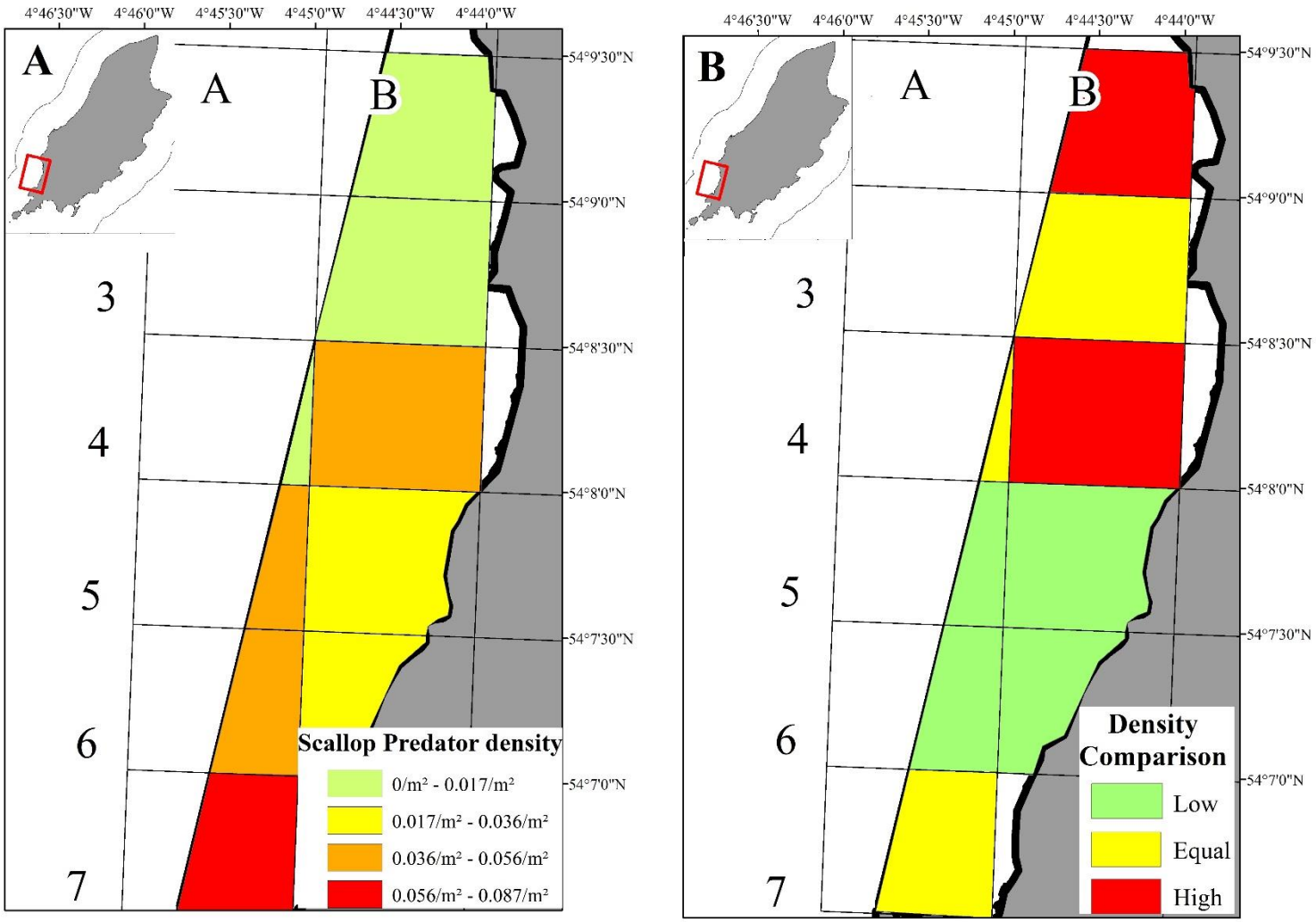

Figure 35: The density of Pecten maximus predators (m^{-2}) recorded within each historical grid layout over Niarbyl Bay marine reserve IOM. Map A (left) indicates the predator density within grid block. Map B (right) indicates whether the density of predators was greater, equal or less than P.maximus density within each grid block.

3.4 Habitat Association

The habitat association was assessed for *P. maximus* within both marine reserves. *P.maximus* was present in nine different substrate types (Figure: 36). The greatest numbers of individual scallops were recorded in gravel sediments (53 individuals), however overall scallops were more abundant in maerl, gravel and mixed sediment substrate (25 – 53 individuals) (Figure: 36). The lowest abundance of scallops was recorded in rocky and sandy substrate with and without biogenic fauna species (less than 8 individual) (Figure: 36). This indicates *P.maximus* had preference for coarser substrate but not hard substrate types.

The graph of the substrate types that *P.maximus* was recorded in, illustrated that *P.maximus* may have had a preference of substrate type depending on size (Figure: 37). Juveniles measuring a mean size of 46.9mm ±13.9mm were observed within the rocky habitat. A smaller mean size was recorded in substrate that was rocky with Rhodophyta and kelp algae (45.8mm ±8.23mm). The other substrate type hosted larger mean size scallop population with the largest mean size being recorded in the mixed sediment substrate type (129mm ±6mm) (Figure: 37).

The complexity of the habitat was compared to the species abundance within each tow using a quantile regression (Figure: 38a). The quantile regression analysis indicated that habitat complexity was not a strong limiting factor to king scallop distribution, as 80th quantile was not significant ($t_{(0.092)} = 1.355$; $p = 0.180$) but 70th quantile was ($t_{(0.260)} = 4.603$; $p < 0.001$) (Figure: 38a). The significance of the 50th quantile ($t_{(0.29)} = 4.994$; $p < 0.001$) suggest that a linear pattern might exist (Figure: 38a). The overall pattern suggests that larger numbers of observations of scallops occurred in more complex habitats. However, a large number of single observations were recorded, thus the sample size may be too small for the analysis. Therefore, no conclusive evidence for scallop association with increased habitat complexity can be found.

The quantile regression analysis indicated that depth was a limiting factor on scallop abundance (80th quantile: $t_{(1.781)} = 7.409$; $p < 0.001$). The pattern observed indicates king scallops had a preference for deeper depths (Figure: 38b). However, there are a large number of single observations recorded.

Figure 36: The abundance of P. maximum in each substrate type within Laxey and Niarbyl Bays marine reserve, IOM.

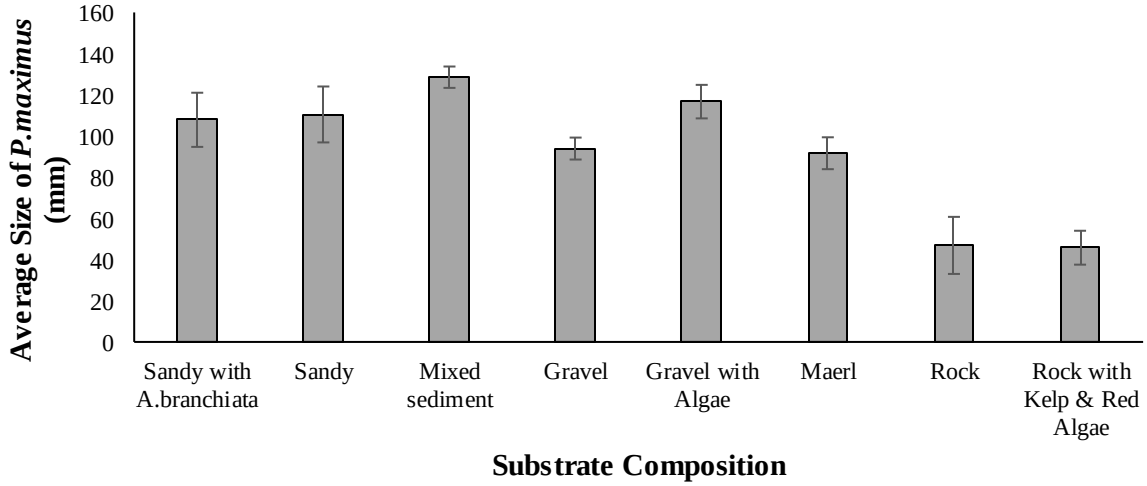

Figure 37: The average size of P.maximus (mm ±SE) observed within each substrate type present in Laxey and Niarbyl Bays marine reserve, IOM.

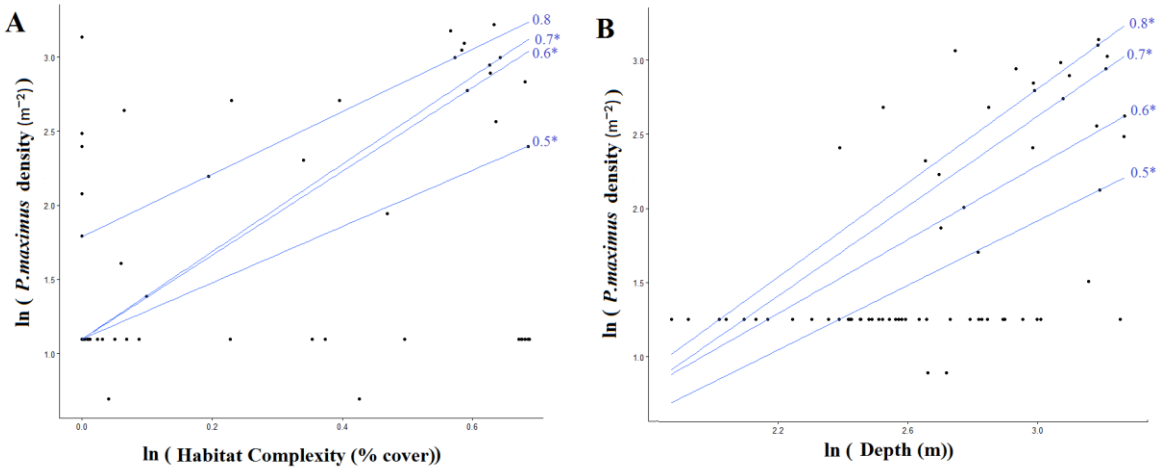

*Figure 38: Quantile regression for P. maximus association with habitat complexity and depth for scallops observed within Laxey and Niarbyl Bay's marine reserves, IOM. Graph A indicated the quantile regression results for natural logged habitat complexity association. Graph B indicates the quantile regression results for natural logged depth association. The quartiles that are significant (<0.05) are indicated by *.*

4 Discussion

This benthic survey provides some insight into the spatial distribution of *P.maximus*, their predators and associated habitats as well as areas of conservation interest; which can be utilised to support the Manx government's future management decisions on the marine reserves. Thus, Laxey and Niarbyl Bays are discussed separately especially as their *P.maximus* population are reproductively isolated (Beukers-Stewart, *et al.*, 2005), and their benthic habitats and communities were extremely different.

4.1 Laxey Bay

P.maximus was isolated in one section of Laxey Bay in the maerl substrate. This population density remained relatively constant over time despite the area being reseeded in 2009 and closed to further fishing activities for 7 years. This corresponds with Beukers-Stewart, *et al.* (2005), finding of no increase in scallop density after 8 years of protection. In contrast, Bradshaw, *et al.* (2001) only recorded an increase in *P.maximus* density after 11 years of protection. Therefore, 7 years of protection may be an insufficient time period for a significant recovery to be identified; but the assumption of the populations temporal pattern was based on data separated by 3 years with a lack of scallop density measurement before reseeding.

In Laxey Bay a greater abundance of smaller sized scallops (60-80mm) were recorded in 2016, with the overall size range of scallops increasing with prolonged protection. This was contradictory to Howarth, *et al.* (2015b) findings which indicated that larger size classes would have a greater abundance as marine reserve eliminated fishing mortality. The temporal comparison of size classes indicated that recruitment has occurred within the bay as more individuals were recorded after the estimated reseeding population; but the source of the spat recruiting in the area is unknown.

4.1.1 Reseeding

In 2009, the area was reseeded with cultured juveniles (51mm). The success of the reseeding was defined as being economically viable (scallop densities recovered by >25% or >60% of the seeded individuals were available for harvest) (Magnesen and Redmond, 2012). As neither of these criteria were met, it can be suggested that reseeding was unsuccessful. In Laxey Bay the *P.maximus* densities remained consistently low, despite years of conservation and the reseeding effort. This may be due to a variety of contributing factors: reaching carrying

capacity, poor larval supply, environmental variables, inadequate reseeding methods (low quality stock), lack of enforcement, inadequate scallop associated habitat and high predation pressure (Beukers-Stewart, *et al.*, 2005; Chi-yan Lo, unpublished).

The lack of enforcement in marine reserves can lead to illegal fishing. In Port Erin marine reserve, Isle of Man, sporadic illegal fishing has been recorded (Beukers-Stewart, *et al.*, 2005; Chi-yan Lo, unpublished); therefore incursions maybe occurring in Laxey Bay as well, which will limit *P.maximus* recovery. Laxey Bay is in close proximity to the local fishing grounds (Chi-yan Lo, unpublished) and larger sized scallops are less abundant in the reserve. Thus, illegal fishing cannot be eliminated as a potential limiting factor, especially since small and sporadic illegal fishing may be occurring on the deeper reserves boarders.

Another limitation is the reseeding methodology and procedure. Handling process and exposure time drastically effects the success of the reseeding as prolonged air exposure and rough handling induces stress in scallops (Christophersen, *et al.*, 2008); which leads to increase mortality. Long periods (12hrs) of air exposure or exposure to extremely cold (<4°C) or hot (>15°C) temperatures during post-larval detachment and out-of-water transport, can be fatal to scallops (Christophersen, *et al.*, 2008). Nevertheless, it is more cost effective to transport shellfish out-of-water than in-water. However, optimum *P.maximus* survival requires air exposure time <9hrs with temperature similar to ambient seawater temperature or 2°C lower (Christophersen, *et al.*, 2008). However these optimum conditions are country dependent, as 2mm scallops in Norway had an emersion time of 11hrs whereas in France emersion time should not exceed 4hrs. The handling stress also influences the time required for recovery, even with optimum transport conditions recovery time is at least 2weeks (Christophersen, *et al.*, 2008). Thus, seeded scallops are highly vulnerable to natural disturbance and predation during the initial reseeding stages. In Laxey Bay, it was suspected that the juvenile scallops reseeded into the area were handled regularly at different life stages as the stock was sourced from a farm (Christophersen, *et al.*, 2008). However, the actual handling frequency, air exposure time, temperatures and handling roughness during the reseeding process is unknown. Therefore, induced stress may be a potential factor limiting the reseeding success.

4.1.2 Predation Pressure

Predation pressure also restrict *P.maximus* density growth as major predators like crab and starfish consume spat, recovering and damaged scallops (Barbeau, *et al.*, 1998). Newly transplanted juvenile scallops are more vulnerable to predation as they are initially weaker, stressed, and unable to escape effectively (Fleury, *et al.*, 1996; Barbeau, *et al.*, 1998). Predation limiting bottom culture has been recorded in Eastern Canada, where abundance and spatial distribution was restricted by crabs and starfish predators (Barbeau, *et al.*, 1998). In Laxey Bay the predator density was extremely high, exceeding *P.maximus* density within every section of the bay. The main predators in Laxey Bay were *Pagurus spp.*, *Asterias rubens*, *Liocarcinus spp.* and *Cancer pagurus*; which are all aggressive scallop predators. There has been a high prevalence of *Pagurus spp.*, *Liocarcinus spp.* and *Asterias rubens* in the Irish sea since the onset of commercial scallop fishing in the 1930's (Veale, *et al.*, 2000a).

The starfish *Asterias rubens* is an aggressive predator that targets juveniles smaller <70mm in length and damaged scallops (Barbeau and Scheibling, 1994a). Scallops have adapted to evade predation by using a swimming escape response thus, reducing capture to <10% (Barbeau and Scheibling, 1994a). However, newly seeded scallops are unable to invoke the swimming behaviour, resulting in a high predation rate (Barbeau and Scheibling, 1994a; Beukers-Stewart, *et al.*, 2005). The success of starfish predation is mostly based on encounters, therefore high density of scallops (>5m^{-2}) caused by reseeding, increase the starfish predation success rate (Barbeau, *et al.*, 1998). Crabs (*Pagurus spp.*, *Liocarcinus spp.* and *C.pagurus*) are another influential predator as they prey upon a range of scallops regardless of size and damage level, however mortality rates are higher amongst juvenile's scallops (<55mm) (Grefsrud, *et al.*, 2003). Scallops are more susceptible to crab predation than starfish, as threatened scallops recess and close their shells rather than swim away (Barbeau and Scheibling, 1994b). Crabs have adapted to break open these shells, especially *C.pagurus* (Grefsrud, *et al.*, 2003). Thus, the prevalence of crabs at such high density within Laxey Bay suggest that scallops of all sizes are at risk of predation and reseeding may be ineffective as crabs shift their diet to the most abundant prey source (Barbeau, *et al.*, 1998). Reseeding increases local scallop density which results in higher predator mortality and alters the predation community composition as predators aggregate to the area (Barbeau, *et al.*, 1998). Immediately after reseeding, predation by crabs increases to 10 per day (Barbeau, *et al.*, 1998). The high densities of *Pagurus spp.* present in Laxey Bay during this study may be due to long-term predator aggregation in

response to the initial reseeding. However, it is unclear whether it was a result of increased prey or natural habitat preference. Thus, the high density of predators within Laxey Bay are limiting scallop population growth.

Seeding scallop survival can be optimised by reseeding scallop at low seawater temperature (4-5°C) (Magnesen and Redmond, 2012); as temperature effects predation rate and scallop recovery time (Barbeau and Scheibling, 1994b). Temperatures higher than ambient temperature increase predator activity (starfish encounter rate increase by >50%) and speeds up scallops swimming speed, reaction and recovery time (Barbeau and Scheibling, 1994b); however overall predator associated mortality increases. When temperatures are extremely low (<2°C) it leads to an increase in juveniles scallop mortality (52-100%) (Magnesen and Redmond, 2012). Therefore, reducing predator mortality can be controlled by reducing handling time, temperature and other induced stresses, thus increasing reseeding success rate.

4.1.3 Laxey Bay Habitat

Laxey Bay closed area encompasses three main substrate types (sandy substrate, maerl and seagrass meadows) with five community assemblages. The greatest benthic diversity occurred in the maerl substrate and seagrass meadow, with the lowest diversity occurred in the sandy habitat. Both biogenic habitats are of conservation interest and protected under the Habitat Directive (Maddock, 2008). In Laxey Bay, the seafloor was predominantly sandy substrate with a relatively small area of maerl substrate on the bay boarders. Within the maerl substrate a scallop population resides, which make up a small component of this benthic community diversity (Alaska, 2004). Habitat type is a highly important factor influencing the diversity and spatial distribution of *P.maximus* as species specific habitat preferences occur at different life stage. Adult scallops prefer habitats with coarser substrate which they can recess into, whereas juvenile's prefer harder substrate with lots of emergent epifauna for spat settlement, and the increased ease of swimming on harder beds (Minchin, 2002). Thus, habitat type especially sediment texture influences seeded scallops making reseeding easier or harder (Fleury, *et al.*, 1996). In Laxey Bay, the maerl habitat supports a low density of scallops (>40mm). Maerl is an ideal habitat for all sized scallops as habitat complexity, fragmented structure and emergent epifauna which are essential for predator refuge, spat settlement (maerl emits a stimulus that encourages settlement) and adult recessing (Kamenos, *et al.*, 2004b). Thus, maerl habitats are usually defined as a nursery ground that also supports an adult

population (Kamenos, *et al.*, 2004b). The maerl bed in Laxey Bay was healthy with high densities of living maerl but the benthic community comprised few bryozoans and hydroids, which indicates that spat settlement was less likely however the scallops, although at low density, were in close proximity so fertilization was still possible and suspected recruitment was apparent in the benthic study. However, further research on the extent of the maerl habitat and the scallop recruitment into the area needs to be measured.

Sandy substrate habitat within Laxey Bay had a relatively low diversity (>1.60) which is a typical characteristic of this habitat epifauna community (Kostylev, *et al.*, 2001); especially as infauna species were not identifiable from surface photographs. However it has been suspected that surf clams, soft-shelled clams and infauna polychaetes are common beneath the surface (Kostylev, *et al.*, 2001). The dominant epifauna within this community were *Pagurus spp*., and the polychaetes (*Arenicola marina* and *Lagis koreni),* which are identified by their distinguishable features on the seafloor. This habitat and its associated species are more resilient to anthropogenic activities, as polychaetes recover quickly (within 1 year) and hermit crabs are scavengers that thrive off by-catch (Howarth and Beukers-Stewart, 2014).

4.1.3.1 Important Conservation Habitats

In Laxey Bay a seagrass bed that comprised *Zostera marina* was found within the shallow southern region of the bay. This biogenic habitat are legally protected under the Annex 1 of the Habitats Directive (EU 1150: lagoons) legislation (Maddock, 2008); as it is highly sensitive to anthropogenic disturbance and has economic value as it provides ecosystem service and functions as a nursery (Bradshaw, *et al.*, 2003; Maddock, 2008); which means it is vital to identify its location and size in order to provide adequate protection.

Zostera meadows have been documented to grow in the sheltered shallow subtidal lagoons and bays within sandy substrate habitats in the Irish Sea (Maddock, 2008). These *Zostera* meadows are recorded to perform several essential ecosystem services, such as substrate stabiliser, resource of food, carbon sink, and importantly a nursery function for flatfish, cephalopods, cod, prawns and other juvenile species (Bradshaw, *et al.*, 2003; Kamenos, *et al.*, 2004c; Maddock, 2008; Howarth, *et al.*, 2011; Gell and Hanley, 2013). This habitat also supports a high level of biodiversity compared to sandy habitat (Bradshaw, *et al.*, 2003); which corresponded with the 2016 findings.

The community within the *Zostera* meadows was dominated by *Pagurus spp*. and *Arenicola marina* and did not vary with changes in *Zosteria marina* patch size. This finding does not concur with previous studies on seagrass meadows that found community assemblages were influenced by patch size (Irlandi, *et al.*, 1999; Maddock, 2008). Larger patches of *Zosteria marina* (8m diameter) alter the hydrodynamics which increases food availability and provides refuge (Irlandi, *et al.*, 1999). This habitat was also associated with a few unique species (pipefish: *Entelurus aequoreus* and *Syngnathus typhle*) (Maddock, 2008). However the lack of observation of this species and juvenile fish species within the Laxey Bay *Zostera* meadow, may be due to a small area of the meadow being surveyed and the high mobility of the juvenile fish.

Laxey Bay seafloor comprised of sandy substrate at shallow depths which are essential conditions for *Zostera* growth. It is suspected that *Zostera* meadows were only present on the southern end of the bay as no sewage outfalls were present in that location, thus pollution did not impair *Zostera* growth (Irlandi, *et al.*, 1999).

4.1.4 Future recommendations

Laxey Bay was not successfully reseeded, this conclusion was drawn as *P.maximus* density was constantly low, few juveniles were observed and less than 60% of reseeded stock were recorded in the area. Therefore it may not be commercially viable to reopen the area to fishing. However, Laxey Bay marine reserve does provide protection for some important habitats which require legal protection, especially since the maerl habitat is stated as healthy with living nodes. If Laxey Bay was to reopen, it is recommended that this occurs in only the north half of the bay, as species within this region are more resilient and no important conservation habitats are present in this region.

If reseeding was to reoccur in the Laxey Bay, it is recommended that: reseeding takes place only in maerl beds; only adults or juveniles (>75mm) should be used to replenish the stocks; reseeding occurs at low sea and air temperatures and predator removal methods are used. These recommendation are suggested because the survival rates of seeded scallop are higher, recovery rate is quicker and vulnerability to predation is reduced (larger sized scallops survivability rate increases by 51%) (Grefsrud, *et al.*, 2003). Furthermore, Laxey Bay had a high density of

predators (especially hermit crab) which predominantly prey on juvenile scallops (<65mm) (Grefsrud, *et al.*, 2003). Reseeding scallops at low temperatures (2°C below ambient temperature) with short air exposure time was recommend because it reduces scallop stress and predator activity, thus increasing scallop survival (Magnesen and Redmond, 2012).

Predator removal methods during initial stages of reseeding is recommended, as predator fences have been shown to increase *P.maximus* survivability by 5-89% as it prevents the congregation of predators to the newly seeded scallops (Magnesen and Redmond, 2012). However, before scallop reseeding occurs in Laxey Bay it is recommended that further studies are undertaken to investigate the appropriate density that allows for maximum scallop restocking whilst avoiding long-term migration of predators to the area (Christophersen, *et al.*, 2008).

Recommendation for further study on Laxey Bay is to survey the extent of the maerl habitat (using drop down cameras) because it is suspected that the closed area may be inadequate to conserve the maerl habitat and the scallops residing within. Further research is also needed on the carrying capacity of the area as it is suspected that Laxey Bay may have been reached and reseeding an area cannot restore stocks beyond the capacity of the system (Borg, 2002).

4.2 Niarbyl Bay

P.maximus inhabits a variety of habitats and was widely distributed throughout Niarbyl Bay. The greatest abundance occurred in the mixed sediment substrate at depths greater than 15m. *P.maximus* population density within the marine reserve fluctuates significantly between years. The greatest density recorded was in 2012 ($0.2m^{-2}$) and the lowest recorded was in 2011 ($0.03m^{-2}$). This yearly fluctuation in density may be due to recruitment success as juvenile abundance typically fluctuates from low to high every two years as it is influenced by environmental variables (Howarth, *et al.*, 2015b). This yearly fluctuation may also be attributed to sampling effort and methodology which changed yearly (ie. dredging sampled within the substrate, whereas video sledge sampled the surface substrate layer). However, it was expected that prolonged protection and stock replenishment would result in an overall increase in scallop densities (Beukers-Stewart, *et al.*, 2005). This cannot be confirmed as scallop densities are unknown prior to reseeding in 2009.

In 2016, the size range of scallop increased with more individuals in the larger and smaller size classes compared to the temporal date. This was suspected to be due to either benefits of prolonged protection or equipment limitations, as dredging gear was unable to survey the rocky terrains or areas were substrate type was unknown, as equipment could potentially get damage (Hinz, *et al.*, 2009). The scallop size distribution indicated that the reseeding population declined in abundance over time, (assumption was based on temporarily tracking of seeded scallops). The decline in larger sized scallops (140mm to 180mm) may be due to migration to deeper depths, illegal fishing or old age mortality. Illegal fishing occurs in Port Erin, Isle of Man (western coast, just south of Niarbyl Bay), therefore it is not outlandish to speculate that illegal fishing could be occurring on the outer boundaries of this marine reserve. Old age mortality may potentially be the cause of the decline of larger scallops, as scallops typically grow to an average length of 150mm (maximum 210mm) (Shumway and Parsons, 2011), and the maximum sized scallop recorded in this study was 186mm. Migration of scallops (>130mm) may also be a factor contributing to the decline, as scallops can migrate 30m in 18 months to areas with more appropriate habitat conditions (Brand, *et al.*, 1980). Adult scallops tend to prefer depths of 22m to 26m, which is deeper than the marine reserve (0m-22m), thus scallops may be migrating out of the bay into deeper waters (Brand, *et al.*, 1980).

The high abundance of *P.maximus* in smaller size classes and a high proportion of individuals after reseeding suggest that recruitment is occurring in Niarbyl Bay. These findings provide supporting evidence that Niarbyl Bay is a scallop nursery ground especially in the southern coast of the reserve, where small (<50mm) *P.maximus* juveniles were recorded. However, the benthic survey failed to provide any supporting evidence that reseeding was successful, as only 0.27% of the seeded scallops were recorded after the reseeding event, therefore the population has not recovered to economically viable levels (Magnesen and Redmond, 2012). However, the reseeding may have been successful if the aim was to encourage fertilization as the high densities it creates, reducing reproductive isolation thus increases recruitment (Howarth, *et al.*, 2011). The lacking overall population increase in scallops, despite years of conservation, may be due to a variety of contributing factors (Howarth, *et al.*, 2015b).

4.2.1 Reseeding

The EU, Australia and Isle of Man have generally been disappointed in the successful scallop reseeding as their results have not been as successful as in Japan (Bradshaw, *et al.*, 2001; Slater,

2006). This is thought to be due to annual fluctuations in spat abundance, environmental variables, and reseeding protocol (Minchin, 2002; Slater, 2006). Reseeding is the artificial enhancement of the local scallop density (Barbeau, *et al.*, 1998), and in 2009 107mm wild scallops were reseeded into Niarbyl Bay. Seeded stock usually take at least two years to mature enough to benefit commercial fishermen and influence recruitment (Minchin, 2002). Initial reseeding can be influenced by translocation protocol, handling time, and environmental conditions which weakens scallops increasing their vulnerable to predation (Fleury, *et al.*, 1996; Minchin, 2002; Christophersen, *et al.*, 2008); which can lead to reseeding failure. The sediment texture is also an important factor that influences scallop survival (Fleury, *et al.*, 1996). *P.maximus* placed on hard bottoms disperse widely, whereas *P.maximus* placed on sand recess rapidly and stay in the same position for 27 days, which increase their vulnerability, as scallop in sandy substrates are less camouflaged and more detectable by predators than those in coarse sediment (Shumway and Parsons, 2011). It is also noted that wildstock can only be transplanted to similar habitat type in order to survive the procedure (Fleury, *et al.*, 1996). However, as initial quality of seeded stock, overall scallop density prior to reseeding, habitat and environmental information were unknown, this study cannot make accurate assumption on initial recovery and survival of seeded scallops.

This study's results do indicate that the reseeded scallops declined after 4 years and the overall *P.maximus* density fluctuated annually. However, reseeding was suspected to be highly beneficial in Niarbyl Bay, even if stock density did not increase permanently. Reseeding increases populations to level where local densities are high enough that broadcast spawners like *P.maximus* can successfully fertilise (Howarth, *et al.*, 2015b). Thus, in Niarbyl Bay reseeding was highly successful as a recruitment agent rather than a stock restoration, as juveniles are recorded in the bay.

4.2.2 Predation pressure

The predation pressures within Niarbyl Bay are considerably lower in comparison to Laxey Bay. Niarbyl Bay predator species were highly diverse, the variety species like *Marthasterias glacialis* (starfish), Asterias rubens, *Luidia ciliaris* (seven armed starfish), *Liocarcinus spp.* (swimming crab) *Pagurus spp.* (hermit crab), *Cancer pagurus* (edible crab), *callionymus lyra* (common dragonet) and cephalopod (octopus); which have been recorded frequently preying upon *P.maximus* (Veale, *et al.*, 2000a). *L.ciliaris*, *C.pagurus* and cephalopod are sensitive to

anthropogenic disturbance (Beukers-Stewart and Beukers-Stewart, 2009); thus their presence in the bay suggest that the protection has also benefited other species besides *P.maximus* (Howarth and Beukers-Stewart, 2014). The low predator density recorded is suspected to be an underestimate as these predators are predominantly nocturnal (Veale, *et al.*, 2000a). The high diversity of predators within Niarbyl Bay suggest that all sizes of scallop are predated upon, as each species targets a specific prey size (Grefsrud, *et al.*, 2003). However, these predators typically switch prey types, although starfish and crabs are major threats to scallop survival (Barbeau, *et al.*, 1998).

Crabs are highly efficient predators consuming a variety of sized scallops including those of a healthy undamaged state (Barbeau, *et al.*, 1998; Jenkins, *et al.*, 2004). They have a high consumption rate of 10 scallops per day as scallop defence response of valve closure is ineffective (Barbeau and Scheibling, 1994a). *C.pagurus* is the most aggressive predator, as they uses a shell-breaking technique that allows them to prey on larger scallops, however their size preference is 30mm to 75mm (Grefsrud, *et al.*, 2003). *C.pagurus* were relatively abundant throughout the bay, but densities are restricted by commercial harvesting. Thus, crab predation may be a potential factor slightly restricting *P.maximus* growth within Niarbyl Bay.

Starfish are also aggressive predators that have a low predation rate 3 scallops per day, predominantly targeting juvenile, damaged and destressed scallops (Magnesen and Redmond, 2012). Starfish have a low predation rate because starfish rely on chance encounters, hunting using only chemosensory signals and physical contact, and scallops have an effective defence response of swimming to evade capture (Magnesen and Redmond, 2012). However larger (105-110mm) or recovering scallop are more ineffective at escaping starfish as they require more time to enact their swimming response than smaller scallops (80-95mm) (Barbeau and Scheibling, 1994b; Shumway and Parsons, 2011; Magnesen and Redmond, 2012). The community composition of starfish predators fluctuates with the changes in anthropogenic disturbance: i.e. *A.rubens* thrives in areas with a high level of fishing activity as by-catch and damaged *P.maximus* are more prevalent, whereas *M.glacialis* and *L.ciliaris* thrive in no take zones in closed area (Howarth, *et al.*, 2015a). In Niarbyl Bay, the most abundant starfish predator was *Marthasterias glacialis*, which suggests that the reserve protection is benefiting other species not only the scallop population. *M.glacialis* has the highest predation rate per month than any other starfish (Magnesen and Redmond, 2012). However, *M.galcialis* has not

been recorded consuming individuals larger than 40mm (Magnesen and Redmond, 2012). Therefore, only smaller juvenile scallops have a high risk of predation.

Predator pressure was not expected to be a factor contributing to the lack of reseeding success in Niarbyl Bay, as the seeded *P.maximus* were a mean size of 107mm, thus had a lower predation vulnerability. However, predator pressure is a factor slightly limiting scallop abundance, especially in the southern region of the bay were juveniles are most prevalent and predate density was greatest.

4.2.3 *P.maximus* Juveniles

P.maximus juveniles are seldom seen in-situ and little is known about their settlement and biology till the end of their first year (Minchin, 1992). In shallow water, spat are attached to materials (rhodophytes, phaeophytes, hydroids and bryozoan) by byssal threads until they reach 22mm length when they settle on the seafloor as juveniles (Minchin, 1992). The juvenile scallops recorded in this study are believed to be within their first year as Gibson (1956) and Minchin (1992) indicated that *P.maximus* attains 44mm in their first year. In Niarbyl Bay high densities of juveniles (<50mm) were clearly identified in the south inshore region of the closed area, with the smallest scallop measuring 27mm ±4mm.

In Niarbyl Bay the juveniles were recorded on rocky terrain with mixed sediments and dead maerl within the rock crevices, which supports variety of encrusting and upright epifauna (*Laminaria saccharina*, hydrobia, and byozoans). Dense aggregations of these upright epifauna are associated with juvenile scallop and spat settlement (Baird and Gibson, 1956; Bradshaw, *et al.*, 2003; Kamenos, *et al.*, 2004a; Kamenos, *et al.*, 2004c). However, rocky substrate is not known to harbour juvenile scallops, as juveniles are usually associated with maerl substrate which is typically characterised as a nursery habitat, as maerl stimulates spat settlement (Kamenos, *et al.*, 2004a; Kamenos, *et al.*, 2004c; Howarth, *et al.*, 2011; Howarth, *et al.*, 2015b). It is suspected that juvenile scallops were recorded on rocky habitats as it encompasses nursery supporting epifauna, structurally complex habitat, silt-free, predation refuge, lower predation pressure and the hard surface makes invoking the swimming response easier (Brand, *et al.*, 1980; Wynberg and Branch, 1994; Bradshaw, *et al.*, 2001; Kamenos, *et al.*, 2004a; Hauser, *et al.*, 2006; Hinz, *et al.*, 2010; Howarth, *et al.*, 2011; Szostek, *et al.*, 2013); which are important function of a nursery area.. The juveniles were recorded in close proximity to *Ophiothrix* beds

which suggest low predation pressure in regions. This rocky nursery areas community composition of bryozoans and hydroids associated with high juvenile abundances concurs with Bradshaw, *et al.* (2001) findings that indicate these epifauna encourage larval settlement. Thus, Niarbyl Bay is suspected to be a nursery habitat, as this region of the marine reserve was characterised by high biodiversity and density of juvenile *P.maximus*. Nursery habitat tend to be highly productive supporting high levels of juvenile survival, growth and density especially cod, crab, echinoderms and scallops (Sheehy and Prior, 2008; Howarth, *et al.*, 2011). Nursery habitat are also highly sensitive to anthropogenic disturbance which alter the nursery function negatively impacting commercial species recruitment (Howarth, *et al.*, 2015a). Nursery areas that are protected are suspected to lead to an overspill effect which benefit the surrounding fishing grounds and increases stock sustainability (Bradshaw, *et al.*, 2001; Howarth, *et al.*, 2015a; Howarth, *et al.*, 2015b). In other studies, juveniles were two to five times more abundant within the marine reserve than surrounding areas (Howarth, *et al.*, 2011); especially as closed areas protect scallops during their vulnerable phase increasing their overall survival and assisting in population recovery (Beukers-Stewart, *et al.*, 2005). Therefore, it is highly important that the marine reserve continuous to protect this essential nursery habitat located within Niarbyl Bay.

4.2.4 Niarbyl Benthic Environment

Niarbyl Bay scallop population inhabited a wide range of sediment types from sand to gravel, which is characteristics of scallop in the Isle of Man (Chi-yan Lo, unpublished). This marine reserve also supported high levels of species and habitat diversity. Niarbyl Bay benthic habitats were predominantly gravel and rocky substrate, maerl bed, macroalgal beds (kelp and Rhodophyta algae) and brittlestar beds. The gravely, rocky and mixed substrate habitats provide predator refuge and are associated with spat settlement, as these habitats support rich emergent fauna communities including *P.maximu*, hydroids, tunicates, sponges and other epifauna (Bradshaw, *et al.*, 2001). Sponges and the sea squirt (*Clavelina lepadiformis*) were present within Niarbyl Bay's rocky substrate, in relatively low abundance. These species are highly vulnerable to smothering by anthropogenic disturbances, taking up to 8 years to recover (Howarth and Beukers-Stewart, 2014). It was noted that sensitive species like Neopentadactyla *mixta* (sea cucumber) were also present in the gravelly substrate (Kostylev, *et al.*, 2001). Niarbyl Bay supports a diverse range of habitat and species that are sensitive to dredging anthropogenic disturbance, such as brittlestar beds (*Ophiothrix fragilis*, *Ophiocomina nigra*

and *Acrocnida brachiate*), seven armed starfish (*Luidia ciliaris*), sea urchin, monkfish (*Lophius piscatorius*), skates, flatfish, spider crabs (*Maja squinado* and *Inachus dorsetensis)*, edible crab (*Cancer pagurus*) and cephalopod (octopus) which are also bycatch products of scallop dredge (Beukers-Stewart and Beukers-Stewart, 2009; Howarth and Beukers-Stewart, 2014). Therefore, the presence of these species suggests that Niarbyl Bay's benthic communities are recovering from historical disturbance.

The shallower sections of the bay (<15m) comprise macroalgal habitat with hard substrates (rock, gravel, and pebbles) base. Macroalgae habitat are predominantly *laminaria spp*., which supports high levels of biodiversity and a variety of larger invertebrates as well as acts as a nursery habitat (Hauser, *et al.*, 2006), which was observed within the Niarbyl Bay.

Therefore, based on the presence of sensitive species, juvenile scallops, high biodiversity regions and nursery habitat, it is suggesting that Niarbyl Bay is successfully conserving vulnerable species and their benthic ecosystems. It is also recommended that the area is considered for continuous closure as the future protection will conserves the high level of biodiversity, nursery areas and vulnerable species.

4.2.4.1 Important Conservation Habitats

In Niarbyl Bay two types of brittlestar beds were discovered. These habitats were initially considered not to be economically valuable, however past studies have suggested that massive aggregation of suspension feeding brittlestars increase water quality and help counteract eutrophication (Hughes, 1998). Echinoderms (*Ophiothrix* species) ingest and absorb pollutions (heavy metals, radio-active fission and activation products, and transuranic isotopes) from the water column transfering these toxins to faeces rather than accumulating contaminants within the tissues (Hutchins, *et al.*, 1996; Hughes, 1998). Hence, Hughes (1998) describes *Ophiothrix* as an organisms that does not decontaminate an area but instead transfer toxins out of the water column into the substrate. These organisms perform an important ecosystem function of organic matter recycling (Davoult and Gounin, 1995). However, Hutchins, *et al.* (1996) argues that *Ophiothrix* removes toxic heavy metals like Ag, Zn, Cd and Co from the environment. These heavy metals are present within the Isle of Man territorial waters and have a negative impact on the shell fishing industry, especially crabs (Chiarelli and Roccheri, 2014). Thus

conserving brittlestar beds that remove toxins may be an essential part of preserving shellfish stock quality.

The first brittlestar habitat comprised *Ophiothrix fragilis* and *Ophiocomina nigra* which occurred in the south east of the marine reserve within rocky substrate; which concurs with Hughes (1998) findings that *Ophiothrix fragilis* and *Ophiocomina nigra* inhabit moderately exposed rock or mixed substrate, where starfish predation is minimal as predation pressure limits *Ophioroids* spatial distribution and aggregation size (Hughes, 1998). Niarbyl Bay's *Ophioroids* brittlestar bed was relatively small and did not monopolize the substratum, this may be due to the presence of predators (*C. pagurus, Necora puber, Liocarcinus spp, Pagurus spp, Luidia ciliaris, Crossaster papposus, Asterias rubens*). This community composition was similar to other studies even though *Ophioroids* display avoidance behaviour to starfish predators (Hughes, 1998; Veale, *et al.*, 2000a).

The second brittlestar habitat comprised of *Acrocnida brachiata* occurring below 15m in soft sand/mud substrate. *Acronida brachiata* lied beneath the surface and only their limbs can be observed on the surface. This habitat community assemblage and diversity is extremely similar to that of sandy substrate despite the presence of these *Acronida brachiata* legs. This sandy brittlestar habitat had a low epifauna diversity which is typical as this habitat was characterised as having a high diverse of infauna community (Hughes, 1998); however this was not assessed in this survey.

4.2.5 Future recommendation

Niarbyl Bay habitats support a high diversity of epifauna and a variety of sized scallops. This reserve also protects important nursery habitats and unique brittlestar beds which are vital for mineral recycling. The closure of Niarbyl Bay has negated anthropogenic disturbance that effect water quality and increase turbidity, as these factors are associated with filter feeding suffocation as siltation clogs their gills (Kostylev, *et al.*, 2001; Beukers-Stewart, *et al.*, 2005). Thus, marine reserves are essential in scallop conservation as it protects scallops during their vulnerable life-phases (Beukers-Stewart, *et al.*, 2005). Therefore, continuous closure of Niarbyl Bay is recommended as it conserves essential habitats that provide a nursery function and have high biodiversity which are required for future *P.maximus* sustainability.

On the other hand, scallop densities are relatively high compared to Laxey Bay, so commercial fishing may be an option in Niarbyl Bay, especially in the gravel and sandy habitats where equipment is less likely to get damaged. However, further research is required to determine if it is commercially viable to dredge the area, especially as risk of gear damage is high and scallops are vulnerable to the allele effect.

The survey on Niarbyl Bay indicates that recovery is occurring as scallop densities increased, so is the appearance of unique habitat and anthropogenic sensitive species (monkfish, flatfish, *L.ciliaris*, octopus as well as crustaceans and molluscs) (Howarth and Beukers-Stewart, 2014). However, recovery does takes time, and the scallop recruitment benefits spreading to surrounding areas has only been observed in other studies after 10-15 years of protection (Beukers-Stewart, *et al.*, 2005; Howarth, *et al.*, 2015b). At present, Niarbyl Bay has only been protected for 7 years which is an insufficient time period to show a stock recovery and benefits to the surrounding areas. Thus, continuous protect is recommended especially as the reserve did show increase in juvenile recruitment. The benefits of increased scallop abundance was speculated to be spreading to surrounding areas as older and larger size classes are lacking within the bay, however more information is required on scallop migration and scallop densities around the reserve. Therefore, future study is required on the species spatial distribution and migration throughout the Isle of Man before this can be concluded.

4.3 Marine Reserve Comparison

The reseeding of scallop was more successful in Niarbyl Bay compared to Laxey Bay, as Niarbyl Bay had greater abundance of newly recruited juveniles. It is suspected that this was because Niarbyl Bay had: lower predator density; more habitat associated with scallop; nursery habitat; reseeded with wildstock; and the seeded scallops were larger (107mm) so were less vulnerable to predation compared to smaller (51mm) cultured scallop that Laxey Bay was reseeded with. Wildstock is less susceptible to predation than cultivated stocks, as cultivated scallops shells have half the strength (Minchin, 2002). Laxey Bay's benthic habitat was not suitable for scallop survival as *P.maximus* had little camouflaged when recessed into sandy substrate (Shumway and Parsons, 2011). Therefore, Niarbyl Bay was more suitable for scallop conservation. However, these marine reserves both encompass habitats of conservation importance and habitats that support a scallop population. In Laxey Bay, the scallop population

were only present in the maerl habitat, which supported more scallops than the maerl habitat within Niarbyl Bay.

4.3.1 Similar conservation and scallop important Habitats

Maerl habitat was present in both closed areas (Laxey Bay and Niarbyl Bay) with residing scallop populations, however the conditions of the maerl and residing community differed despite both communities consisting of *P.maximus*. Maerl habitats are important nursery ground for juvenile scallop species. Maerl is highly vulnerable to anthropogenic activities that cause smothering or structural damage as maerl growth is dependent on the survival of the upper coralline layers (Hall-Spencer and Moore, 2000; Howarth and Beukers-Stewart, 2014). Thus, this maerl species *Phymatolithon calcareum* was listed under the OSPAR threatened species list and the habitat is currently protected under the Annex 1 of the Habitats Directive legislation (EU 1160: large shallow inlets and bays and sandbanks) (Barbera, *et al.*, 2003; Maddock, 2008; Gell and Hanley, 2010; Gell and Hanley, 2013). Therefore it is important to identify the location of this habitat and assess its health, as the state of the living maerl (structural complexity and percentage cover of live maerl) stipulates the biodiversity level and communities it can support (Kamenos, *et al.*, 2004c; Hinz, *et al.*, 2010). Healthy maerl bed harbour biodiverse communities due to its structural heterogeneous, which provides refuge from predation, habitat for spat settlement and supports hydroid colonies (Hall-Spencer and Moore, 2000; Bradshaw, *et al.*, 2003; Kamenos, *et al.*, 2004b; Talman, *et al.*, 2004). The maerl bed within Laxey Bay was deemed to be of a healthier condition, as a greater proportion of living maerl was recorded compared to Niarbyl Bay maerl habitat which mostly comprised dead maerl (Personal observations). The high proportion of dead maerl in Niarbyl Bay may be due to inefficient recovery time (7 years) as maerl typically has a slow growth rate and poor recruitment (Howarth and Beukers-Stewart, 2014). Never the less, marine reserves acts as a safe haven, encouraging recovery (Howarth, *et al.*, 2015a). Therefore, long term protection of several decades is suggested for recovery to occur (Howarth, *et al.*, 2015a).

The maerl bed community differed between the reserves. Laxey Bay benthic community was predominately *Pagurus spp.*, *Ophiura ophiura*, *Hydrobia spp.*, *Pecten maximus* and turf algae. Whereas, Niarbyl Bay benthic community contains Ophiura *ophiura*, *Cerianthus lloydii*, *Pecten maximus* and *Rhodophyta spp*. Both these maerl habitat were characterised *Ophiura ophiura* (brittlestar) which is an indicator species of chronic fishing disturbance (Hinz, *et al.*,

2012). The presence of these species suggesting that chronic illegal fishing may not be occurring or has not altered the benthic community composition, as communities were not dominated by a single dredging resilient species (personal observations). Therefore, the difference between the communities assemblages may be attributed to maerl health and other environmental factors that are characterised by maerl habitats (strong current, clear water and coarse underlying sediment) (Kamenos, *et al.*, 2004b; Howarth and Beukers-Stewart, 2014). Overall maerl within Laxey and Niarbyl Bays had a greater diversity index than sandy substrate but not as higher as gravel substrate diversity; which contradict Kamenos, *et al.* (2004b) findings which indicate that maerl habitat have the greatest diversity compared to non-biogenic habitats. This variability between Kamenos, *et al.* (2004b) and this study's findings may be due to sampling method limitation which did not record infauna, and cryptic species.

4.4 Scallop Habitat Association

Benthic habitat are important parts of fisheries management, as understanding the habitat preference of *P.maximus* is an essential aspect in avoiding stock collapses (Kamenos, *et al.*, 2004c). The spatial distribution of *P. maximus* within the two marine reserves shows a preferences to specific habitat. This was especially apparent in Laxey Bay were *P. maximus* only occurred in the structurally complex maerl habitats. However, scallops in Niarbyl Bay were observed in a range of habitat types but the size and abundance of the scallops inhabiting the habitat varied; suggesting size specific habitat selection (Kamenos, *et al.*, 2004a). Size specific habitat preference was apparent in this study as larger individuals (mean 129mm±5mm) were recorded in mixed sediment, medium sized individuals were recorded in coarse substrate (mean 93mm ±5mm) and maerl substrate (mean 91mm±8mm) and juveniles were predominantly recorded in rocky substrate (mean 46mm±13mm). This contradicted previous studies that found maerl beds to be the most important habitat for juveniles as maerl supplies many prerequisites of a nursery area (Kamenos, *et al.*, 2004c). Thus, maerl was expected to support the greatest abundance of scallops especially juveniles, however this was not the case especially in Niarbyl Bay.

Overall the greatest abundance *P. maximus* occurred in the substrate gravel and mixed sediment. However, this contradicted Kamenos, *et al.* (2004b) findings which indicated that scallop density was greatest on living maerl patches compared to gravel; the maerl populations also had a lower mortality rate. However, high density of *P.maximus* does occur in gravel

substrate (Kostylev, *et al.*, 2001; Kamenos, *et al.*, 2004a; Beukers-Stewart, *et al.*, 2005; Howarth, *et al.*, 2011).

Gravel, maerl and mixed sediment habitat are characterised by a rough benthic topography (structural complexity and sediment type) which is an important factor associated with *P.maximus* spatial distribution(Mendo, *et al.*, 2014). Rough benthic topography increases turbulence reducing food availability to suspension-feeding bivalves resulting in a slowed growth rate (Kamenos, *et al.*, 2004b). However, the increased structural complexity assists with scallop camouflage (Hall-Spencer and Moore, 2000; Shumway and Parsons, 2011). No supporting evidence was found during the quantile regression analysis which indicated that scallops preference habitat with an increased complexity. This contradictory finding may be due to low sample size; inaccurate measurement of topography roughness or other variables (larval arrival, settlement, competition, predator densities, depth, food availability, clean water, bottom currents and low level of suspended silt) were more influential in determining spatial distribution than topography (Kostylev, *et al.*, 2001; Mendo, *et al.*, 2014). Scallops do inhabit non-complex habitats as the growth rate is faster due to increases in food supply; however productivity is reduced due to increased predation pressure as the habitat provides no refuge and scallops are at risk of suffocation (due to silt clogging the cilia in the gills) (Kamenos, *et al.*, 2004b). Like other studies, *P.maximus* was recorded at low abundances in sandy substrate within Niarbyl Bay, however it is speculated that they only reside in sandy substrate due to competition as increased growth rate is less beneficial when predation levels are high (Kostylev, *et al.*, 2001; Szostek, *et al.*, 2013).

P.maximus spatial distribution is also influenced by depth as *P.maximus* abundances was greater between 22m to 26m (Brand, *et al.*, 1980). This study provides supporting evidence that depth was a limiting factor on scallop distribution, with scallops' abundance being greater at depths deeper than 15m. However further research is required due to the low sample size and small depth range recorded within the marine reserves.

4.5 Conclusion

In conclusion, *P.maximus* had a size specific distribution with adult congregating in mixed, gravel and maerl sediment and juveniles inhabiting rocky substrates. Laxey Bay scallop population was suspected to have reached maximum carrying capacity for the maerl habitat

within the marine reserve as densities remained constant over the years. Laxey Bay also consisted of important conservation habitats, *Zostera* meadows and maerl beds, which require legal protection, however the majority of the bay benthic habitat was sandy substrate. Therefore, continued protection is only recommended for the southern region of Laxey Bay conserving the *Zostera* meadows and maerl habitat which *P.maximus* resides. Further research is recommended to measure the extent of the maerl bed as it is suspected that Laxey Bay's closed area does not provide adequate protection to the residential scallop population.

Niarbyl Bay's scallop population was widely distributed throughout the bay, with juveniles being most prevalent in the southern inner regions. This marine reserve supports a high level of biodiversity and important nursery areas. Therefore it is recommended that continued protection occurs in the southern region and areas where biodiversity was greatest biodiversity and *P.maximus* abundance was recorded, as well as functioned as a nursery ground. However, further research is required into the economic viability of harvesting the scallop within the northern and deeper areas of the bay before a recommendation can be suggested.

Therefore, these marine reserves should remain closed (especially Niarbyl Bay), as they consist of a diverse range of important habitat and support a *P.maximus* population, however if commercial fishing is required in the area, a compromise of sections reopened within Laxey Bay and Niarbyl Bay northern sector is recommended, but it still may not be economically valuable to harvest scallops in these marine reserves, as densities are either low or fishing gear is at high risk of damage.

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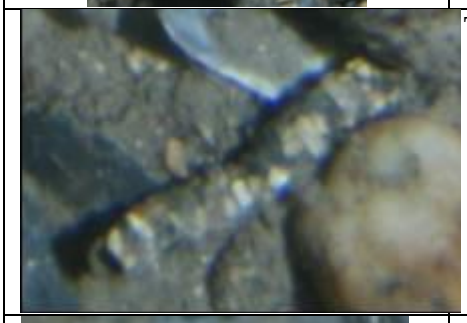
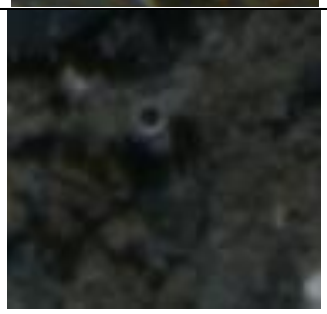
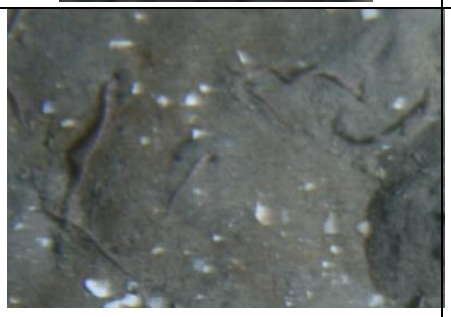
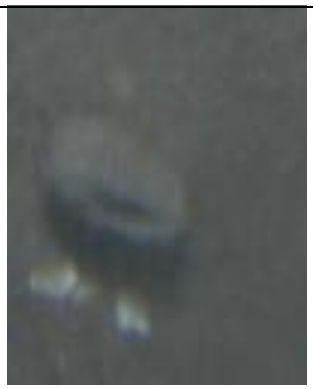
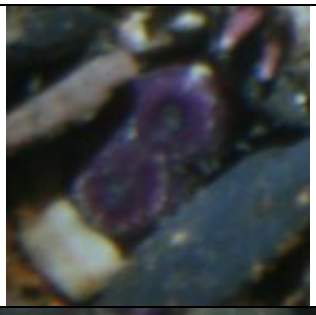
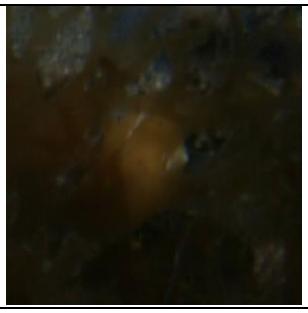
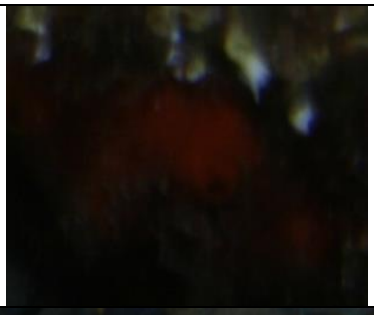
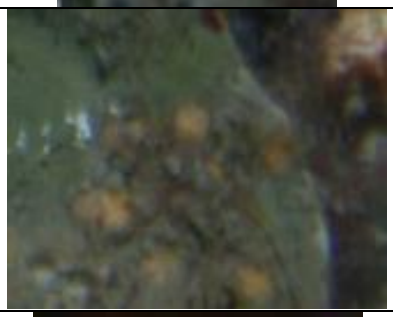
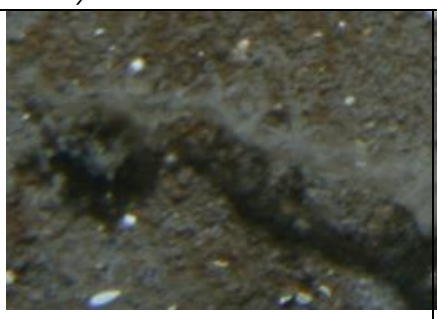
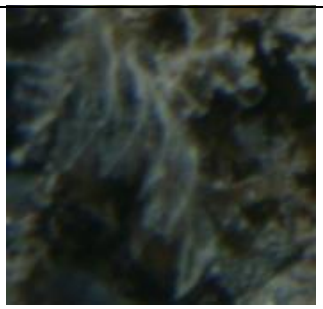
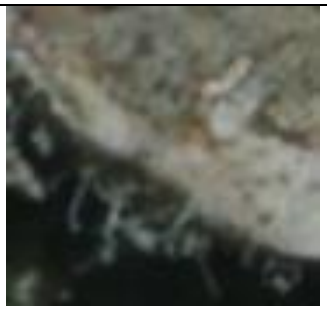
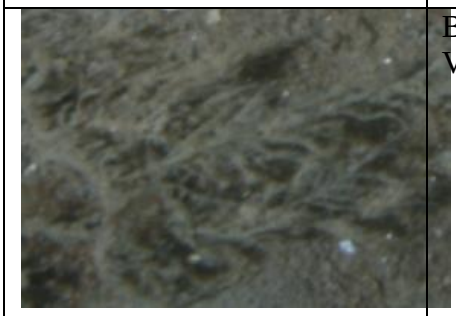
6 Appendix

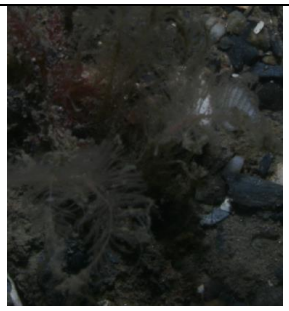
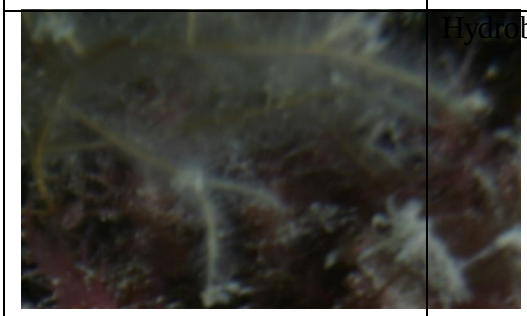
Appendix 1: The species identified in Laxey and Niarbyl bay with species names or ID codes

BODY PARTS			
	Tentacle I		Tube V
	Tube I		Tube VI
	Tube II		Tube VII
	Tube III		Brittlestar leg
	Tube IV		Syphons I

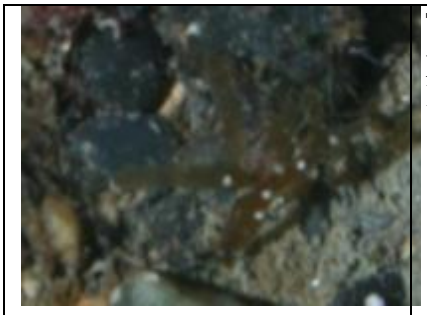
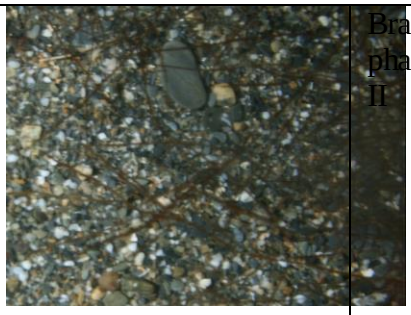
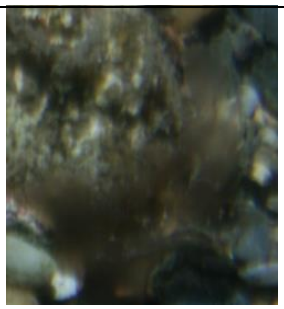
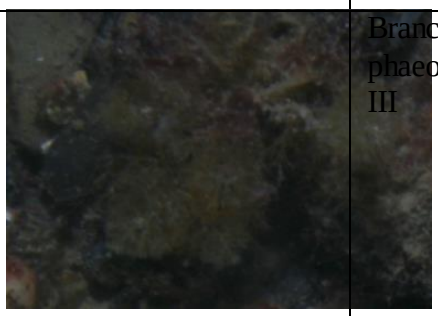
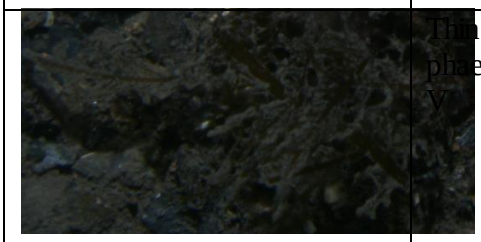
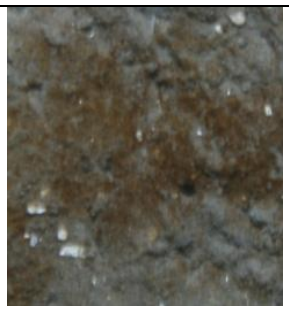
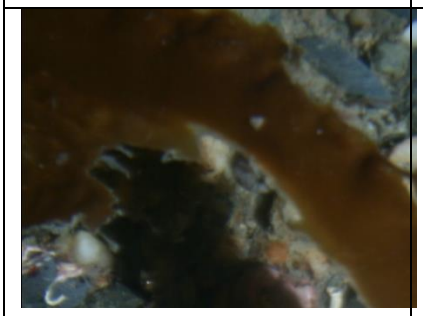
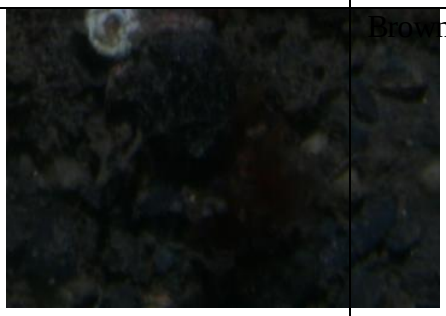
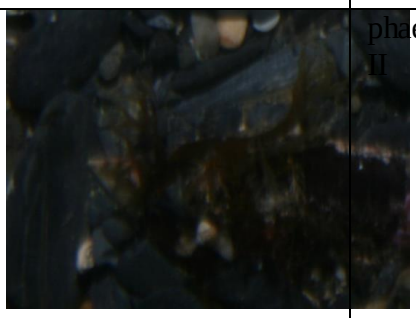
	Syphons II		Syphons VI
	Syphons III		Syphons VII
	Syphons IV		Burrow I
	Syphons V		
Sponge			
	Sponge I		Sponge V

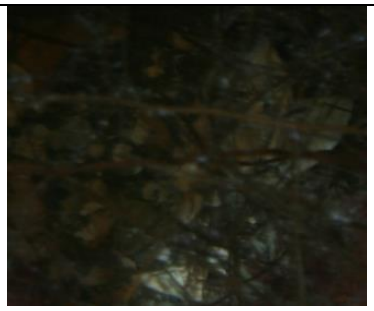
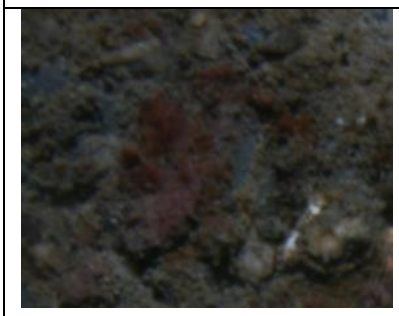
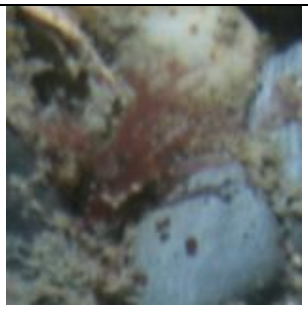
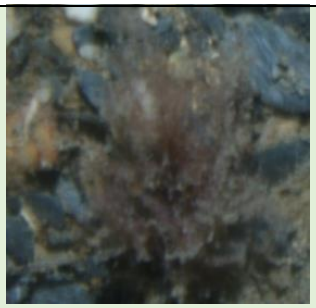
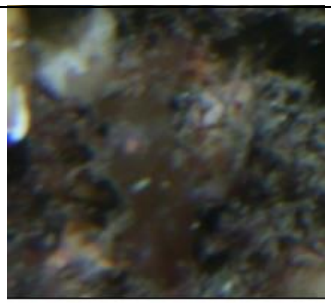
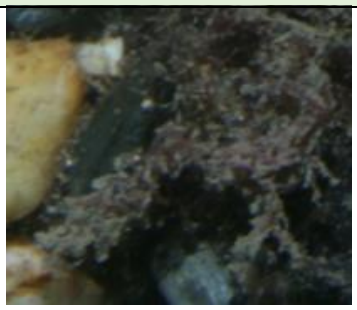
	Sponge II		Sponge VI
	Sponge III		Encrusting sponge
	Sponge IV		
Bryozoans and hydroids			
	Bryozoan I		Bryozoan VII
	Bryozoan II		Bryozoan VIII

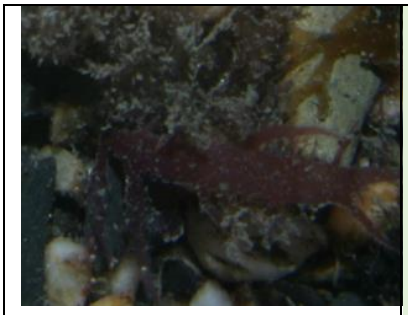
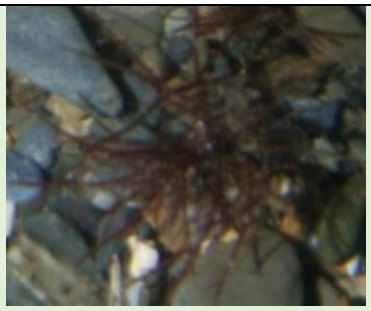
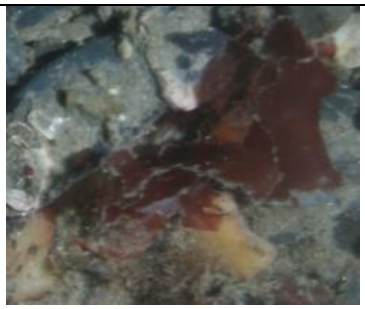
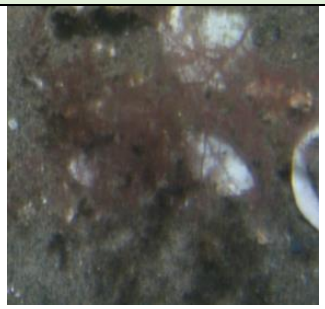
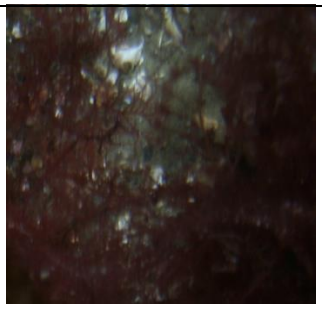
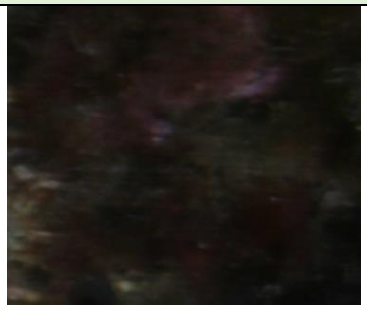
	Bryozoan III		Bryozoan IX
	Bryozoan IV		Obelia geniculata
	Bryozoan V		Electra pilosa
	Bryozoan VI		Corymorpha nutans Nodding hydroid
	Nemertesia antennina		Hydrobia III

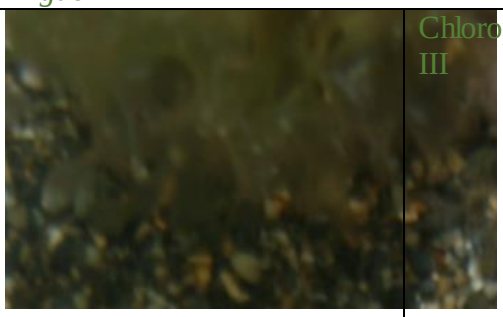
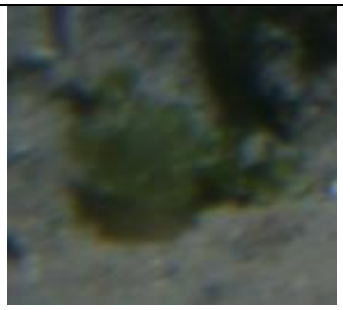
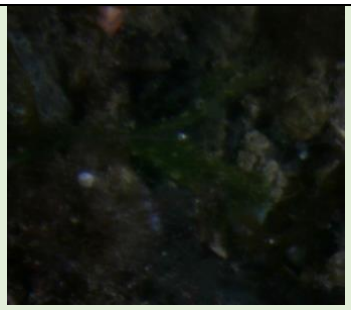
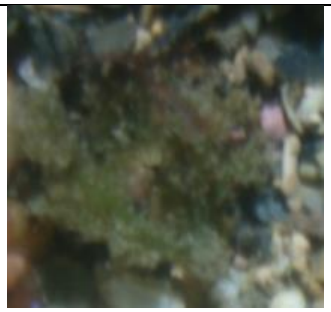
	Hydrobia I		Hydrobia VI/ IV
	Hydrobia II		Hydrobia V

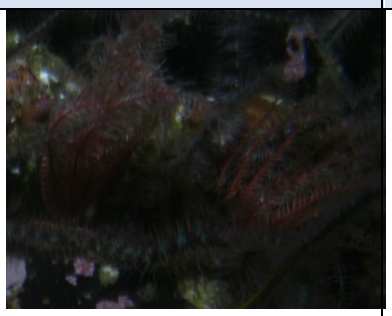
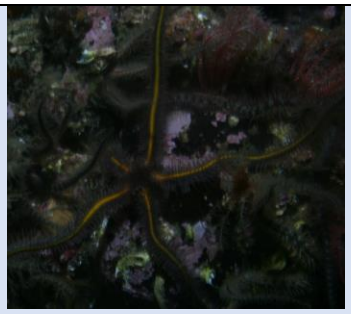
Brown Algae			
	Brown turf algae I		Thin phaeophyceae VI
	Thin phaeophyceae I Dictyota spp. Dictyota dichotoma		Thin phaeophyceae VII
	Thin phaeophyceae II		Branching phaeophyceae I

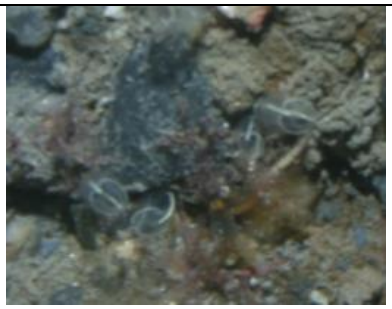
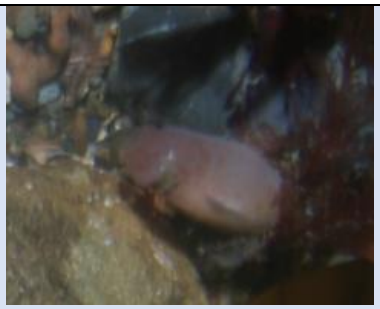
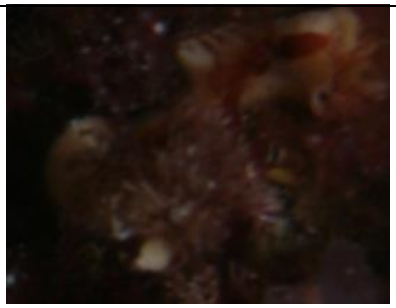
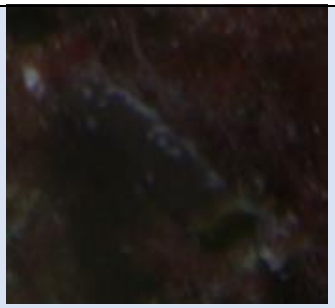
	Thin phaeophyceae III		Branching phaeophyceae II
	Thin phaeophyceae IV		Branching phaeophyceae III
	Thin phaeophyceae V		Encrusting brown algae
	Laminaria spp.		Brown I
	phaeophyceae I		phaeophyceae II

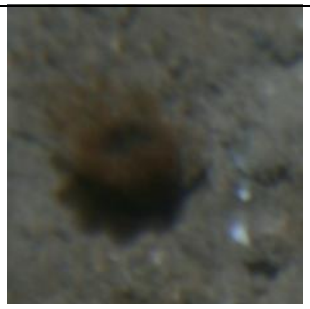
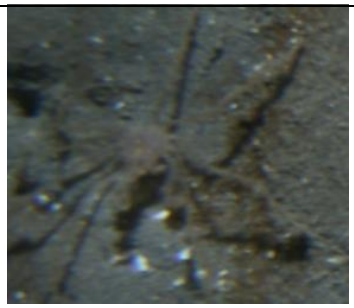
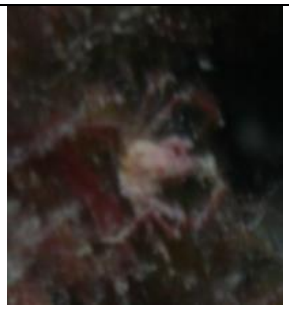
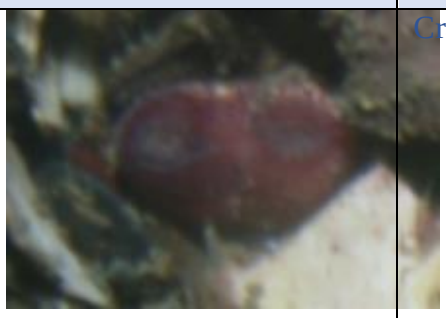
	Dictyopteris polypodioides		
RED ALGAE			
	Turf red		Thin Rhodophyta VII
	Thin Rhodophyta I		Thin Rhodophyta VI
	Thin Rhodophyta II		Rhodophyta I
	Thin Rhodophyta III		Rhodophyta II

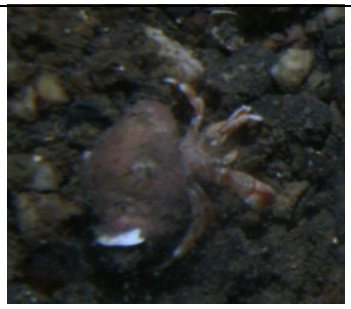
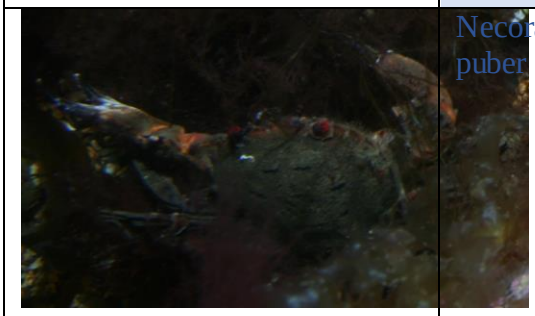
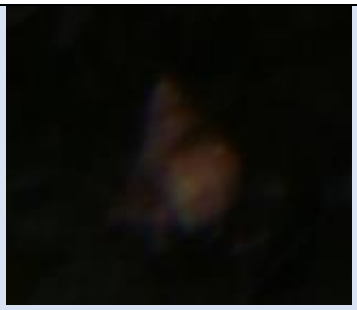
	Thin Rhodophyta IV		Rhodophyta III
	Thin Rhodophyta V		Rhodophyta IV
	Rhodophyta V		Rhodophyta IX
	Rhodophyta VI		Rhodophyta X
	Rhodophyta VII		Encrusting Coralline algae

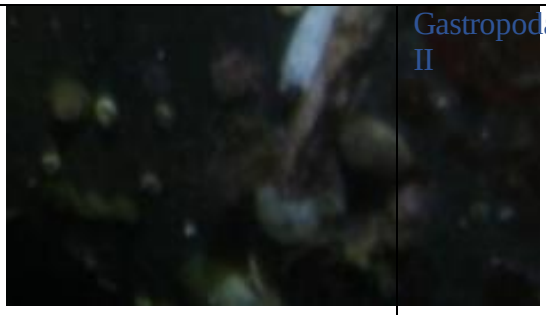
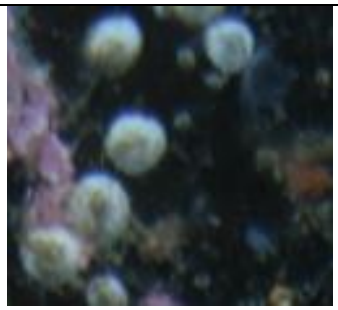
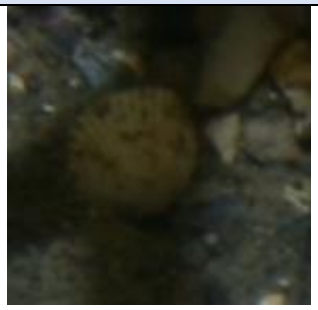
	Rhodophyta VIII		
Green Algae			
	Chlorophyta I		Chlorophyta III
	Ulva spp		Chlorophyta IV
	Chlorophyta II		Chlorophyta V
Polychaete			
	Spirobis spirobis		Unknown tube worm

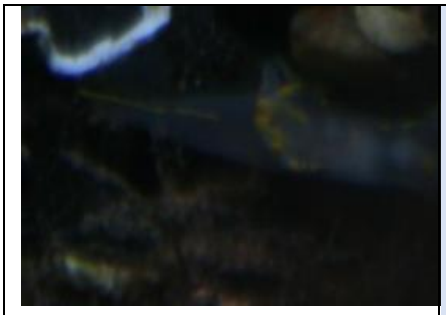
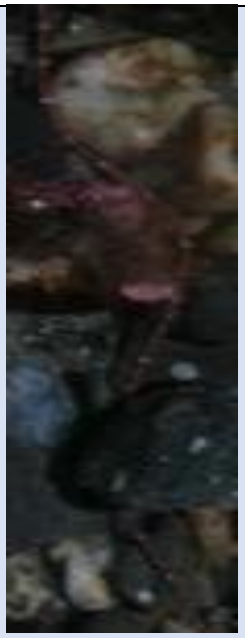
	Arenicula		Lagis koreni
Echinodermata			
	Cerianthus lloydii		Neopentadactyla
	Ophiura ophiura		Antedon Bifida
	Ophiura albida		Ophiocomina nigra
	Asterias rubens		Ophiothrix fragilis

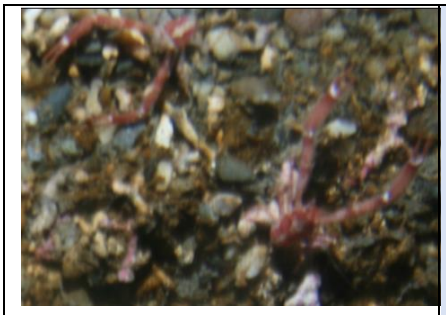
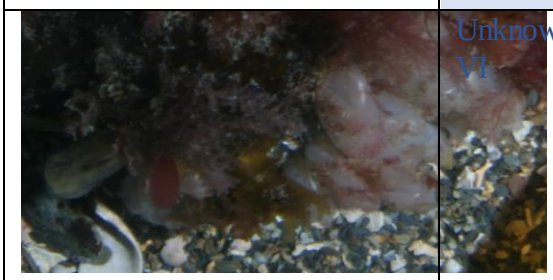
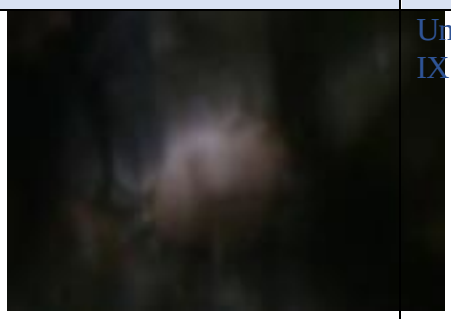
	Marthasterias glacialis		
Sea squirt			
	Clavelina lepadiformis		Sea squirt III
	Sea squirt I		Sea pen
	Sea squirt II		
Sea Anemone			
	Sea anemone I		Tube anemone

	Sea anemone II		Anemone
	Sea anemone III		Anemone II
	Sea anemone IV		
Crustacean			
	Macropodia spp		Crab I
	Macropodia spp II		Crab II

	Liocarcinus spp.		Crab III
	Pagurus spp.		Crab IV
	Pagurus bernhadus		Sponge crab
	Necora puber		Bivalve III
	Bivalve II		Gastropoda I

	Turritella communis		Gastropoda II
	barnacle		Gastropoda III
	Coryphella browni		Gastropoda IV
	Gibbula spp.		Small gastropoda
	Gibbula cineraria		Gastropoda V

	Polycera faeroensis		
Unknonwns			
	Unknown I		Unknown VII Deadman fingers
	Unknown II		Unknown VII
	Unknown III		Unknown VIII
	Unknown IV		

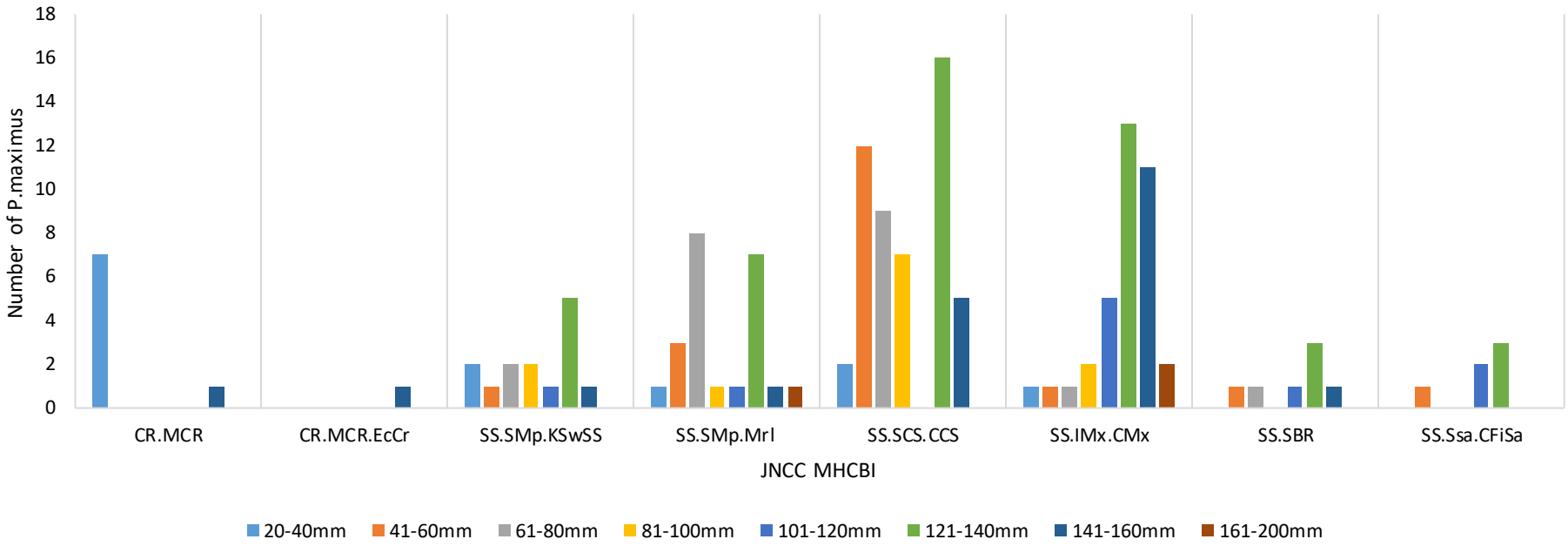
	Unknown V		
	Unknown VI		Unknown IX
Fish			
	Fish 1		Jellyfish
	Fish II		shrimp
	Callionymus lyra		

Appendix 2: The species variables that contributed to the highest similarity within each cluster Env. Factor category defined by the SIMPROF analysis within both Laxey and Niarbyl Bay marine reserves. The species were identified to contributed >4% to similarity within the groups.

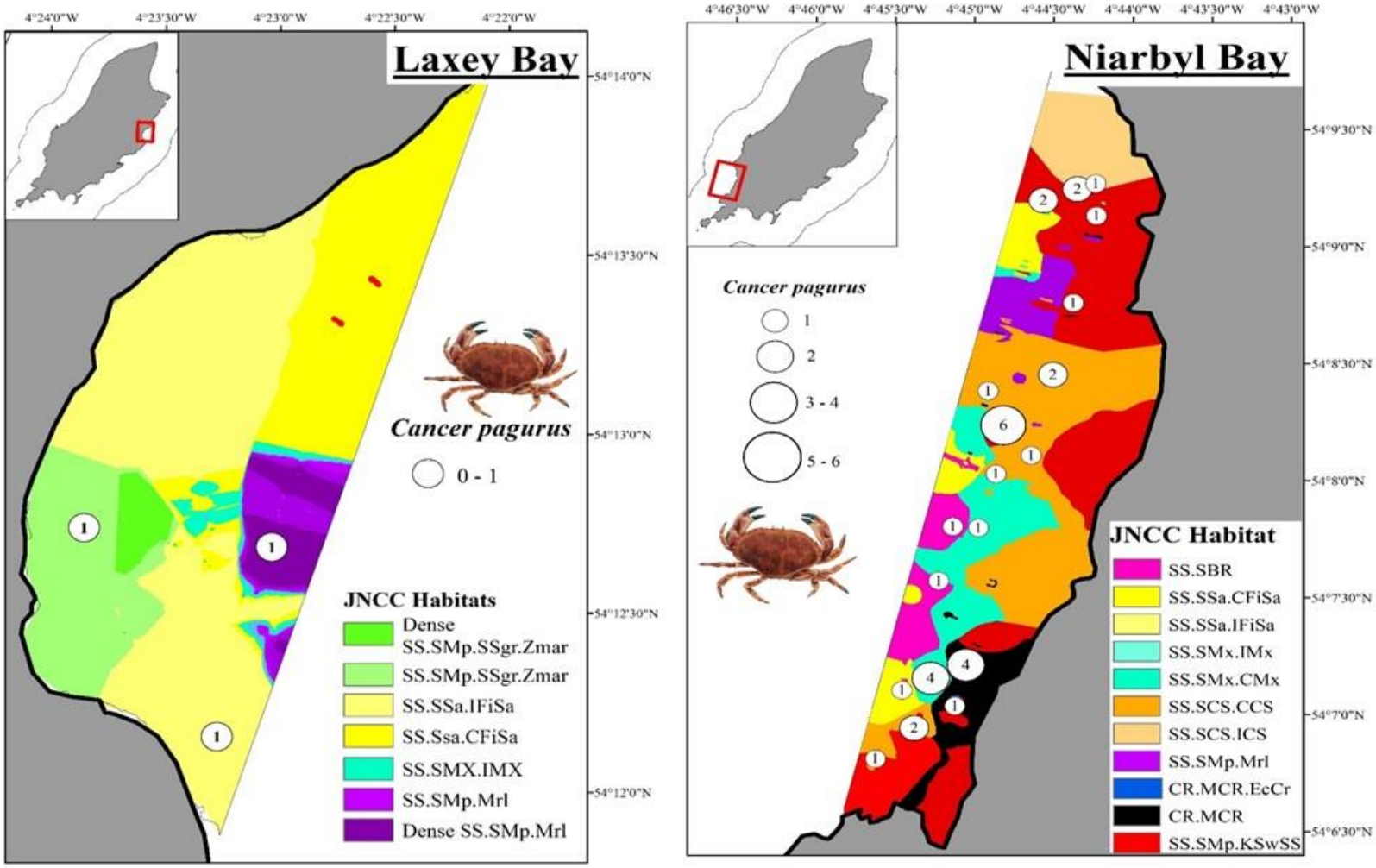
Cluster Group	Species	Cluster Group	Species	Cluster Group	Species
Group a	Less than 2 samples in group	***Group o***	Turf Brown	***Group x***	Spirorbis spp.
Group b	Less than 2 samples in group		Coralline crust		coralline crust
Group c	Less than 2 samples in group	***Group p***	clavelina lepadiformis		Thin Red II
Group d	Less than 2 samples in group		Thin Red I	***Group y***	Less than 2 samples in group
Group e	Less than 2 samples in group	***Group q***	Sponge I	***Group z***	Red IV
Group f	Tube's		Turf Brown		Red V
	Zostera marina		Bryozoan I		coralline crust
Group g	Arenicola marina		Thin Brown I		Thin Red I
	Pagurus spp.		Spirorbis spp.	***Group aa***	saccharina latissima
	Zostera marina	***Group r***	Spirorbis spp.		electra pilosa
Group h	Pagurus spp.		Encrusting brown		Red V
Group i	Phymatolithon calcareum		Red I		coralline crust
	Hydrobia		Thin Brown		Spirorbis spp.
	Turf Brown	***Group s***	Less than 2 samples in group	***Group ab***	Phymatolithon calcareum
Group j	Less than 2 samples in group	***Group t***	Less than 2 samples in group		ophiura ophiura
Group k	Pagurus spp.	***Group u***	Less than 2 samples in group		Red I
	ophiura ophiura	***Group v***	Spirorbis spp.		Red V
	Hydrobia		Gastropoda I		
	Phymatolithon calcareum		Bryozoan I		
Group l	Tube's	***Group w***	encrusting brown		
	Lagis koreni		gibbula cineraria		
	Hydrobia		Red I		
	Arenicola marina		small gastropoda		
Group m	Cerianthus lloydii		Thin Brown I		
	Acrocnida brachiata		Turf Brown		
	Arenicola marina		Unknown V		
Group n	Less than 2 samples in group				

Appendix 3: The PermANOVA pair wise results for the Spp. Factors defined by the Cluster analysis in PRIMER v.6 within both Laxey and Niarbyl Bay marine reserves. The dark blue colour indicates the significant differences between the factors.

Cluster	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y	z	aa
f	No	0.254	0.238	0.24	0.252																						
g	0.139	0.151	0.149	0.142	0.141	0.012																					
h	0.343	0.298	0.338	0.347	0.332	0.097	0.029																				
i	0.087	0.105	0.098	0.095	0.101	0.003	0.001	0.016																			
j	No	No	No	No	No	0.265	0.153	0.319	0.09																		
k	0.176	0.174	0.173	0.161	0.165	0.008	0.001	0.06	0.001	0.169																	
l	0.09	0.094	0.083	0.072	0.088	0.006	0.001	0.013	0.001	0.082	0.001																
m	0.095	0.095	0.104	0.1	0.102	0.004	0.002	0.025	0.001	0.108	0.001	0.001															
n	No	No	No	No	No	0.24	0.151	0.343	0.089	No	0.175	0.098	0.102														
o	No	No	0.11	0.107	No	No	0.001	0.038	0.001	No	No	0.001	0.001	0.114													
p	0.149	0.146	0.147	0.129	0.119	0.009	0.005	0.028	0.001	0.161	0.004	0.002	0.002	0.152	0.003												
q	0.25	0.241	0.261	0.248	0.232	0.099	0.008	0.096	0.007	0.238	0.014	0.002	0.007	0.286	0.006	0.01											
r	0.105	0.103	0.098	0.115	0.1	0.005	0.002	0.026	0.001	0.086	0.001	0.001	0.001	0.097	0.001	0.001	0.007										
s	No	No	No	No	No	0.251	0.146	0.342	0.11	No	0.185	0.082	0.087	No	0.115	0.147	0.248	0.112									
t	No	No	No	No	No	0.241	0.137	0.319	0.102	No	0.171	0.079	0.297	No	0.116	0.15	0.241	0.091	No								
u	No	No	No	No	No	0.249	0.131	0.333	0.095	No	0.162	0.08	0.092	No	0.116	0.144	0.251	0.096	No	No							
v	No	No	No	No	No	No	No	No	No	No	No	0.019	0.028	No	0.023	0.033	0.099	0.014	No	No	No						
w	0.359	0.323	0.34	0.324	0.35	0.109	0.034	0.323	0.019	0.317	0.046	0.013	0.033	0.335	0.021	0.035	0.116	0.021	0.353	0.348	0.361	0.335					
x	0.001	0.025	0.019	0.02	0.03	0.001	0.001	0.002	0.001	0.025	0.001	0.001	0.001	0.025	0.001	0.001	0.001	0.001	0.125	0.052	0.063	0.004	0.019				
y	No	No	No	No	No	0.247	0.139	0.364	0.095	No	0.174	0.078	0.091	No	0.125	0.129	0.26	0.083	No	No	No	No	0.346	No			
z	0.239	0.24	0.272	0.249	0.254	0.097	0.012	0.105	0.003	0.243	0.022	0.009	0.005	0.229	0.011	0.011	0.106	0.008	0.25	0.242	0.233	0.101	0.127	No	0.241		
aa	0.063	0.066	0.065	0.045	0.052	0.001	0.001	0.006	0.001	0.05	0.001	0.001	0.001	0.054	0.001	0.001	0.001	0.001	0.07	0.057	0.078	0.004	0.007	0.001	0.036	0.001	
ab	0.258	0.25	0.26	0.237	0.266	0.092	0.013	0.091	0.005	0.25	0.023	0.004	0.005	0.268	0.008	0.01	0.085	0.009	0.264	0.23	0.239	0.05	No	0.002	0.268	No	0.002



Appendix 4: The number of scallop recorded in each size class for each JNCC benthic habitat type identified within Niarbyl and Laxey Bays marine reserves in the Isle of Man territorial seas.



Appendix 5: Cancer pagurus (edible crab) abundance from each 10 minute tows was superimposed onto the Biotope map for Laxey Bay (left) and Niarbyl Bay (right) marine reserve in the Isle of Man territorial waters. The biotope maps were generated in ArcGIS according to the JNCC habitat categories. The scallop image © McCartney, 201