MSc Dissertation

Don’t take the “P” out of MPAs: Identifying conservation priorities for the South Arran Marine Protected Area

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Abstract

Twenty dive surveys that took place within the south Arran MPA, in the Firth of Clyde, Scotland, has provided valuable baseline data before any management plans have been established. It highlights the need for effective management measures to guarantee the recovery of the marine habitats within this area. This data will allow key comparisons to be made between subsequent surveys, and enable the tracking of changes to occur. The original management plans favored by the Scottish government allowed destructive methods of fishing, such as trawling, to continue within certain areas of the MPA boundaries. This would of afforded very little protection to the area, while hampering its recovery. New management measures have recently been announced to address these issues, however they are not fixed, and are currently under a one-month consultation period. As a result, there is still a degree of uncertainty surrounding the measures that will be eventually implemented by the Scottish government. Due to this uncertainty, this study made comparisons between inside and outside the originally proposed dredging boundaries, a measure originating from the originally favored plan. These comparisons highlighted a significantly lower number of king scallops (*Pecten maximus*) inside the dredging boundaries, where dredging was set to continue within the MPA. This stresses the need for recovery, and the likelihood that this area would no longer be a viable fishing ground for much longer. Additionally, the presence of juvenile gadoids within four of the transects, highlights the potential of this area as a nursery habitat. Existing seagrass and maerl beds, which will be protected under the new management measures, are favored by these commercially important species.

Introduction

Many fish stocks worldwide are in decline (Worm and Branch, 2012, FAO, 2014), with recent FAO estimates suggesting that only 9.9% of monitored stocks are underfished (FAO, 2014). The remainder has been expressed as overfished (28.8%) and fully fished (61.3%); this is despite an increase in fishing effort (Watson *et al.,* 2012, FAO, 2014). Traditional fisheries for large predatory fish, such as cod (*Gadus morhua*), have now been replaced with fisheries of previously suppressed species, often compromising of invertebrates (Pauly *et al.,* 2002). This is often referred to as "fishing down the food web" (Pauly *et al*., 1998).

Decades of intensive fishing has resulted in many marine ecosystems shifting to less productive states (Roberts et al., 2005). The use of destructive methods such as trawling and dredging has reduced habitat structural complexity and lowered species diversity in fished ecosystems (Sheehan et al., 2013). Reducing the biodiversity of marine ecosystems decreases their resilience to environmental perturbations that are likely to become more common due to climate change (Hughes *et al.,* 2003, Hughes *et al.,* 2007). Maintenance of ecosystem integrity helps ensure the viability of marine resources into the future (Sheehan *et al.,* 2013).

Many benthic habitats have suffered major damage due to intensive fishing (Sheehan *et al.,* 2013), however, they are essential in maintaining productive fisheries (Thrush and Dayton, 2002). They provide high amounts of 3-dimensional structural complexity (3D), compared to the often-barren seafloor

(Beukers-Stewart and Beukers-Stewart, 2009). Organisms favour this complexity as it provides refuge and greater feeding opportunities (Peters *et al.,* 2014). Furthermore, they act as nursery areas, with seagrass beds, maerl beds and large areas of macroalgae shown to contain high densities of commercially exploitable species, such as juvenile cod, and scallop spat (Howarth *et al.,* 2011, Lilley and Unsworth, 2014, Peters *et al*., 2014, Howarth *et al*., 2015). It is therefore in the interest of marine managers, and ultimately fisherman, to protect and restore these habitats to increase recruitment into local fish stocks (Gell and Roberts, 2003).

Marine protected areas (MPAs) are becoming increasingly common as a method of protecting these habitats while boosting stock size and reproductive output of commercially important species (Roberts *et al.,* 2001, Gell and Roberts, 2003, Beukers-Stewart *et al.,* 2005, Roberts *et al.,* 2005, Howarth *et al.,* 2011, Howarth *et al.,* 2015). Benefits of this approach include: an increase in the biomass and abundance of target species, greater survival of juveniles, and greater reproductive output (Roberts *et al.,* 2001, Halpern and Warner, 2002). Combining all these factors, it is hoped that this increase in biomass i.e. larger and older fish will "spillover" into adjacent fishing grounds, fueling an increase in landings (Roberts *et al.,* 2001, Gell and Roberts, 2003, Beukers–Stewart *et al.*, 2005).

Due to the benefits attained from MPAs, the World Parks Congress in 2014 called for 10% of the oceans to be protected by 2020 (IUCN, 2014), but at present only 3.4% is formally under any protection (Juffe-Bignoli *et al.,* 2014). Recent

proceedings have shown a more positive trend towards increasing this percentage further. For example, the British government passed the Marine and Coastal Access Act, along with the Marine Scotland Act, in 2009 and 2010 respectively, which included the provision for the creation of Marine Conservation Zones (MCZs) (Rodwell *et al.,* 2013, JNCC, 2015). Scotland has designated a total of 30 MPAs (Scottish Government, 2014a), which recently have been assessed, to determine the management practices that will apply within these areas.

One particular MPA has been established around the South of Arran, within the Firth of Clyde (COAST, 2014b). This area once supported diverse and productive fisheries, with large aggregations of cod and various flatfish being caught in large numbers (Thurstan and Roberts, 2010, Heath and Spears, 2011, McIntyre *et al*., 2012). As fishing intensified, predominantly by trawling, landings decreased to near zero. Now the only fisheries that exist today are for invertebrates, principally *Nephrops* and scallops (Thurstan and Roberts, 2010, Heath and Spears, 2011, McIntyre *et al*., 2012). An organization known as the Community of Arran Seabed Trust (COAST) has campaigned relentlessly in recent years to try restore, and protect the marine habitats around the island (COAST, 2014a), from destructive methods of fishing. Initially, this resulted in a fully protected marine reserve being established in 2008 in Lamlash Bay, the only no take zone (NTZ) within Scotland (Axelsson *et al*., 2009). All types of fishing were prohibited within the boundaries of the reserve. The intention was to regenerate the local marine environment and improve populations of commercially important shellfish and fish populations inside and outside the reserve (Axelsson *et al*.,

2009, COAST, 2014a). Several investigations have already revealed the benefits of this protection (Howarth, 2011, Howarth *et al.,* 2015). For example, Howarth *et al.* (2015) revealed that a greater size and reproductive biomass of scallops was attained within the reserve than outside.

Despite the success of this reserve, it only stands at approximately 2.6km^2 (Axelsson *et al.,* 2009, COAST, 2014a), and although benefits are clearly being attained from its protection (Howarth *et al.,* 2011, Howarth *et al.,* 2015), a larger reserve that encompasses a greater range of habitats would be beneficial to the area. The establishment of the South Arran MPA was proposed in order to achieve this, and was put forward with the prospect of banning all destructive methods of fishing (COAST, 2014b). However, the management proposals initially favored by the Scottish government allowed dredging to continue within the MPA (COAST, 2014c). A campaign was launched to try and raise public support in favor of banning dredging (Marine Scotland, 2015). Over 4,750 responses were received in favor of greater protection throughout Scotland's 30 MPAs (Marine Scotland, 2015). In response to this support, the Scottish government drafted new measures (Scottish Government, 2015a). These revised management measures for the South Arran MPA included (figure 1):

1) Banning suction dredging, mechanical dredging and beam trawling throughout the MPA.
2) Prohibiting demersal trawling across the whole MPA apart from in certain designated areas.

3) Creel fishing, long lines and set nets are prohibited in certain zones (Scottish government, 2015a).

These new measures were welcomed by COAST and various NGOs (COAST, 2015). Despite this progress, demersal trawling is still allowed within large areas of the south Arran MPA (Scottish government, 2015a). There now exists a one-month consultation period where objections to these measurements can be made (Scottish government, 2015b). As a result, these new measures are not fixed, and still need to be passed through parliament where they could face tough opposition. If this occurs, the Scottish government could revert back to the original measures (COAST, 2014c).

The aim of this study was, therefore, to identify any major conservation priorities in light of the designated south Arran MPA. Due to the uncertainty surrounding these new measures, comparisons have been made between outside and inside the proposed dredging boundaries from the original management plans, favored by the Scottish government. This investigation will analyze quantitative data from dive surveys within the MPA conducted in summer 2014 (prior to introduction of management measures), quantifying the abundance and distribution of mobile species of commercial and conservation importance. These surveys will provide valuable baseline data enabling the tracking of changes to the site under future management schemes.

Methodology

Study Area

The Isle of Arran is located in North Ayrshire, off the west coast of Scotland, and is the largest island within the Firth of Clyde (Duncan, 2003, Axelsson *et al.,* 2009). In July 2014 the Scottish government, under the Marine Scotland Act, designated the South Arran MPA (COAST, 2014b, Scottish Government, 2014a). The total area of this MPA stands at 280km^2 (SNH, 2014), including waters north of Drumadoon point on the west coast, to Corriegill Point on the east, incorporating the current NTZ within Lamlash Bay (Scottish government, 2014b) (figure 1).

Past investigations have reported that the majority of the MPA is characterized by burrowed mud, especially in the deeper southern portions (Scottish Government, 2014c). However, in shallower regions there exist a greater variety of habitats, including macroalgal communities, mearl beds, (Duncan, 2003) and seagrass beds within Whiting Bay, believed to be the largest within the Clyde (SNH, 2014).

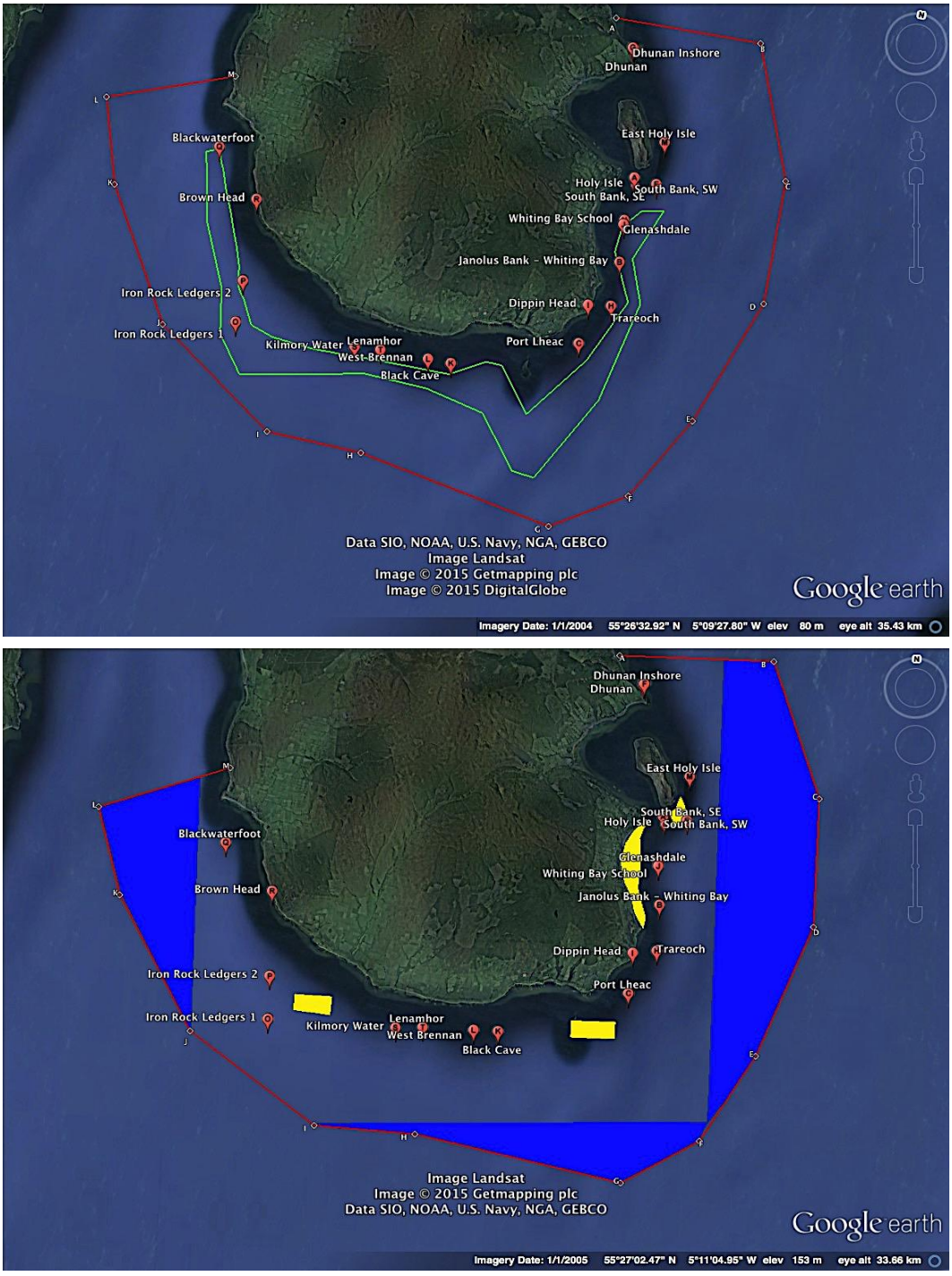

Figure 1. Both maps display the south of the Isle of Arran. Within the **top** map the red outline indicates the "South Arran MPA" boundary. The green outline signifies the proposed boundary where dredging will have been allowed to continue in the original management plans, initially favored by the Scottish government (Scottish government, 2014c). Within this green outline the area is referred too as "inside the dredging boundary," outside this green outline is referred too as "outside the dredging boundary." The **bottom** map has been edited to represent the new management measures. The blue areas indicate where demersal trawling will be allowed to continue. The yellow areas are zones where creel fishing, set nets and long lines will be prohibited. Dredging and beam trawling are prohibited throughout the MPA (Scottish government, 2015b). The 20 dive survey transects are signified by the red labels and their associated locations upon both maps (Image adapted from Google Earth version 7.1.2).

Dive Surveys

Overall 20 surveys took place, 19 between July and September 2014, and one from the previous summer. Three volunteers from COAST conducted all 20 surveys within the proposed MPA (figure 1), with sites chosen to be representative of the range of habitats present within the inshore portion of the MPA. The transects were limited to depths of less than 25m due to the decompression limits of recreational SCUBA diving. After further research it was apparent that 12 of the transects sat within or extremely close to the area proposed to still be open to dredging, under the original management measures favored by the Scottish government (figure 1). This allowed a comparison to be made between transects inside and outside these proposed dredging boundaries.

Transects were carried out along a 50m leaded line, with both ends secured by weighted anchors. The latitude and longitude were recorded at each end of the transect, using a global positioning system (GPS). Two divers would simultaneously work along the transect, one diver recording everything one meter either side of the line using the SACFOR (Super abundant, Abundant, Common, Frequent, Occasional, Rare) scale, but individually recording all megafauna. The second diver was equipped with a video camera, utilizing a Tocina fisheye 10-17 lens (figure 2). Both sides of the transect were recorded, with a one meter steel bar attached to the camera housing, with the addition of two green laser pointers at each end. One laser is focused upon the rope transect, while the other marks one meter. In total an area of $100m^2$ was surveyed per transect (figure 2).

A)

B)

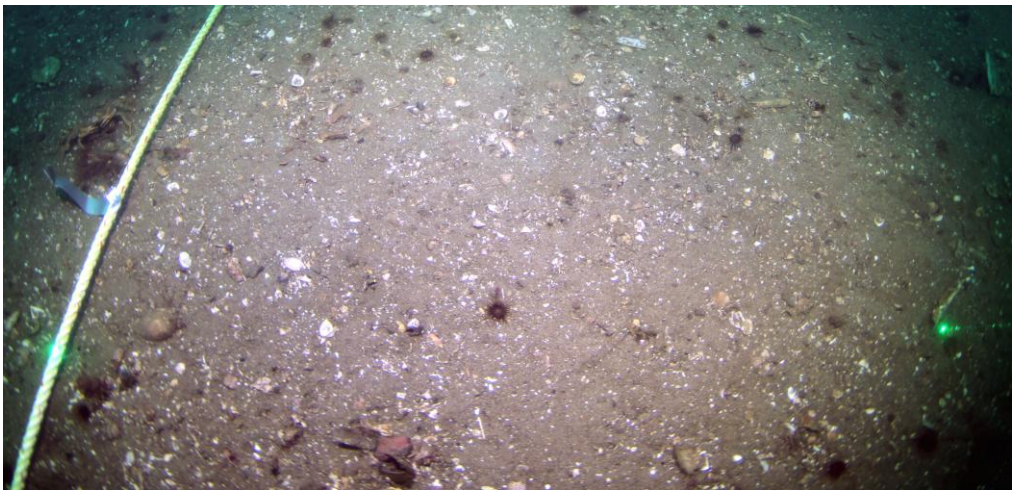

Figure 2. A) This image displays the camera set up used to film the transects. The red circles indicate the location of the laser pointers, which are sat upon a steel rod, spaced one meter apart. Also note the camera sat in the middle of the rod, displaying the fish eye lens. **B)** This image is a still from one of the transects. Note the yellow transect rope to the left of the image, and the green laser pointers marking one meter (Image credit: Howard Wood).

Video analysis

The number of mobile species was determined by analyzing the videos frame-by-frame, enabling accurate counting. If a mobile species passed through the one-meter area created by the lasers, it was counted. If less than 50% of an organism's area was inside the lasers, or completely outside, it was ignored. All organisms were identified to the highest taxonomic level possible. Any species that were taxonomically similar, which could not be identified fully, were grouped, such as flatfish species. The SACFOR survey forms allowed an insight in what species to expect from any particular site.

Data Analysis

Univariate Analysis

The primary focus of data analysis was to identify any significant differences in species abundance and composition between inside and outside the originally proposed dredging boundaries. This was to try and understand the repercussions of the original management plan being adopted, instead of the new measures that have recently been announced. The analysis focused upon scallop data, fish abundance and distribution, the total number of organisms and species, and how they varied between treatments.

To begin with, the data was explored and checked for error, skew, outliers and non-normal distributions, using a variety of diagnostic plots, such as box plots, Q-

Q plots and histograms. The Shapiro-Wilks test was used to check for normality, due to its appropriateness for small and medium sized samples (Crawley, 2005).

King (*Pecten maximus*) and queen scallop (*Aequipecten opercularis*) densities were found to display a non-normal distribution, which even after transformations had been performed, could not be normalized. As a result, a non-parametric test known as the Wilcoxon rank sum test was employed to test for significance between the abundance of king or queen scallops residing in each treatment i.e. inside and outside the originally proposed dredging boundaries. The students t-test was used to analyze the total number of scallops, total number of species, and total number of organisms between treatments, as all these variables demonstrated a normal distribution. Simpson's species diversity was calculated, which displayed a strong positive skew and was subsequently transformed to the power 3 (n^3). A Student's t-test was applied to the species diversity between treatments. These data are displayed in bar graphs using ±1 standard error (SE) bars to indicate any disparity around the mean. Cumulative species curves were also plotted, displaying the number of species plotted against their cumulative percentage per transect site. All univariate stats were carried out using the statistical package R Studio, version 0.98.1074.

Multivariate Analysis

For this analysis the statistical program PRIMER 6.1.14 was used. The first step was to create a resemblance matrix with the count data, utilizing the Bray-Curtis similarity measure (Bray and Curtis, 1975). Secondly, a non-parametric multidimensional scaling (MDS) ordination was performed upon the similarity matrix. This determined how similar the species compositions were between sites. An Analysis of Similarity (ANOISM) (Clarke, 1993) was executed, identifying any differences between the two treatments. Finally, to highlight any major groupings of sites, a Similarity Profile (SIMPROF) was run, which was subsequently displayed in a dendrogram.

The above methods were carried out upon untransformed data, and with the following transformations: square root, fourth root and logx+1. The decision to utilize any of these transformations was determined by the following outputs within PRIMER:

1) The stress value attained from the MDS ordination. The stress value indicates how well the two-dimensional plot represents the multi-dimensional relationship.
2) The R value created by the ANOISM and its significance level. The output will create an R value between -1 and 1. The closer the R value is to 1, the greater the difference between the treatments i.e. they are not related. If the R value is closer to -1, it indicates that the variation in a single treatment is greater than the variation between treatments.

Following this process, it was deemed most appropriate to use the untransformed data. Despite the transformations the final outputs did not differ enough to justify their use.

Claire Youdale and Howard Wood during data collection. Copyright: Angus Robson

Results

Species Composition of the South Arran MPA

A total of 30 species were identified within the transects, with a total of 1372 individuals counted altogether (table 1). The top five dominant species in descending order were: hermit crabs (*Pagarus* spp.), common starfish (*Asterias rubens*), common sea urchin (*Echinoderm esculentus*), juvenile whiting (*Merlangius merlangus*), and cushion stars (*Porania pulvillus*). These five species accounted for 48.2% of the total individuals counted. The steep gradient of points upon the cumulative species curves (figure 3), indicate that two to three species were dominant at each site. This is confirmed from the cumulative percentage data, where the most common two species within each transect, always made up 30% or more of the total organisms sampled. In extreme cases, such as the "Glenashdale" transect, one species accounted for over 70% of the total organisms.

Table 1. The overall mean densities, and densities for outside and inside the originally proposed dredging boundaries for all organisms encountered throughout all 20 transects. The numbers in brackets indicate one ±SE.

Common Name	Latin Name	Overall Mean Density (per 100m^2)	Mean density outside dredging zone (per 100 m^2)	Mean Density within dredging zone (per 100m^2)
Common Starfish	*Asterias rubens*	9 (2.95)	8.25 (3.33)	9.50 (4.50)
Sand sea star	*Astropecten Irregularis*	0.15 (0.11)	0.00	0.25 (0.18)
Common sunstar	*Crossaster papposus*	0.95 (0.34)	1.25 (0.73)	0.75 (0.30)
Feather Star	*Leptometra celtica*	1.35 (0.86)	3.13 (2.05)	0.17 (0.11)
Bloody henry starfish	*Henricia oculata*	1.40 (0.47)	0.88 (0.48)	1.75 (0.71)
Seven armed starfish	*Luidia ciliaris*	2.10 (0.52)	2.38 (1.08)	1.92 (0.51)
Spiny starfish	*Marthasterias glacialis*	2.70 (1.08)	2.38 (1.36)	2.92 (1.60)
Cushion star	*Poranis pulvillus*	3.60 (1.06)	5.00 (2.29)	2.67 (0.92)
Common urchin	*Echinoderm esculentus*	5.25 (2.33)	1.38 (0.63)	7.83 (3.74)
Edible crab	*Cancer Pagurus*	1.45 (0.55)	1.50 (0.82)	1.42 (0.77)
Harbour crab	*Liocarcinus depurator*	2.80 (0.67)	2.25 (1.08)	3.17(0.87)
Velvet crab	*Necora puber*	1.25 (0.40)	1.00 (0.46)	1.42 (0.61)
Hermit crabs	*Pagurus spp.*	10 (4.45)	9.13 (5.76)	10.58 (6.54)
Broad clawed porcelain crab	*Porcellana platycheles*	0.05 (0.05)	0.13 (0.13)	0.00
Great spider crab	*Hyas araneus*	0.10 (0.07)	0.00	0.17 (0.11)
Small spider crabs	*Inachus spp*	3.35 (1.08)	3.13 (1.98)	3.50 (1.31)
Spider crab	*Macropodia deflexa*	0.05 (0.05)	0.00	0.08 (0.08)
Squat lobster (long clawed)	*Galathea strigosa*	0.95 (0.48)	0.50 (0.33)	1.25 (0.78)
Squat lobster (spiny)	*Munida rugosa*	0.05 (0.05)	0.00	0.08 (0.08)
King scallop	*Pecten maximus*	2.65 (0.55)	4.13 (0.72)	1.67 (0.67)
Queen scallop	*Aequipecten opercularis*	2.35 (0.67)	3.50 (1.21)	1.58 (0.73)
Cod (Juv)	*Gadus morhua*	2.95 (2.85)	7.38 (7.09)	0.00
Whiting (juv)	*Merlangius merlangus*	4.70 (4.70)	0.00	7.83 (7.83)
Dogfish	*Scyliorhinus canicula*	0.05 (0.05)	0.00	0.08 (0.08)
Flatfish (juv)	*Pleuronectiformes*	0.30 (0.16)	0.25 (0.16)	0.33 (0.26)
Grey gurnard	*Eutrigla gurnardus*	0.05 (0.05)	0.00	0.08 (0.08)
Goldsinny wrasse	*Ctenolabrus rupestris*	3.35 (1.68)	0.63 (0.50)	5.17 (2.70)
Dragonet	*Callionymus lyra*	1.15 (0.54)	1.13 (1.13)	1.17 (0.55)
Sand gobies	*Pomatoschistus minutus*	3.35 (2.29)	5.88 (5.59)	1.67 (1.08)
Two spotted goby	*Gobiusculus flavescens*	0.75 (0.52)	0.00	1.25 (0.84)

Univariate Analysis

Scallop Data

The mean overall density of king scallops was 2.65 (±SE 0.55) per 100m^2. Outside the dredging boundaries the mean density of king scallops was 4.13 (±SE 0.72) per 100m^2, whilst the mean density inside the dredging boundaries was 1.67 (±SE 0.67) per 100m^2 – which was significantly different (Wilcoxon-Rank Sum test, $W = 78.5$, $p < 0.05$) (figure 4). Likewise, the mean overall density of queen scallops was 2.35 (±SE 0.67) per 100m^2. Outside and inside the dredging boundaries, the mean density of queen scallops per 100m^2 was 3.5 (±SE 1.21) and 1.58 (±SE 0.73) respectively, however, this result was not significantly different (Wilcoxon-Rank Sum test, $W = 62$, $p > 0.05$) (figure 4). When combining both species to create a total scallop density, there was no significant difference between outside, (mean = 7.63 ±SE 1.78 per 100m^2) and inside the dredging boundaries (mean = 3.25 ±SE 1.02 per 100m^2; t = 2.1288; p = > 0.05 (two-tailed), d.f. = 11.576) (figure 4).

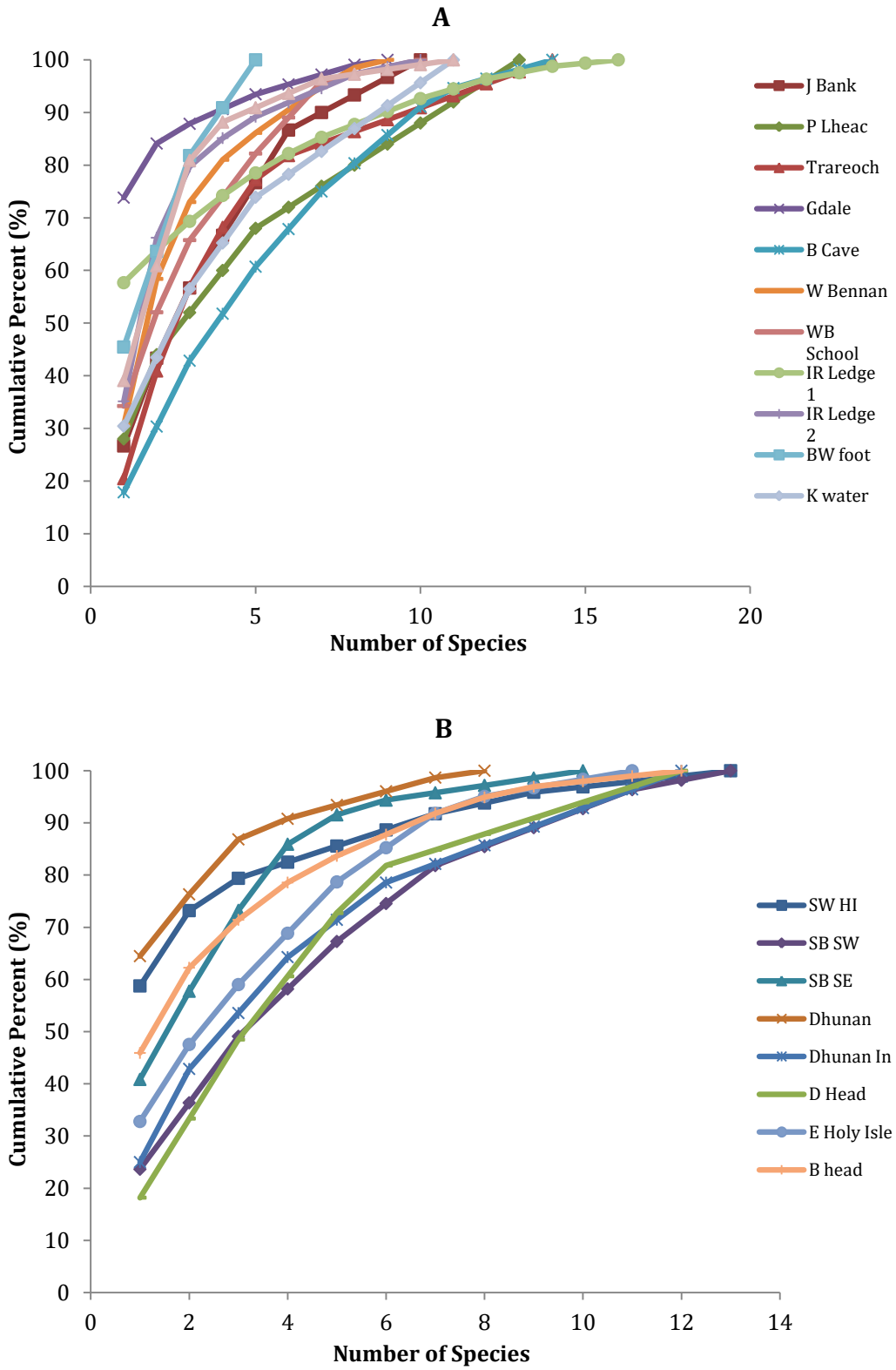

Figure 3. A) Cumulative species curve for transects inside the originally proposed dredging boundaries.
B) Cumulative species curve for transects outside the originally proposed dredging boundaries.

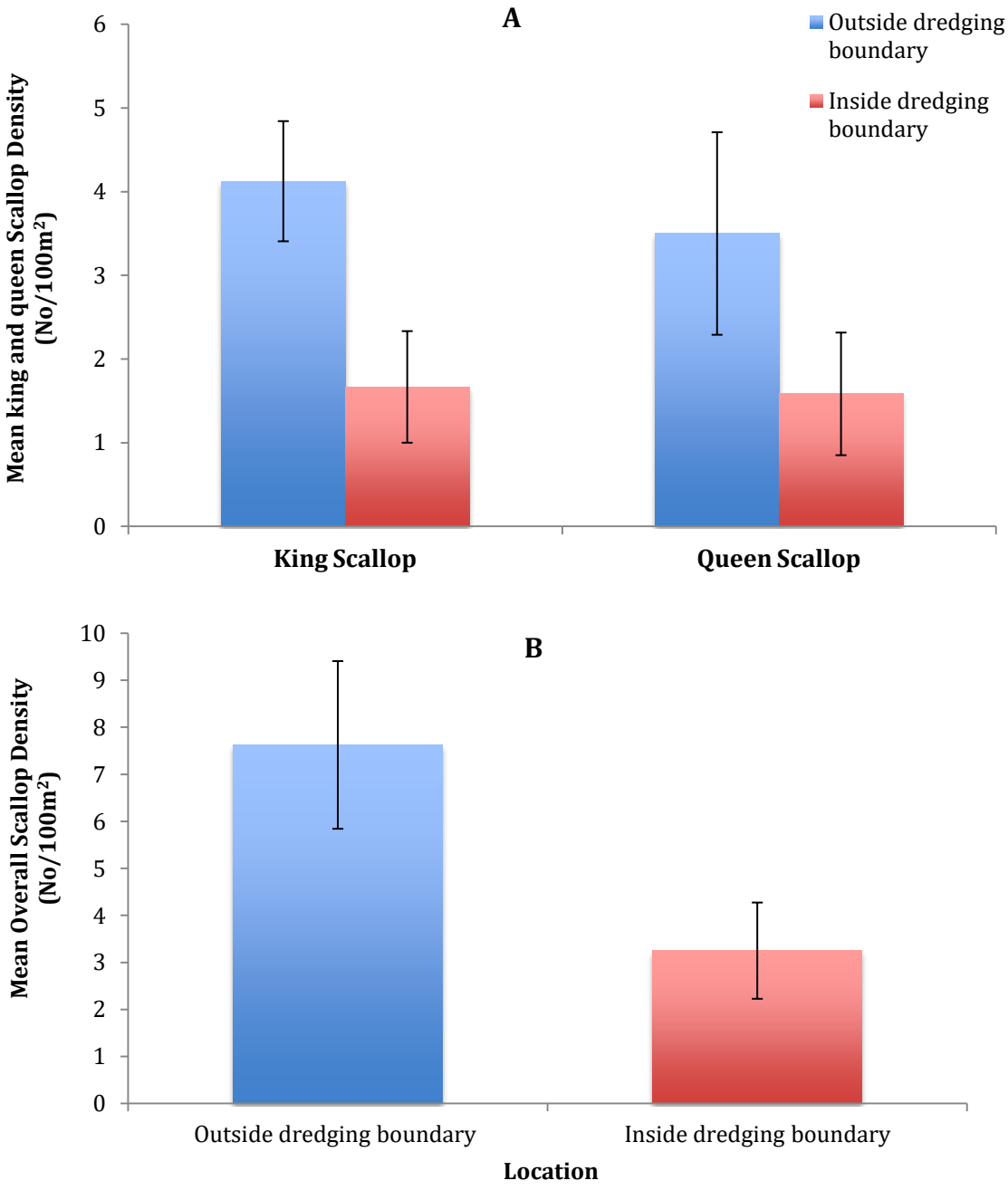

Figure 4. A) The mean density of king and queen scallops outside and inside the originally proposed dredging boundaries. Error bars represent ±1 SE.
B) The mean overall scallop density outside and inside the originally proposed dredging boundaries. Error bars represent ±1 SE.

Fish abundance and distribution

In total 333 (mean density = 16.65 ±SE 5.64 per 100m^2) individuals were recorded from nine fish species across all 20 transects. Outside the dredging boundaries, 122 individuals were recorded (mean density = 15.25 ±SE 8.80 per 100m^2), compared to 211 (mean density = 17.58 ±SE 7.66 per 100m^2) inside the dredging boundaries (figure 5), a difference that was found not to be significant (Wilcoxon-Rank Sum test, $W = 38$, $p > 0.05$). The high variability around the mean in both boundaries (figure 5) was likely due to two shoals of juvenile whiting and cod within two separate transect. These shoals amassed to 153 individuals in total, accounting for 46% of the total number of fish sampled (table 2).

Table 2. The abundance of the top five fish species across all 20 transects.

	Juvenile whiting (*Merlangius merlangus*)	**Goldsinny wrasse *(Ctenolabrus rupestris)***	**Sand gobies (*Pomatoschistus minutus)***	**Juvenile cod *(Gadus morhua)***	**Dragonet (*Callionymus lyra)***
Abundance	94	67	67	59	23

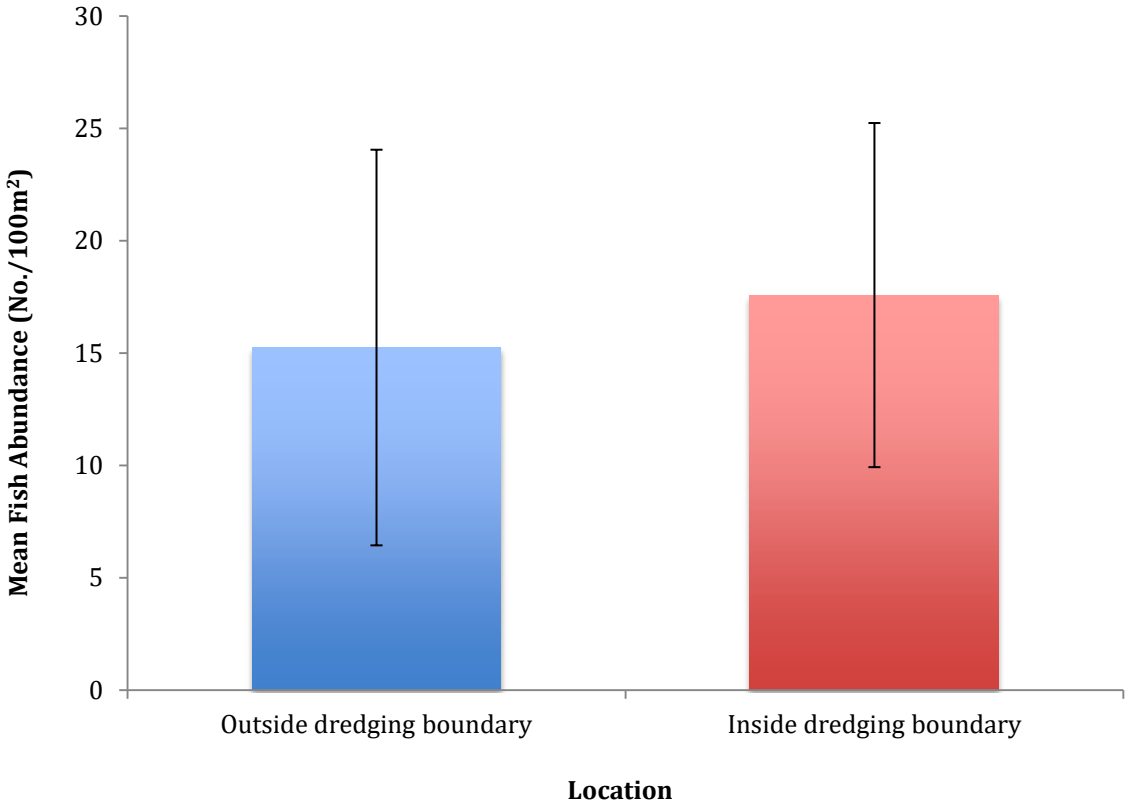

Figure 5. The mean abundance of all sampled fish species, outside and inside the originally proposed dredging boundaries. Error bars represent ±1 SE.

Total number of organisms and species

On average there were a greater number of organisms inside the dredging boundaries (mean = 71.2 ±SE 14.1 per $100m^2$) than outside (mean = 64.9 ±SE 9.2 per $100m^2$)(figure 6), however, there was no significant difference between both areas (t = -0.3729; p = > 0.05 (two-tailed), d.f. = 17.727). Similarly, there was no significant difference between the number of species outside (mean = 11.3 ±SE 0.59 per $100m^2$) and inside the dredging boundaries (mean = 11 ±SE 0.84; t= 0.2428; p = > 0.05 (two tailed); d.f. = 17.727) (figure 6). Finally, for Simpson's species diversity index, which was transformed to the power three (n^3), there was no significant difference between outside (mean = 0.51 ±SE 0.077 per $100m^2$) and inside the dredging boundaries (mean = 0.53 ±SE 0.059 per $100m^2$; t = -0.256; p= > 0.05 (two tailed); d.f. = 14.52). This indicates that both areas displayed very similar species diversity between transects and treatments (figure 6).

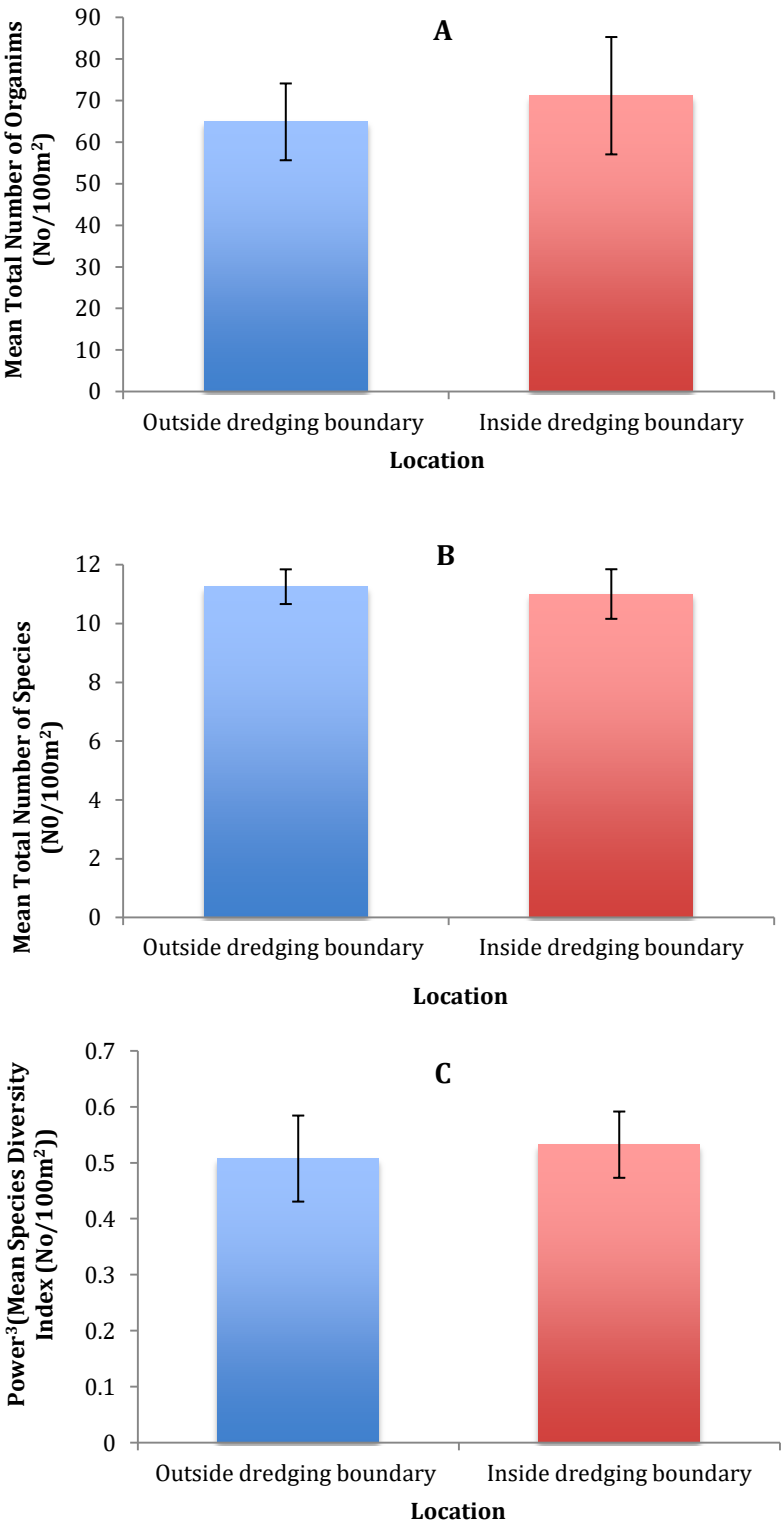

Figure 6. A) The mean total number of organisms outside and inside the originally proposed dredging boundaries. Error bars represent ±1 SE. **B)** The mean total number of species outside and inside the originally proposed dredging boundaries. Error bars represent ±1 SE. **C)** The mean Simpson's Species diversity to the power^3 (n^3) outside and inside the originally proposed dredging boundaries. Error bars represent ±1 SE.

Multivariate Analysis

A resemblance matrix was constructed by employing the Bray-Curtis similarity measure. The results indicated that the majority of sites were relatively comparable, with an average overall similarity of 24.7%. Between the different treatments, the average similarity did not differ measurably either, with a similarity of 26.4% and 21.6% outside and within the originally proposed dredging boundaries, respectively. From the MDS plot (figure 7), which is based upon the similarity matrix, there seemed to be no real distinct pattern or separation between inside and outside the dredging boundaries. However, a couple of sites, such as "Blackwater foot" and "Brown head" were distinctly separate. It could be argued that the species composition outside the boundary was less variable than inside. The majority of the "outside" points are concentrated within the center, whereas the "inside" points have a greater distribution across the plot. As the MDS plot is initially a 3D plot, PRIMER has to adjust the data to display it as a 2D graph. The rate at which these adjustments have been made is reflected in the stress level. Figure 7 generated a stress level of 0.15, as this was less than 0.2 the result can be treated without caution.

Following the ANOISM test between each treatment, a Global R value of -0.082 and a significance value of 86.1% was attained. This indicated that there was no real variation between sites sampled in and outside the originally proposed dredging boundaries. The SIMPROF test results are represented by the dendrogram (figure 8), and reveal three distinguishable groups that are statistically different ($p < 0.05$).

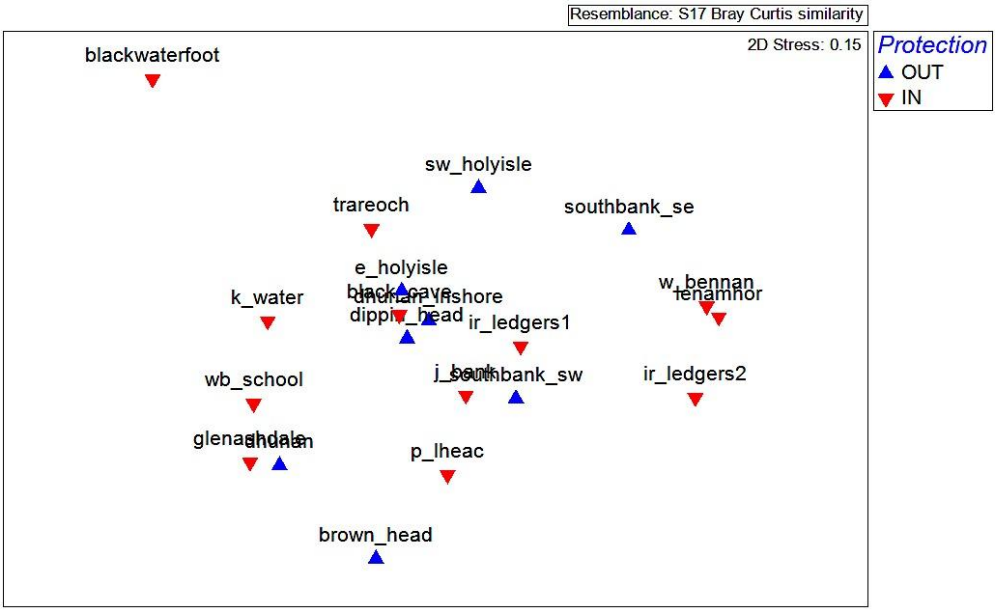

Figure 7. An MDS plot of Bray_Curtis similarity values derived from untransformed species abundance from all 20 transects, for outside and inside the proposed dredging boundaries. There seems to be no distinct separation between either treatment, yet certain sites are clearly distinct from the rest.

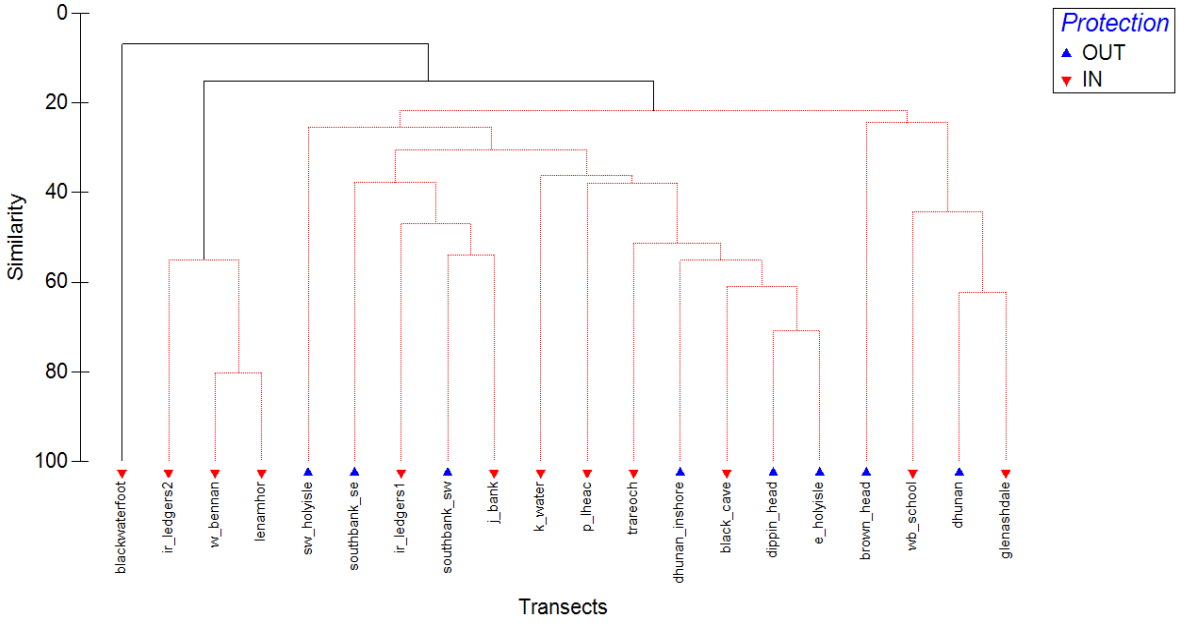

Figure 8. A dendrogram creeated from the SIMPROF test based on Bray-Curtis similarities derived from untransformed species abundance data, across all 20 transects. The sites, which are connected via the red-dotted lines, represent statistically similar sites ($p > 0.05$). The black lines indicate sites that are significantly different ($p < 0.05$).

Discussion

The recent management measures announced by the Scottish government have been a major step in ensuring meaningful protection for the South Arran MPA (Scottish government, 2015b). These new measures are distinctly different from the original proposals, which afforded very little protection (Scottish government, 2014b). Although these decisions have to be applauded, the measures are yet to be passed through parliament, and are facing tough opposition from the Scottish Fishermen's Federation (who largely represent trawlers and dredgers); in the current one-month consultation period (Scottish government, 2015b, SFF, 2015). This could ultimately mean backtracking to the original management proposals, which this investigation has revealed could be detrimental to the area.

This investigation has allowed data to be collected prior to the establishment of any management measures, providing valuable baseline data. This will allow the effectiveness of the management measures to be assessed much more conclusively, while allowing the tracking of changes to the site to occur more easily, a luxury that many MPAs do not have (Halpern, 2003). The south Arran MPA was primarily designated to conserve habitats of conservation importance, such as maerl beds, and not necessarily as a tool to increase fish stocks (Scottish government, 2014b). It is hoped, however, this may be an added benefit, as protecting these areas will increase the likelihood of commercial species reaching maturity, generating large amounts of larvae, which are then exported into adjacent fishing grounds, fueling recovery in these areas (Roberts *et al.,*

2001, Gell and Roberts, 2003, Halpern, 2003, Beukers–Stewart *et al.*, 2005). Howarth *et al.* (2011) investigations have already revealed a recovery in the macroalgal communities within the Lamlash Bay NTZ, which encouraged greater scallop spat settlement. This gives an indication of what recovery may occur if adequate management measures are implemented, however, there is a great deal of uncertainty surrounding the extent and rate at which it will occur. This uncertainty stems from the lack of information on the state of community assemblages in the Clyde before intensive fishing occurred (Thurstan and Roberts, 2010). This lack of information highlights the need for effective and greater protection, as insufficient management may unintentionally preserve an already degraded ecosystem.

Focusing upon the scallop data to begin with, a distinct difference in the densities between inside and outside the originally proposed dredging boundaries was clear, although only the king scallop data achieved a significant result. This is unsurprising considering this is the most intensely dredged area within the MPA (appendix 1), indicating that sustained scallop dredging, within the originally proposed dredging boundaries, has likely had a negative effect upon the population within this area (Scottish government, 2014c). If the dredging were to continue at a sustained level, populations would likely decrease further, and the fishery would no longer be viable.

The rate at which this recovery may take can be gleaned from recent investigations by Howarth *et al.* (2015). The investigation compared scallop abundances between inside and outside the Lamlash Bay NTZ, over several

surveys. It revealed that two years after establishment in 2010, the mean density of king scallops was lower within the reserve boundaries: an estimated 6.2 individuals per 100m^2 within the reserve, compared to 7.6 per 100m^2 outside (Howarth *et al.,* 2011, Howarth *et al*., 2015). There was no baseline data to compare this data too, however, subsequent years showed a steady increase inside the reserve than outside. For example, in 2012 the mean density of king scallops per 100m^2 in and outside the NTZ was 6.71 and 4.67 respectively (Howarth, 2012). However, statistical tests revealed neither protection nor year was having a significant effect on the king scallop density. The king scallop data within this investigation highlighted similar densities, specifically outside the originally proposed dredging boundaries, with 4.13 king scallops (±SE 0.72) per 100m^2, a very similar value attained during transects taken place outside the NTZ in 2012. Much lower densities of 1.67 (±SE 0.67) per 100m^2 were found inside the dredging boundaries. Howarth *et al*. (2011, 2012, 2015) investigations give an indication that recovery within the South Arran MPA will not be immediate. A study by Beukers-Stewart *et al.* (2005), within a closed area off the Isle of Man, revealed a similar pattern of low densities of scallops immediately after the area was established. As time passed, however, there was an exponential increase in scallop densities within the closed area, with increasing densities in adjacent fishing grounds as well. For example, in 2003, 14 years after the closed area had been established, the density of scallops was 4.85 times higher within the closed area than outside (14.05/100m^2 in the closed area compared to 2.90/100m^2 in the fished area). It would be likely, that the average overall scallop densities throughout the South Arran MPA would also increase

with time, however this wholly relies on sufficient management measures being put in place.

Although fish species and abundance varied greatly between all 20 surveys, it was encouraging to see evidence of juvenile gadoids in four transects. Due to overfishing, by-catch and habitat degradation, many commercial important finfish species have been largely absent from the Clyde (Thurstan and Roberts, 2010, Heath and Spears, 2011), however their presence in this study suggests populations still exist, although these recruits could be coming from outside the MPA. Nevertheless, this highlights the potential importance of this area as a nursery habitat for commercially important species. The habitats of conservation importance, such as maerl beds and seagrass habitats, which are due to be highly protected under the new management plans (Scottish government, 2015a), are known to provide refuge for these species (Barbera *et al*., 2003, Lilley and Unsworth, 2014). Evidence from seagrass habitats in North Wales, has shown that species of commercial importance such as cod and whiting have enhanced growth and survival within these areas, increasing the likelihood of reaching maturity (Cullen – Unsworth *et al.,* 2014, Lilley and Unsworth, 2014). Likewise, maerl beds also provide this 3D structural complexity, favored by many commercial species, such as cod and Pollock, and are characterized by high biodiversity (Barbera *et al*., 2003). It has to be stated, however, that maerl beds within the south Arran MPA are likely to be highly degraded due to the detrimental effects of long-term trawling and dredging (Hall-Spencer and Moore, 2000). For example, only 0-10% of the maerl beds within the Lamlash bay NTZ are said to be living, a percentage that will only increase extremely slowly, even

with protection, due to the slow growth exhibited by maerl (Kamenos et al. 2004).

Despite the new measures, concerns still remain about the management of the MPA. Firstly, destructive demersal trawling will impact large areas of the MPA that are still open to this method of fishing. For example, Hiddink *et al.* (2005) revealed bottom trawling upon benthic fauna had a negative impact upon biomass, production and species richness. Examples from the North Sea show that a bottom trawl fleet reduced benthic biomass and production by 56% and 21% respectively (Hiddink *et al.,* 2005). There is also a danger that the south Arran MPA could become a victim of its own success. If populations of commercially viable species, such as edible crab (*Cancer pagarus*), increase in abundance, methods of fishing such as creeling, which are not banned under the new management measures, could increase in popularity. Already, the Scottish Creel Fishermen's Federation has stated their support for the new measures (Latham, 2015), primarily because they can fish freely without disturbance from mobile fishers. Unfortunately, species targeted by this fishery could eventually become overfished, as many species targeted, such as crabs, have no catch limits (Scottish government, 2013). This could result in a shift in fishing effort to these alternative methods (Hilborn *et al*., 2004). Despite this, it should not hamper the creation of the MPA in the first instance (Ballantine, 2014); it may just require the introduction of additional catch controls in the future, such as additional zonation.

Although this investigation has provided good baseline data, some limitations do exist. Firstly, due to time constraints, sessile species, flora and substrate type were not analysed. Howarth (2012) demonstrated this within his statistical analysis using PRIMER. By labelling each transect with a specific habitat type, he observed clear clustering of similar habitats within the MDS plots. Identifying the major flora and sessile species would have provided more data upon which to measure the recovery of the MPA. While counting the number of organisms using video analysis is relatively accurate, identifying each organism to species level is less so. As the data reveals, certain species had to be grouped together, whilst large aggregations of shoaling gadoids made the chance of counting the same fish twice more likely.

In conclusion this investigation has provided valuable baseline data for the South Arran MPA, before management measures have been implemented. This will allow key comparisons to be made between subsequent surveys that will take place as part of COAST's on-going monitoring programme within the area. As a network of MPAs slowly becomes more promising for Scotland it is vital that any management measures that are implemented are effectively assessed regularly, so they can be adapted within the future. Lesson learned from the South Arran MPA, one of the first to be established in Scotland, will also be crucial for ensuring the effective development of the wider networks of MPAs around Scotland. It will also provide a case study for establishing further temperate MPAs around the world. The newly amended proposals take protection a step further (Scottish government, 2015a), ensuring areas of the south Arran MPA

will be protected from destructive methods of fishing, allowing a range of habitats to recover.

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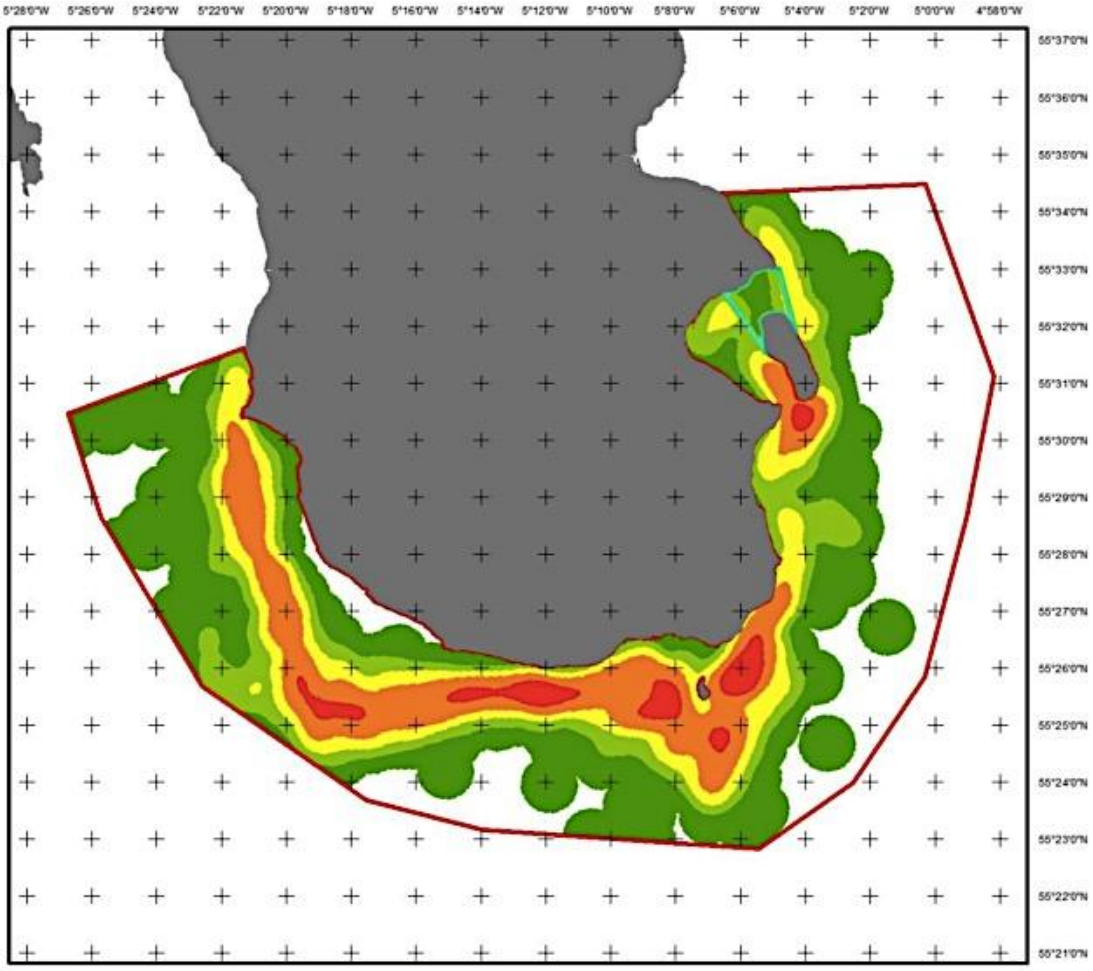
Appendices

Appendix 1 – A map displaying the south Arran MPA, with vessel monitoring system (VMS) data overlaid for scallop dredging between 2007 and 2013. It is quite clear to see that the originally proposed dredging boundaries mirror the most intense areas of dredging (Scottish government, 2014c).