Investigating spatial trends in biodiversity around the South Arran Marine Protected Area

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With thanks to: the Blue Marine Foundation, Dr Bryce Stewart, Dr David Bailey, Natasha Walker-Milne and Arran COAST

Acknowledgments

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Abstract

The South Arran marine protected area (MPA) on the West coast of Scotland contains one of only three no-take zones within the UK and has strict management plans for zonation within the MPA. Two years on from it's formation, this study looks to use baited remote underwater surveys to investigate the fish assemblage and biodiversity within the MPA. Biodiversity showed no obvious pattern in spatial variability; however, biodiversity was higher in kelp habitat and in areas of greater kelp coverage. Kelp was also found to be particularly important for wrasse, a group of species which are subject to growing pressure from fisheries for use in aquaculture. 3D complexity was also found to have a significant effect on fish diversity in the MPA, which is aligned with the objectives put forward to protect benthic structure. Given the importance of kelp habitat for fish diversity presented here, further study and protection should be afforded to it around the UK, especially in light of growing pressure to harvest this resource.

Introduction

There is increasing awareness globally of the necessity to protect marine ecosystems. Target 11 from the Aichi Biodiversity Targets from the convention on biological diversity says that by 2020, 10% of marine and coastal areas, particularly those which provide important ecosystem services or support high levels of biodiversity, should be protected (UNEP CBD). In the UK, as in the rest of the world, this has led to a rush to designate areas as marine protected areas (MPAs)(Hawkins et al., 2016; Di Franco et al., 2016). Globally, since 2006, 12,000 MPAs have been created, covering an area of 12 million km^2 (Di Franco et al., 2016). By February 2016, around 17% of the UK's seas were within MPAs in various conservation designations (Hawkins et al., 2016). By March 2018, after the second round of MCZ designations, 24% of UK waters were contained within MPAs (JNCC). However, Aichi target 11 also states that these areas should be conserved through effective management, which some have cited as lacking in many marine protected areas.

The Isle of Arran is an island situated within the Firth of Clyde on the West coast of Scotland. Historically, the Firth of Clyde has been impacted by large levels of fishing pressure for various species and fisheries (Thurstan and Roberts, 2010). In the 1800s the Firth of Clyde supported fisheries for species such as herring (*Clupea harengus*), cod (*Gadus morhua*), turbot (*Psetta maxima*) and other species alongside the predators these populations supported such as cetaceans, seabirds and dogfish including the spurdog (*Squalus acanthias*), now critically endangered within UK waters (IUCN redlist, Thurstan and Roberts 2010). The industrialisation of fisheries via the propagation of trawling and the introduction of steam powered vessels lead to unsustainable levels of fishing in the Clyde, which was already beginning to be over exploited (Thurstan and Roberts 2010). Fears over the

damaging nature of trawling on spawn lead to the closure of steam trawling in the Firth of Clyde, though other fishing methods were permitted and continued to increase in technological complexity (Thurstan and Roberts 2010). However, with the decline of the herring fishery in the 1950s trawling was re-opened due to pressure from fishers and trawling within the 3 mile inshore limit was opened in 1984 (Thurstan and Roberts 2010). Fish landings subsequently collapsed and now make up less than 2% of landings whilst prawns (*Nephrops norvegicus*) and other invertebrates such as scallops (*Pecten maximus, Aequipecten opercularis*) make up the majority of landings (Thurstan and Roberts 2010).

Recently, fishing activity in the waters surrounding the Isle of Arran has predominantly been dredgers for scallops, along with some *Nephrop* trawl activity slightly further offshore (McIntyre *et al.* 2012, Ryan and Bailey 2012). Dredging is one of the most damaging fishing methods, reducing the complexity of benthic communities and the substrates within the area (Collie et al., 2000; Boulcott and Howell, 2011). The damaging nature of these fisheries lead to the designation of a no-take zone (NTZ) in Lamlash Bay on the East coast of the Isle of Arran in September 2008 (COAST). This covers an area of 2.67km² and is one of only three such NTZs in the UK (Bower 2011, JNCC). Following this, a much greater area around the South coast of Arran was designated as a MPA in February 2016 called the South Arran MPA (COAST). This area has multiple management restrictions; the no take zone in the North part of Lamlash bay, the four areas off limits to trawls, dredges and creels, an area off limits to trawls and dredges and finally an outer area where dredges are prohibited but demersal trawls are sometimes permitted (COAST, figure 1). This constitutes a multi-use MPA, where there is a strict NTZ surrounded by a buffer zone where sustainable small-scale fishing is permitted. These kind of multi-use MPAs have been shown to be effective at increasing fish stocks, fisher income and social acceptance of marine protection (Di Franco et al., 2016). In the case of the South Arran MPA, COAST work with local fishers, helping to promote cooperation, whilst the MPA itself allows for sustainable fishing methods such as creeling. The conservation objectives of the South Arran MPA, as stated by Scottish Natural Heritage, are to lead to the recovery of the maerl beds and to conserve other protected features such as seagrass beds, kelp and seaweed communities and other benthic habitats (SNH). However, there is no mention of protection for fish communities or the improvement of fish biodiversity.

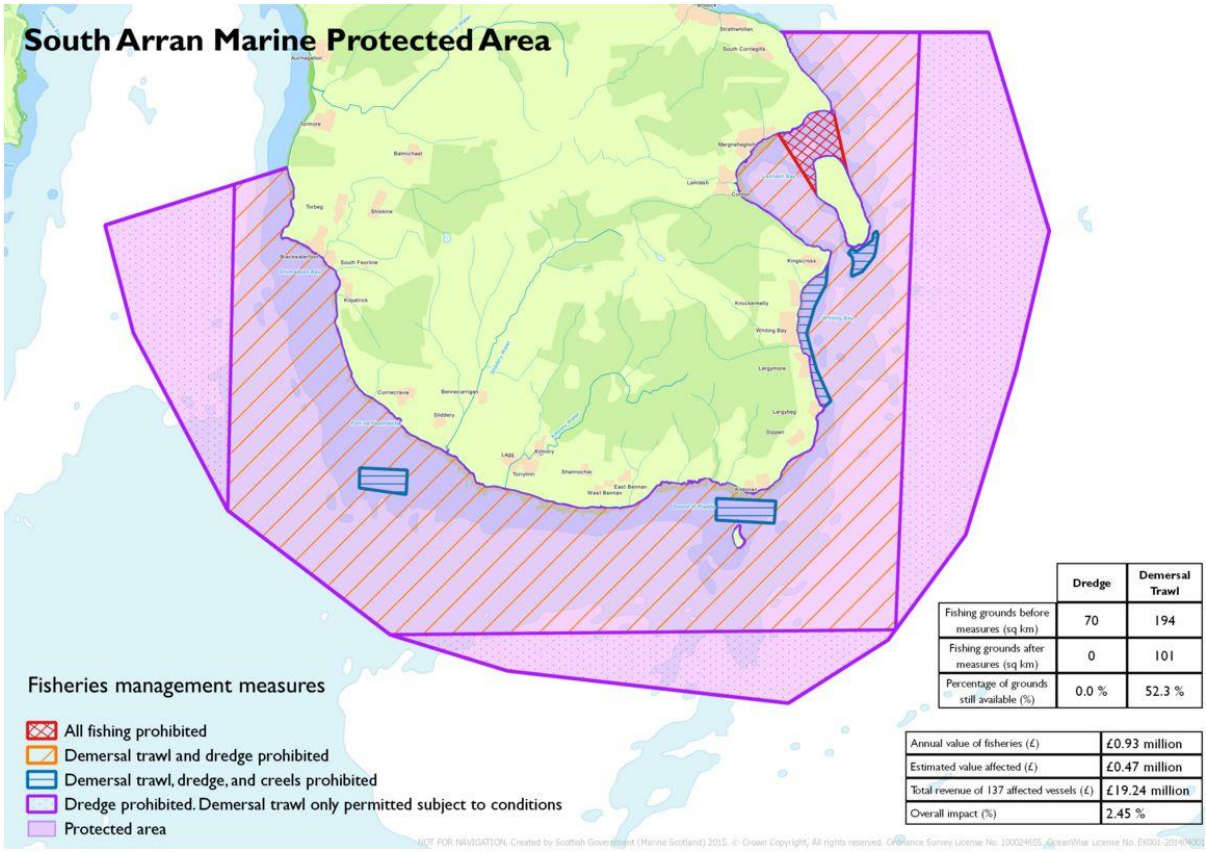

Figure 1 The South Arran Marine Protected Area as published on the COAST website

Salmon farming in Scotland is a growing industry creating many jobs, but also presenting environmental and social issues (Tett et al., 2018). In 2016, Scottish salmon farming production was 163,000 tonnes, estimated to rise to around 200,000 in 2020 and aiming to reach 300,000 tonnes by 2030 (Tett et al., 2018). Environmental concerns such as damage to benthic habitats, eutrophication and escapes may not be compatible with the idea of an MPA. Another growing issue with salmon farming is the largely unregulated fishery for wrasse species (*Labridae*) as cleaner fish (Tett et al., 2018). Use of wrasse in Norwegian salmon and rainbow trout farms grew from between 86,000 to 1.1 million between 2002 and 2010 (Skiftesvik et al., 2014). This demand has led to the development of creel fishery within South Arran MPA for wrasse species.

Baited remote underwater video (BRUV) surveys have become a common tool for assessing biodiversity and abundance within fish communities. They are particularly compatible within an MPA due to their non-destructive nature, where other survey methods are not (Wraith et al., 2013). In Australia, BRUV monitoring programs have become a standard for collecting data on diversity (Wraith et al., 2013). Often biodiversity surveys in the UK involve the use of trawls, such as the International Bottom Trawl Survey, which are not only destructive and therefore not compatible with the objectives

of the South Arran MPA, but also do not provide detail on habitat or substratum types which may be crucial for identifying more fine scale locations of species (Wright et al., 2010; Elliott et al., 2017).

Aims

This study aims to investigate fish diversity with the South Arran MPA and how this is distributed spatially. It will also investigate whether this differs between areas of different management levels, and areas of different habitat types. Proxies for habitat health such as kelp coverage and 3d benthic complexity will also be estimated and compared with biodiversity levels. Furthermore, I will focus specifically on wrasse, identifying key areas for wrasse species, how these are covered by current protection levels and mapping their distribution around the MPA, along with distribution of other abundant species.

Methods

Study Site

Surveys were conducted within the South Arran marine protected area (MPA) between the 04/07/2018 and 04/08/2018 for 5 days each at 9-day intervals. The marine protected area was divided into 5 survey zones described by Elliot *et al.* from previous studies in the MPA differing in wave fetch (Elliot et al., 2017). Between 9 and 11 drops were conducted each day between 7:30 and 18:00. All surveys were within the MPA covering a number of different management levels, although due to weather survey effort was not equal throughout the MPA (figure 2). Depths of areas surveyed ranged from 5 to 43 metres.

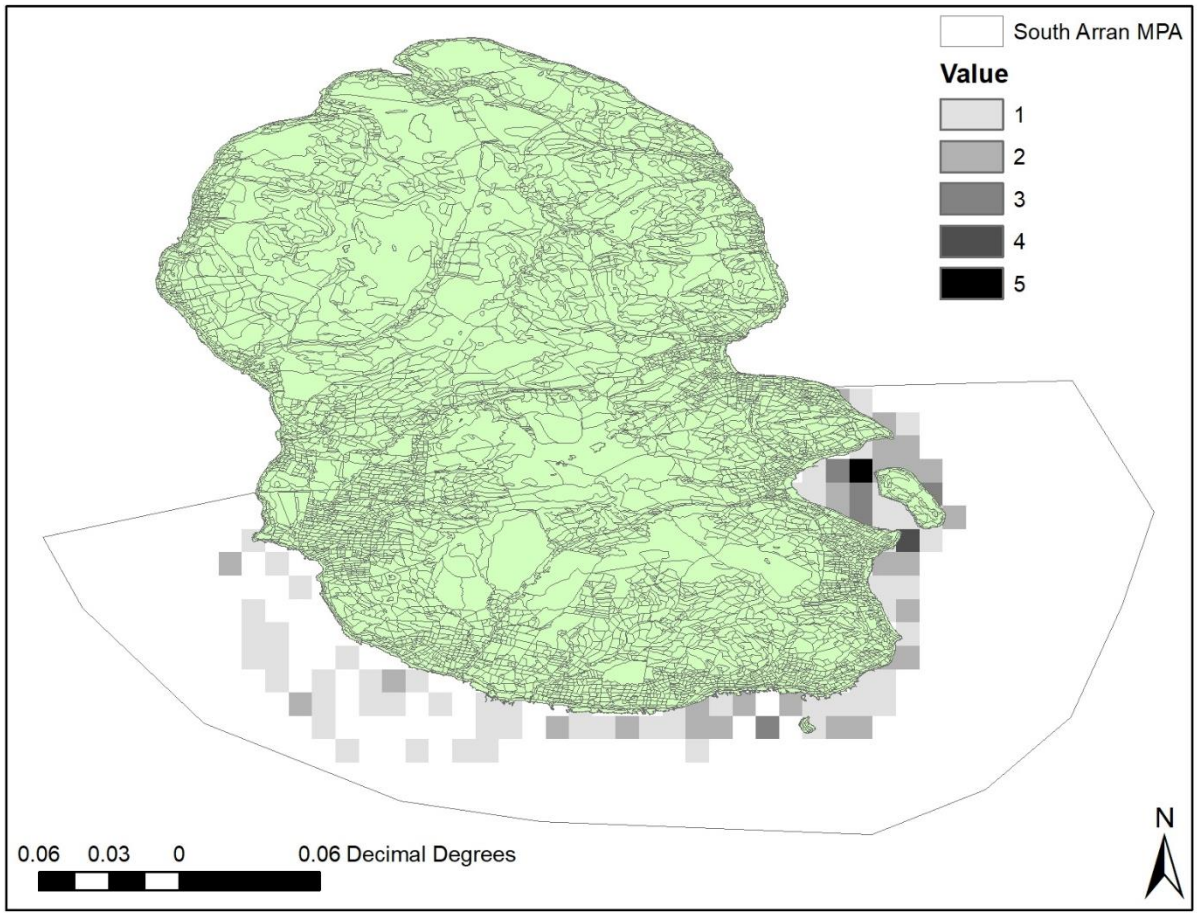

Figure 2 Survey effort around the South Arran marine protected area between 04/07/2018 and 04/08/2018

Survey Equipment

Three stereo baited remote underwater video (BRUV) systems were dropped at random locations within each survey zone, at least 500m apart. The stereo BRUV rigs consisted of a large metal frame which all other equipment was attached to, designed to keep the cameras off the seabed, offer some protection and allow for the whole rig to be winched back to the surface. A bar with two SeaGIS waterproof camera housings attached facing a convergent point was fixed to the rig. Canon HD Legria HF G25 cameras were used in each. Two Archon W38VR diving torches were fixed to each rig, except for one rig which only had one due to malfunctions. A bait arm was fixed to each rig, 112cm in length. Cameras were transported to each site on a creel fishing vessel with a mechanical winch for hauling the rigs aboard.

Data Surveys

During the study period a total of 140 drops were conducted over 15 days at sea. Of these, 2 drops were unsuitable for analysis due to tipping of the rig leading the camera to point either straight down or straight up. Random locations were generated using ArcMap's 'Generate Random Points'

tool at least 500 metres apart (ArcGIS 10.3.1). On each survey day between 9 and 11 drops were conducted due to limitations of battery life and SD card storage space. Due to fuel efficiency constraints all surveys on one day were generally conducted within one survey zone or between two adjacent survey zones. Originally it was intended that each survey zone would be visited on one day each week leading to equal survey effort of each zone. However, due to stormy weather making travel outside zone 1 impossible, this area has the greatest survey effort (figure 2). In total, 50 drops were conducted in zone 1, 19 in zone 2, 26 in zone 3, 22 in zone 4 and 21 in zone 5. All three rigs were simultaneously recording footage in order to maximise time efficiency; however, rigs were dropped at least 500m apart to prevent pseudoreplication. Atlantic mackerel, *Scomber scombrus*, was used for bait during each drop, cut coarsely shortly before the rig was dropped. Camera focus was set to infinite, and torches set to their brightest mode prior to drop. Deployments were timed in order to ensure that cameras spent at least 60 minutes recording on the seabed. Camera batteries were checked upon retrieval and torch batteries were replaced after 2 drops. Coordinates of drop location and depth were noted using the onboard telemetry.

Video Analysis

Since this project was not investigating the lengths of fish recorded, only one camera video from each survey was analysed. Cameras were allowed to settle on the seabed for two minutes before the following 60 minutes were analysed. MaxN, the number of individual fish from a species on screen at any one time, was recorded for each video as a measure of abundance. This is a conservative estimate of fish numbers but avoids the repeated counting of individuals as they move in and out of the frame. Depth, time of recording, date, and coordinate location were also noted. Habitat type was classified into one of seven categories: sand, mud, gravel, algal-boulder-cobble, algal-gravel-pebble, kelp/seagrass and maerl (Table 1). Where multiple habitat types were present the predominant habitat type was recorded. 3d benthic structure level (none, low, medium, high) was scored for each video location, based on substrate types, topography, benthic flora and epifaunal levels. Kelp/Seagrass percentage frame cover was estimated by splitting the frame into a transect. This was both as a measurement of benthic health but also due to the reduced visibility caused by kelp cover.

Habitat Type	Sediment Description	Macrophyte type and coverage
Algal-Boulder-Cobble	>6.4 cm	Algae coverage >50%
Algal-Gravel-Pebble	1 - 6.4 cm gravel, stone, shells	Algae coverage >50%
Gravel	1 – 6.4 cm	Algae coverage <50%

Sand	0.1 – 1 cm sand, low levels of shells	Absence of macrophytes
Mud	<0.1 cm grain size	Absence of algae
Kelp/Seagrass	No sediment visible	Near total kelp or seagrass cover
Maerl	Maerl live or dead present	-

Table 1 substrate category types used in analysis

Data Analysis

Total MaxN was used for general abundance of fish and species richness were both calculated for each drop. Shannon diversity indices were calculated for each of the drops in order to quantify biodiversity for each area. The equation below shows the formula for Shannon diversity index:

$$H' = -\sum_{i=l}^{R} p_i \ln p_i$$

where p_i is the proportion of individuals from a species from the total MaxN. Therefore, for a drop where 2 species were present, and the total MaxN was 3, Shannon's biodiversity index would be calculated by:

$$H' = -\left(\left(\frac{1}{3} \times \ln\frac{1}{3}\right) + \left(\frac{2}{3} \times \ln\frac{2}{3}\right)\right)$$

These Shannon's diversity indices give us the α diversity, or the diversity of each sample (Gray, 2000) . Berger-Parker index for rank 1 dominance, the proportion of abundance accounted for by the most abundant species, was also calculated as another measure of evenness (Gray, 2000).

Multiple factors were tested for effects on the different metrics of diversity and abundance (Shannon diversity, MaxN, Berger-Parker index and species richness). Benthic 3D complexity, substrate, zone and the frame used were all tested for significant effects on the on these metrics of diversity using a kruskal-wallis test and a post-hoc dunn test. Percentage kelp cover and depth were tested for effects on the metrics of diversity using a spearman's rank correlation test.

Results

Fish Assemblage

From the 138 videos suitable for analysis, 1160 individual fish from 21 different species were recorded. On average, 8.4 distinct individuals were recorded per video using the total MaxN as a measurement, with 3.7 species recorded per video. On average, the most abundant species across

all surveys were whiting (*Merlangius merlangus*), 2.01, small-spotted catshark (*Scyliorhinus canicula*), 1.44, haddock (*Melanogrammus aeglifinus*), 1.29, and cod (*Gadus morhua*), 1.28. A single spurdog (*Squalus acanthias*) was recorded during surveys, a species which is critically endangered in British waters (IUCN redlist).

Habitat Distribution

Average kelp cover was 26% across all videos. Median 3d complexity was Medium, and the mode was low. The most common habitat type found was sand with 56 videos being classified as sand. Gravel and algal-gravel-pebble were also common with 24 and 29 instances recorded respectively. Kelp/seagrass habitat, videos where substrata composition was not visible, were only found at depths less than 12m.

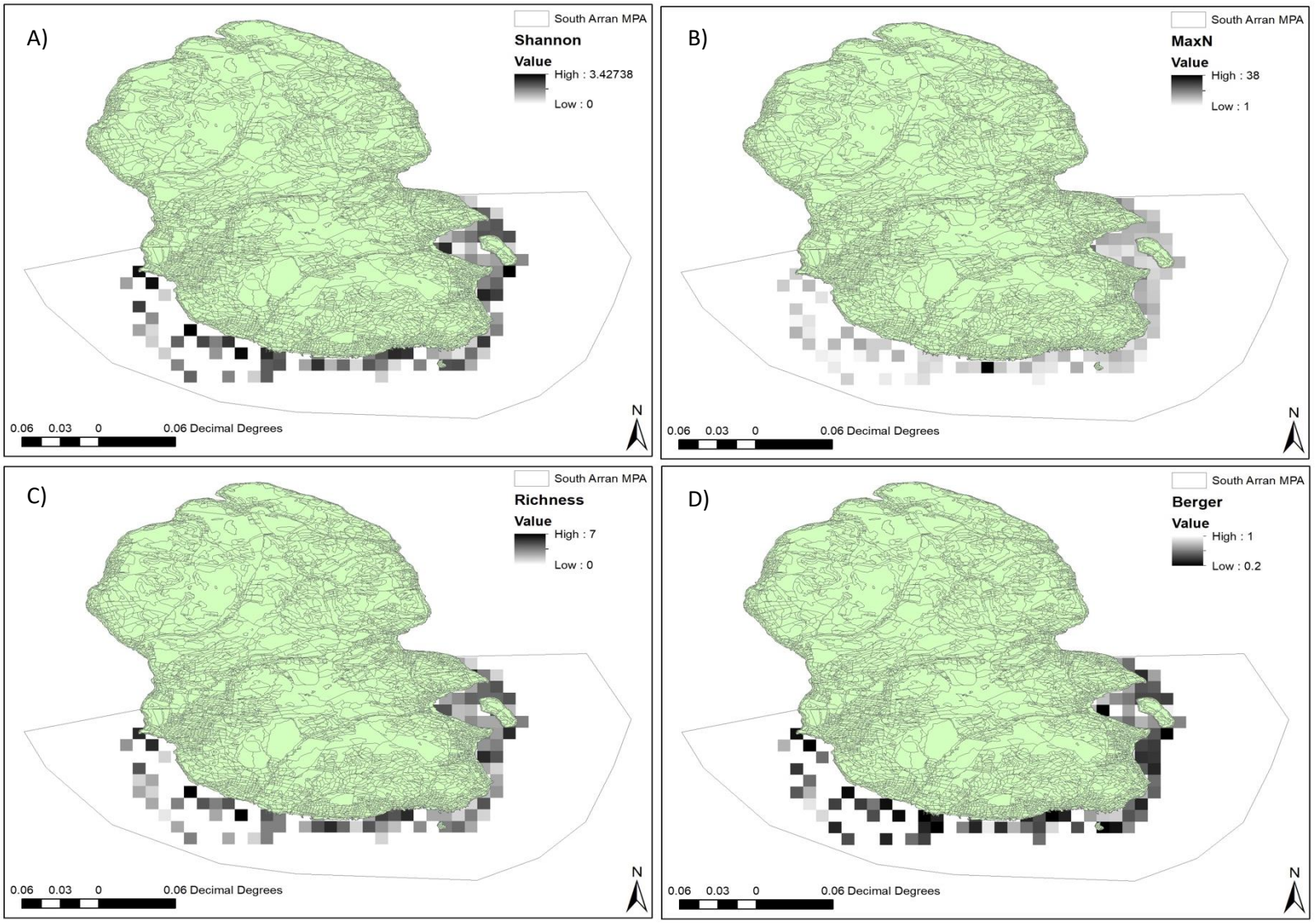

Figure 3 spatial distribution of the four measured biodiversity metrics around the South Arran marine protected area. A) represents Shannon diversity index, B) MaxN, C) species richness and D) Berger-Parker index. Darker colours represent higher levels of diversity for Maps A-C and represent greater evenness for map D).

Factors Effecting Diversity

Biodiversity was spatially variable around the marine protected area with no clear pattern (figure 3). A number of different variables were tested for their effect on the four diversity metrics discussed previously. Substrate type significantly affected Shannon diversity, richness and Berger-Parker index, however, no significant relationship was found between substrate and total MaxN (table 2, Appendix). Further analysis using a post-hoc dunn test showed that kelp had significantly higher Shannon diversity than all other substrate types except for algal-boulder-cobble and mud (table 3). No other substrate types differed significantly in Shannon diversity. Kelp was found to have greater

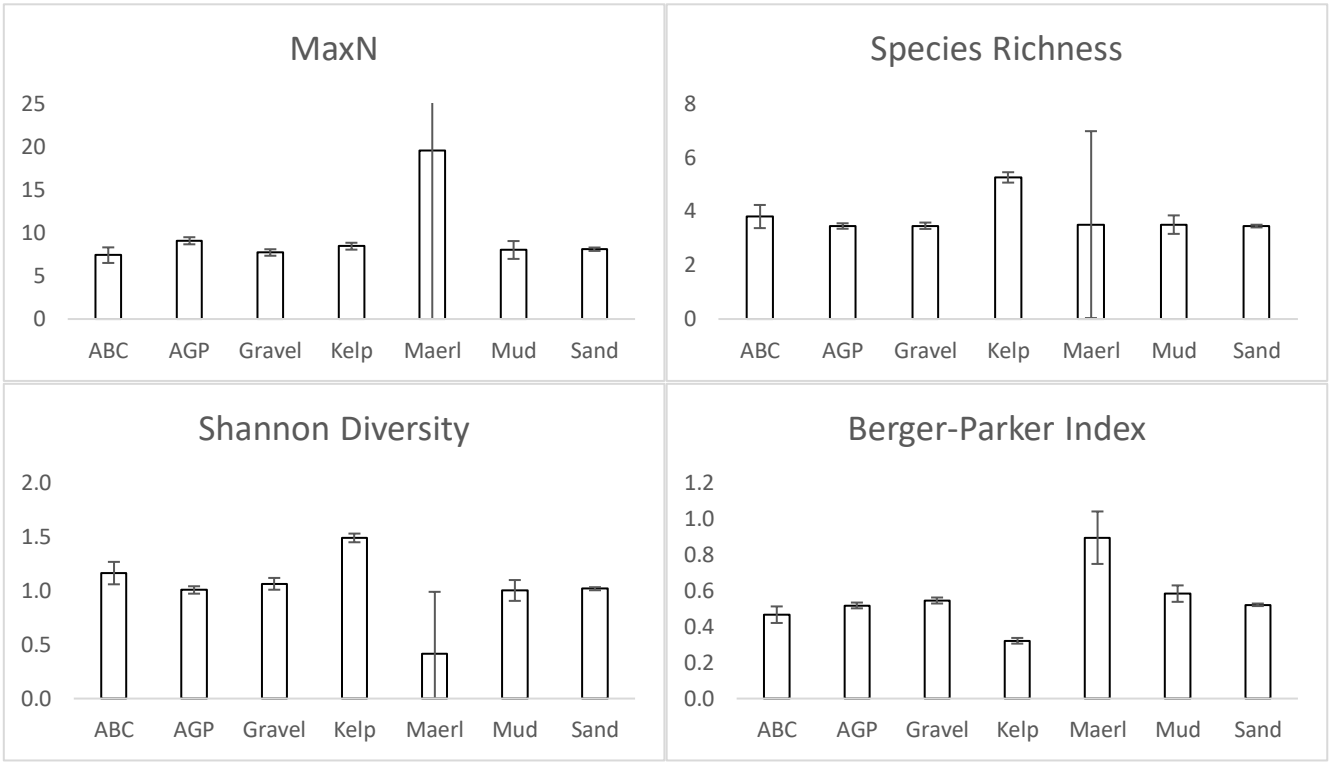

Figure 4 Substrate types against the four measure metrics of biodiveristy as specified by the title of each graph

species richness than algal-gravel-pebble, gravel and sand (table 4). No other substrates were found to be significantly different. Kelp Berger-Parker index differed significantly from that of all variables other than algal-boulder-cobble (table 5, figure 4).

Benthic 3D complexity had a significant effect on all four diversity metrics (table 2, figure 5). Surveys with 3D benthic complexity scored as high had significantly greater shannon diversity indices than those scored with no or low 3D complexity (table 8). Species richness also differed significantly between areas with high or medium complexity and those with low or no 3D complexity (table 7). The same results were found for MaxN, with areas scored as high or medium for benthic complexity had higher total MaxN that that scored as low or none (table 6). Berger-Parker index only differed significantly between high and low areas (table 9).

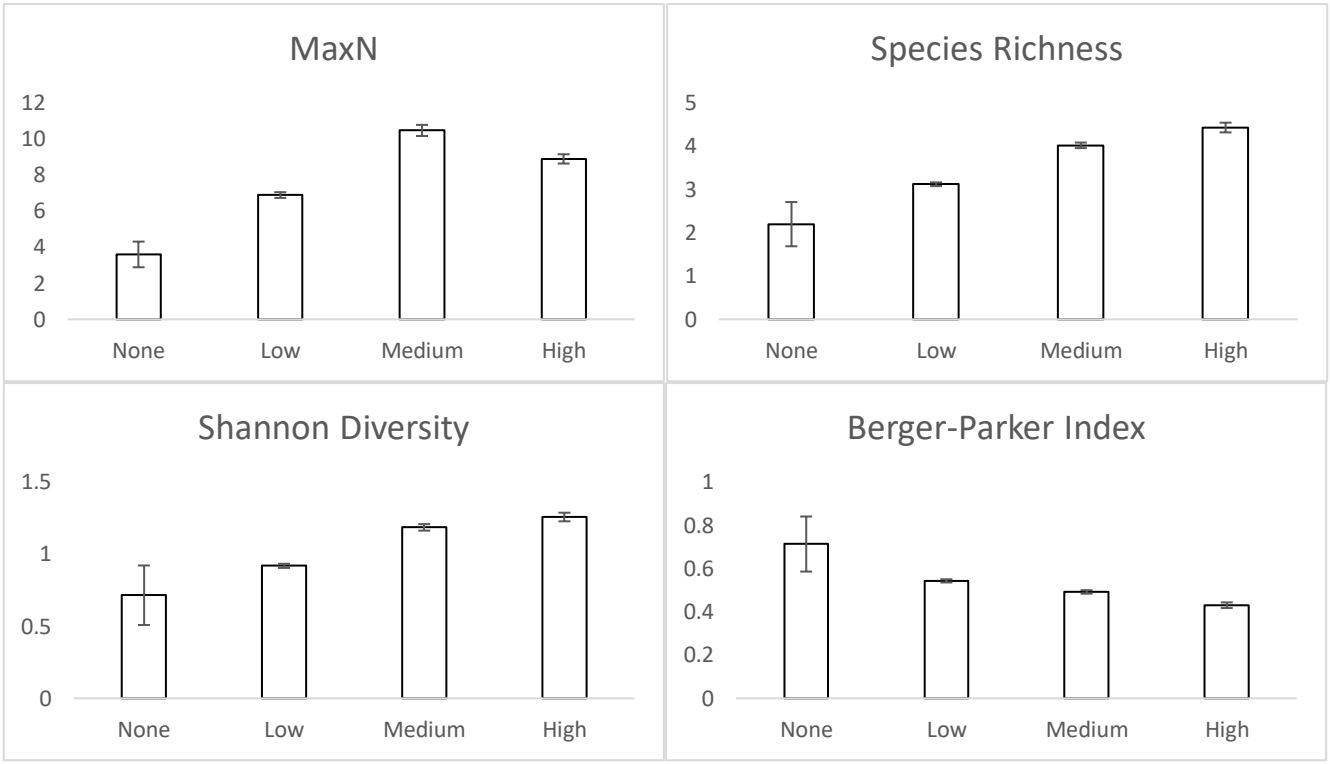

Figure 5 3D complexity against the four metrics of diveristy calculated as specified by graph title

Zone had no significant effect on shannon diversity or species richness, however the Kruskal wallis test was significant for Berger-Parker index and MaxN (table 2). Berger-Parker index differed significantly between zones 1 and 4, whilst MaxN did not differ significantly between zones in the dunn test, there was a near significant results between zone 1 and 5 as well as zone 1 and 4 (table 10, 11). The frame used for each survey did not cause significant differences in shannon diversity, species richness or Berger-Parker index, however there was a significant difference found for MaxN using the Kruskal wallis test. Further analysis found a close to significant difference between MaxN for surveys using frame 2 and 3 (table 2, 12).

Correlation tests were also conducted for continuous variables the might have an effect on diversity. There was a significant correlation found between depth and all diversity metrics except Berger-Parker index (table 13). The direction of this relationship was negative meaning that shannon diversity, total MaxN and species richness all reduced at greater depths. There was no relationship between Berger-Parker index and depth, suggesting that surveys were no more likely to be dominated by a single species at greater depths.

The correlation test between percentage kelp cover and diversity found that kelp cover was significantly correlated with all diversity metrics (table 13, figure 6). This relationship was positive for shannon diversity, MaxN and species richness but negative for Berger-Parker index. Therefore, these

results suggest that areas with higher kelp cover had greater diversity, greater species richness, greater abundance and were less dominated by a single species.

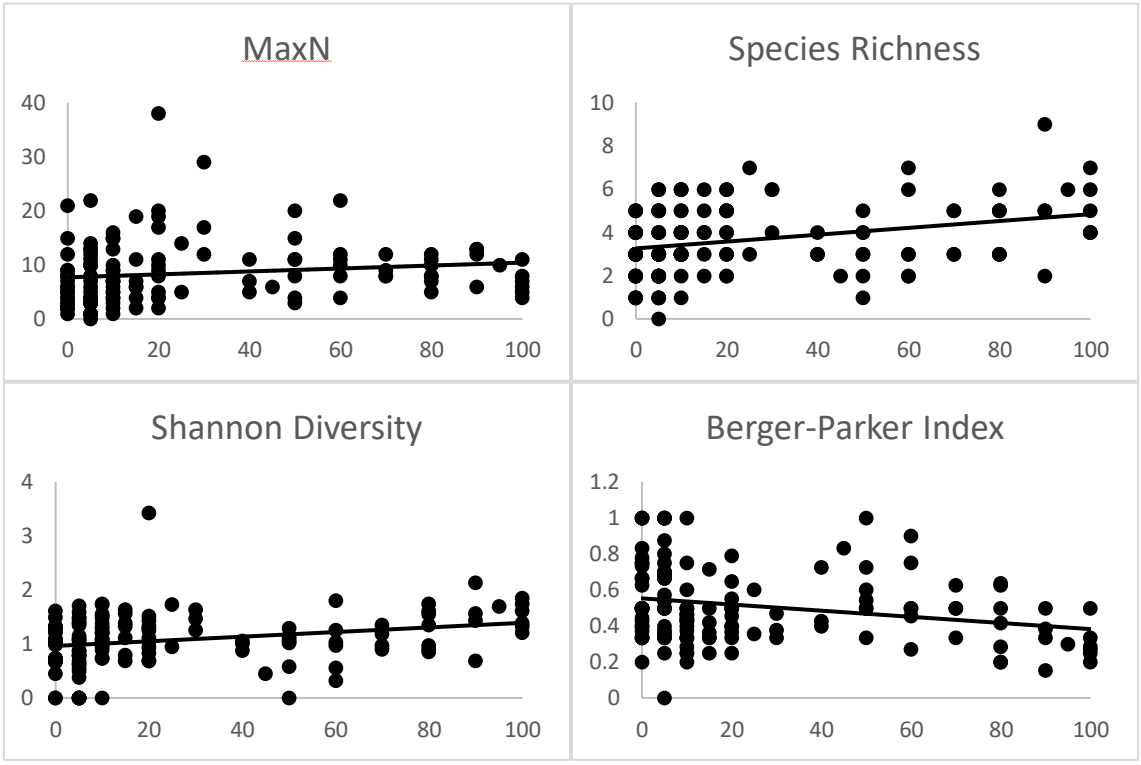

Figure 6 Relationship between the four biodiversity metrics and % kelp cover

Wrasse Distribution

When mapping wrasse distribution and abundance using data collected from the BRUV surveys, wrasse seem to be concentrated around the South Western part of the island. The areas where wrasse creels were concentrated, around Holy Isle and the South Eastern coast of the island, wrasse were found in lower abundances (figure 7).

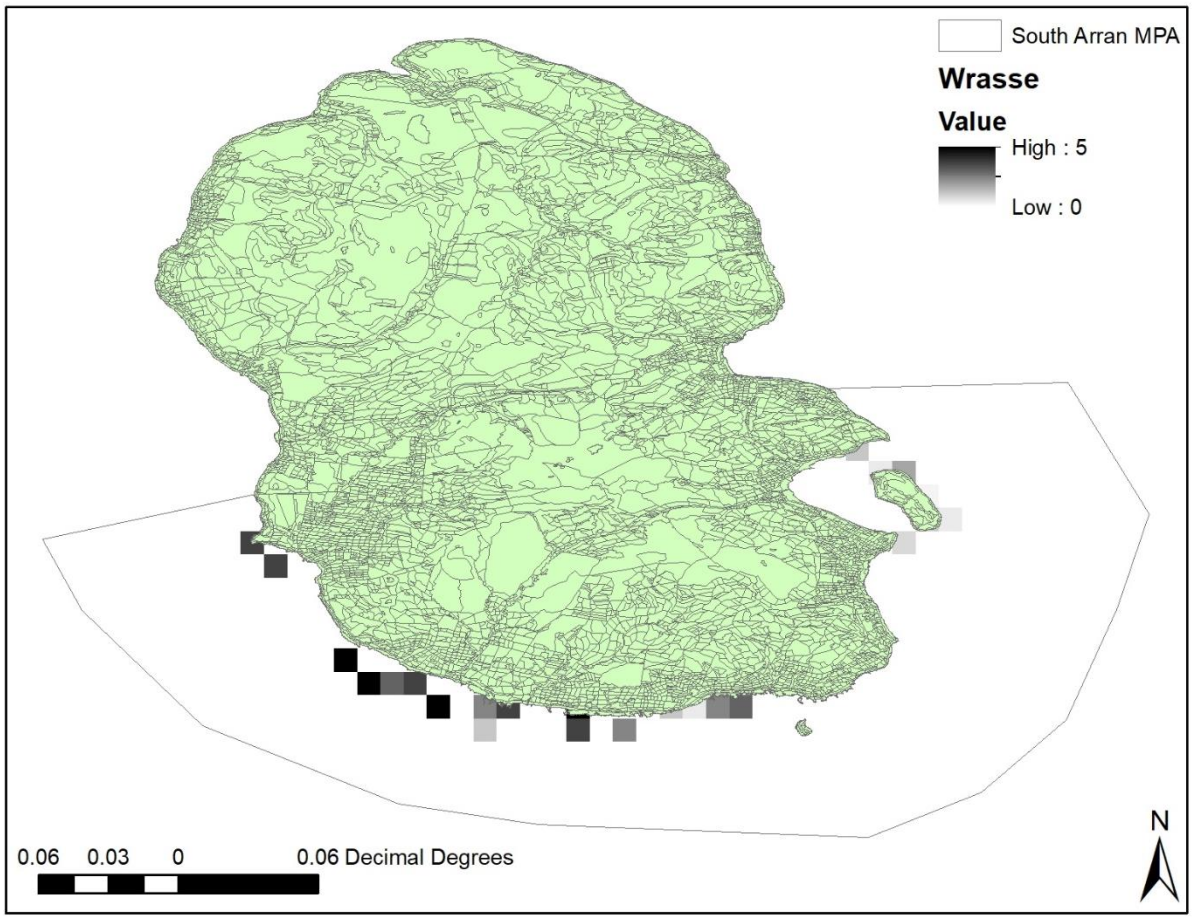

Figure 7 Wrasse distribution and abundance around the South Arran marine protected area

Four species of wrasse were observed during surveys of the South Arran MPA. Wrasse were found at depths between 5.8m and 30.3m but were more commonly found at depths of less than 15m. Correlation test between wrasse MaxN and depth found a significant negative correlation between wrasse numbers and increasing depth ($p<0.001$, rho=-0.45, cov=-5.35). Similarly, the correlation test between wrasse species richness and depth found a significant negative correlation ($p<0.001$, rho=-0.45, cov=-3.77) (figure 8). The correlation test between percentage kelp cover and MaxN, as well as kelp cover and wrasse species richness both showed a significant positive correlation ($p<0.001$, rho=0.58, cov=24.89 and $p<0.001$, rho=0.59, cov=17.81).

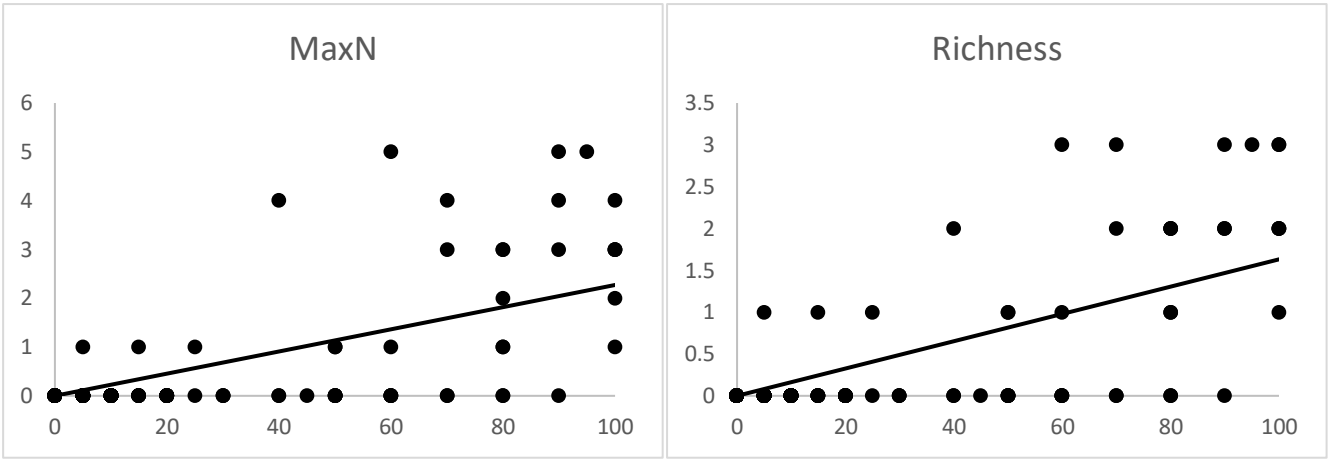

Figure 8 Wrasse abundance (MaxN) and species richness against % kelp cover

A kruskal-wallis test on MaxN and substrate found that substrate had a significant effect on MaxN ($p<0.001$, $chi^2=93.684$, df=6). Further analysis using a Dunn test found that kelp habitats had significantly greater MaxN than all other substrates except for algal-boulder-cobble, whilst algal-boulder-cobble showed had greater MaxN than all other substrates except kelp and maerl (table 15, figure 9). A Kruskal-wallis test on richness and substrate was also significant ($p<0.001$, chi^2, df=6). Again, a Dunn test found that kelp had greater species richness than all other substrates except for algal-boulder-cobble, and algal-boulder-cobble had greater species richness than all substrates except for kelp and maerl (table 16).

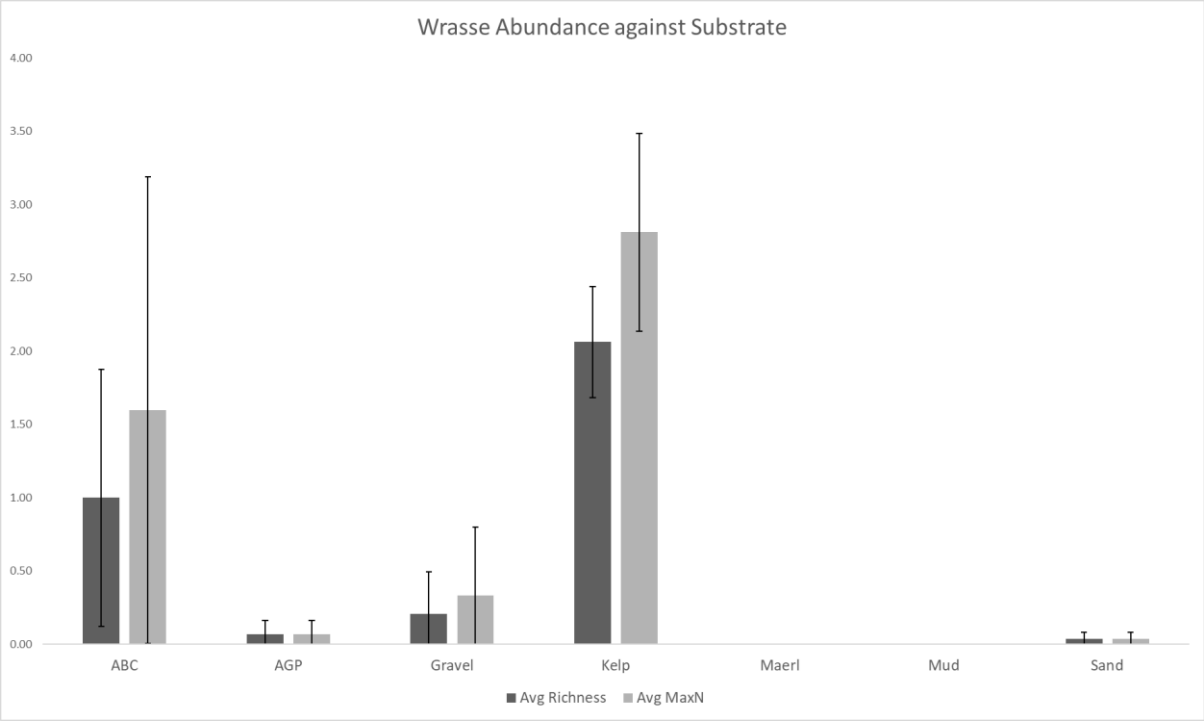

Figure 9 Wrasse abundance by substrate type

Kruskal-wallis test investigating 3D complexity and its effect on MaxN and wrasse species richness were both found to be significant ($p<0.001$, $chi^2=71.496$, $df=3$ and $p<0.001$, $chi^2=72.266$, $df=3$). Further analysis using a Dunn test on both of these found that areas which were scored as high for benthic 3D complexity had significantly higher wrasse MaxN and species richness than all other areas (table 17, 18).

Discussion

Advantage and Disadvantages of Baited Remote Underwater Surveys

Biodiversity in the marine protected area (MPA) was found to be fairly variable, both spatially, between habitats and within areas of the same habitat in our surveys. A certain amount of this variation in diversity observed during our surveys is likely down to survey method. Whilst video analysis is an effective and non-extractive method for diversity surveying which aligns with the objectives of MPAs it is liable to miss some individuals due to constraints on the field of view. Previous studies have shown that different aspects of the fish assemblage of an area are better surveyed by different techniques (Watson et al., 2010). Stereo baited remote underwater video (BRUV) surveys have been found to sample a greater proportion of large bodied predatory or cryptic fish, whilst diver operated video surveys recorded a greater number small bodied species such as labrids (Stewart and Beukers, 2000; Watson et al., 2010). For monitoring to be most effective, multiple survey techniques should be employed to cover all aspects of the fish assemblage (Murphy and Jenkins, 2010). An advantage of BRUV surveys, however, is the volume of surveys which can be undertaken in a short period of time. Over the course of 15 survey days 140 BRUV surveys were deployed, constituting 140 hours of video covering a wide area around the MPA, a level of sampling which could not be achieved in the same period using divers. Likely, the best monitoring plan for the South Arran MPA will include the use of both BRUV surveys as well as diver operated video or transect surveys enabling wide coverage of the MPA as a whole, whilst also allowing targeted surveys of specific areas.

Biodiversity and the Marine Protected Area

Kelp habitats within the South Arran MPA contained significantly more fish biodiversity than many other habitat types. Kelp dominated habitats has significantly higher Shannon's biodiversity index than all other habitat types except for mud (close to significant at $p=0.06$), and algal-boulder-cobble, a habitat type which contains reasonably high levels of kelp. Percentage kelp cover was also significantly positively correlated with Shannon's biodiversity index, species richness and total MaxN and was negatively correlated with Berger-Parker index. This is significant considering that, whilst

kelp communities are a protected feature according to the Scottish Natural Heritage (SNH) aims and objectives of the MPA, there are no special designated areas within the MPA for kelp protection. This is not an issue if creel fishing is not damaging to kelp habitats since kelp habitat around the South Arran MPA are contained within the area off limits to trawls and dredges. However, creel fishing has been found to be damaging to some benthic habitats (Eno et al., 2001). Further study to ensure that creel fishing does not have any significant negative effects on kelp habitat would be advantageous to ensure that the MPA is able to fully achieve it's goals. If creel fishing is found to be damaging to kelp habitats, it is recommended that some areas of particularly dense kelp habitat be selected for further zonation within the MPA.

Benthic 3D complexity was found to have a positive effect on biodiversity within the MPA. This shows that the aims and objectives of the South Arran MPA, whilst not being specifically designed to improve fish diversity, are beneficial to biodiversity levels (SNH). The exclusion of scallop dredging allows benthic habitats to recover and maintain benthic complexity which would be damaged producing a monoculture-style benthos without this exclusion (Collie et al., 2000; Boulcott and Howell, 2011). Therefore, continuation of dredge exclusions will help improve biodiversity and overall ecosystem health with the potential to improve commercial stocks as well given the prevalence of whiting, cod and haddock within the MPA. These results were similar to those found by Elliot *et al.* who found that cod, *Gadus morhua*, whiting, *Merlangius merlangus*, and haddock, *Melanogrammus aeglifinus*, were found in higher abundance in areas with greater 3D complexity.

Wrasse in the South Arran Marine Protected Area

As discussed previously, BRUV surveys are not always the best survey technique for sampling all aspects of fish assemblage, particularly small bodied labrids, such as wrasse (Watson et al., 2010). Therefore, for further study on wrasse habitats, abundance and distributions, it may be more effective to use dive operated video surveys. However, this study provides a good basis upon which to build. The data here provides an insight into population distribution and the assemblage of wrasse species around the MPA. Four wrasse species were found within the South Arran MPA, goldsinny wrasse, *Ctenolabrus rupestris*, cuckoo wrasse, *Labrus mixtus*, ballan wrasse, *Labrus bergylta*, and rock cook wrasse, *Ctenolabrus exoletus*. The most abundant of these species was the goldsinny wrasse (n=35) whilst the least abundant species in our samples was the ballan wrasse (n=2). With the growing market for wrasse as cleaner fish in aquaculture (Skiftesvik et al., 2013, Tett et al., 2018), gaining an understanding of the abundance and distribution of wrasse species is important before the population becomes too exploited. Currently there is one creel fisher targeting wrasse within the South Arran MPA, however, with the growth of aquaculture, wrasse specific surveys are

required sooner rather than later, both within the South Arran MPA as well as throughout British waters.

Wrasse species richness and total MaxN was greatest within areas with greatest kelp coverage and highest 3D complexity. This study seems to show that areas dominated by kelp are of particular importance for wrasse species, and therefore, protection of kelp habitats around the UK will assist in protecting wrasse species. These near shore coastal areas would also be a good place to start for a more targeted wrasse census involving diver operated video surveys. Further study could then look to ascertain whether other bait types, such as a marine invertebrates might provide results closer to that of diver operated videos.

Importance of Kelp

This study shows the importance of kelp as a habitat for fish biodiversity. These findings are in contrast to those found by Elliot *et al.* who found that cod, whiting and haddock were more abundant in areas of gravel-pebble substrates. However, this could be due to the fact that this study looked at biodiversity as a whole and not the relative abundance of these three commercially important species. This is of particular importance currently given the recent proposal by Marine Biopolymers to dredge for kelp throughout the West coast of Scotland (Marine Biopolymers Ltd 2018, The Guardian 2018). Given the high levels of fish diversity supported here by kelp habitats, removal or damage of these could have significant effects on biodiversity throughout the West coast of Scotland if what is found in Arran is consistent throughout Scotland's coast. Kelp was the most important habitat for wrasse species as well, with significantly greater abundance and species richness of wrasse in areas with high levels of kelp. Harvesting of this kelp will likely not only lead to bycatch of animals living within the kelp, such as wrasse species, but will also reduce their habitat and range as well. Given the growing pressure from aquaculture on wrasse, further pressures from habitat loss before we have a full census of their numbers could seriously impact the population. This will also impact species further up the food chain which feed on these species such as seabirds and seals. A previous study on kelp harvest in Norway found that cormorants dived more frequently in harvested areas due to lower foraging yield and numbers of juvenile gadoid fish were 92% lower (Lorentsen et al., 2010). Overall, further study into kelp habitat and it's importance for fish communities throughout the UK is necessary before any large scale kelp harvesting takes place.

Limitations and Future Study

Due to time constraints and inclement weather, sampling effort was fairly skewed towards the areas in the immediate proximity of Brodick Harbour, zone 1. Stormy weather meant that at times we

were unable to get further than this zone due to concerns over fuel efficiency and safety. This was further limited by the scheduling of survey weeks, which meant, because we had set pre-designated survey days, we were unable to avoid stormy weather. All surveys were conducted during the day time. This may reduce the number of species found by excluding those which exhibit nocturnal behaviours. Surveys were also only conducted over the time period of around a month, due to time limits for video analysis. A more complete and robust picture of the biodiversity within the MPA would be attained if surveys were conducted all year round. This would also allow for analysis of seasonal as well as spatial trends in diversity within the MPA. Further surveys were conducted after this period, but unfortunately time did not allow for analysis of these, which means that not all management zones were covered considerably. The use of mackerel as bait may also influence the assemblages recorded during the survey. Some species seemed actively interested in the bait box such as the small-spotted cat shark, *Scyliorhinus canicular*, and whiting, *Merlangius merlangus*, however many species showed very little interest in the bait box. Our skipper, an experienced fisher, suggested that catsharks are particularly attracted to mackerel. It would be interesting to study how use of different bait types effects assemblage and interest of different species. Although oily fish, such as mackerel used in this study, have been found to produce the most consistent results, different feeding guilds have been shown to react differently to different bait types (Wraith *et al*. 2013). Wrasse species were never observed to show any interest in the bait box, and therefore, for future study in to wrasse abundance, species richness and distribution, a different bait type may yield better results. However, this study still provides a good baseline of wrasse distribution and species richness to build upon.

Conclusion

Whilst BRUV surveys may not be able to provide the whole picture of fish assemblage within the South Arran MPA, they do provide us with good stepping point for further surveys. A more complete monitoring programme would be achieved using diver operated video surveys alongside BRUV surveys, particularly for smaller bodied species and wrasse. Kelp cover is particularly important for fish biodiversity within this MPA, and therefore a focus on protection of this as a habitat could be crucial in order to restore and maintain fish biodiversity. If the results of this study are true of the rest of the West coast of Scotland it raises serious concerns over plans to dredge for kelp and the impact this may have on biodiversity in the region.

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AppendixT

Kruskal-wallis Test Outputs			
Variables Tested	Chi^2 value	Df	p-value
Shannon Index~Substrate	19.055	6	0.004722
Species Richness~Substrate	15.788	6	0.01494
MaxN~Substrate	1.6439	6	0.9494
Berger-Parker Index~Substrate	23.58	6	<0.001
Shannon Index~3D Complexity	16.115	3	0.001074
Species Richness~3D Complexity	20.061	3	<0.001
MaxN~3D Complexity	15.453	3	0.001467
Berger-Parker Index~3D Complexity	9.1906	3	0.02686
Shannon Index~Zone	3.999	4	0.4061
Species Richness~Zone	3.5976	4	0.4632
MaxN~Zone	11.606	4	0.02053
Berger-Parker Index~Zone	11.524	4	0.02126
Shannon Index~Frame	1.5229	2	0.467
Species Richness~Frame	2.2476	2	0.325
MaxN~Frame	6.0579	2	0.04849
Berger-Parker Index~Frame	2.3479	2	0.3092

Table 2 Statistical outputs of kruskal-wallis tests conducted on full dataset of diversity

Substrate~Species Richness Dunn test outputs		
Variables Tested	Z	Adjusted p-value
ABC~AGP	0.455833426	1.0
ABC~Gravel	0.567447857	1.0
AGP~Gravel	0.210996902	1.0
ABC~Kelp	-1.583226736	0.476153137
AGP~Kelp	-3.313501489	0.006449493
Gravel~Kelp	-3.377605354	0.007677593
ABC~Maerl	0.225923422	1.0
AGP~Maerl	-0.043372675	1.0
Gravel~Maerl	-0.122196275	1.0
Kelp~Maerl	1.333577889	0.638197817
ABC~Mud	0.319188653	1.0
AGP~Mud	-0.061208469	1.0
Gravel~Mud	-0.187708446	1.0
Kelp~Mud	2.098208084	0.188405531
Maerl~Mud	0.005214023	0.995839830
ABC~Sand	0.530059117	1.0
AGP~Sand	0.116600907	1.0
Gravel~Sand	-0.129312949	1.0
Kelp~Sand	3.734277997	0.003953344
Maerl~Sand	0.081132622	1.0
Mud~Sand	0.126006534	1.0

Table 3 Statistical outputs of Dunn test on Substrate~Species Richness

Substrate~Shannon Diversity Index Dunn test output		
Variable Tested	Z	Adjusted p-value
ABC~AGP	0.4778945	0.885815430
ABC~Gravel	0.7119646	0.833851678
AGP~Gravel	0.4297349	0.875947389
ABC~Kelp	-1.4840790	0.361693408
AGP~Kelp	-3.1846873	0.010143735
Gravel~Kelp	-3.4403346	0.006100452
ABC~Maerl	1.6239682	0.365339114
AGP~Maerl	1.5419535	0.369254708
Gravel~Maerl	1.3705673	0.358070730
Kelp~Maerl	2.8254313	0.024788932
ABC~Mud	0.6804507	0.801584722
AGP~Mud	0.4027242	0.848833776
Gravel~Mud	0.1359105	0.891892027
Kelp~Mud	2.4490587	0.060156643
Maerl~Mud	-1.1594364	0.470167740
ABC~Sand	0.6531729	0.770467250
AGP~Sand	0.3210812	0.872840301
Gravel~Sand	-0.1849757	0.895910497
Kelp~Sand	3.7577915	0.003599812
Maerl~Sand	-1.4644332	0.333843114
Mud~Sand	-0.2494721	0.887521461

Table 4 Statistical outputs from Dunn test on Substrate~Shannon Diversity Index

Substrate~Berger-Parker Index Dunn test outputs		
Variables Tested	Z	Adjusted p-value
ABC~AGP	-0.1486197	0.881853711
ABC~Gravel	-0.6036921	0.674530348
AGP~Gravel	-0.8146562	0.581376786
ABC~Kelp	1.7420118	0.171163397
AGP~Kelp	3.0970410	0.008209439
Gravel~Kelp	3.6848744	0.002402562
ABC~Maerl	-1.9031329	0.149685924
AGP~Maerl	-2.0795284	0.131490831
Gravel~Maerl	-1.7602414	0.182856082
Kelp~Maerl	-3.3130542	0.006459816
ABC~Mud	-1.0500251	0.474449077
AGP~Mud	-1.2572107	0.398384057
Gravel~Mud	-0.7428194	0.600588193
Kelp~Mud	-3.1925924	0.007402597
Maerl~Mud	1.1714114	0.422508521
ABC~Sand	-0.4433355	0.726736017
AGP~Sand	-0.5899176	0.647786854
Gravel~Sand	0.3682550	0.748317224
Kelp~Sand	-3.8784706	0.002207420
Maerl~Sand	1.9251021	0.162649756
Mud~Sand	0.9984445	0.477095788

Table 5 Statistical outputs from Dunn test on Substrate~Berger-Parker index

3D Complexty~MaxN Dunn test outputs		
Variables tested	Z	Adjusted p-value
None~Low	-1.6827278	0.11091336
None~Medium	-2.8594857	0.02545971
Low~Medium	-2.8338002	0.01379943
None~High	-2.6938896	0.01412471
Low~High	-2.2895097	0.03307463
Medium~High	0.1927609	0.84714625

Table 6 Statistical outputs from Dunn test on 3D complexity~MaxN

3D Complexity~Species Richness Dunn test outputs		
Variables tested	Z	Adjusted p-value
None~Low	-1.2421145	0.257033185
None~Medium	-2.4910114	0.019107005
Low~Medium	-2.9952412	0.008226838
None~High	-2.8519862	0.008689396
Low~High	-3.5391876	0.002408163
Medium~High	-0.8720276	0.383193302

Table 7 Statistical outputs from Dunn test on 3D Complexity~Species Richness

3D Complexity~Shannon Diversity Index Dunn test outputs		
Variables tested	Z	Adjusted p-value
None~Low	-0.7026002	0.482304965
None~Medium	-1.8500124	0.096467641
Low~Medium	-2.7419453	0.018322955
None~High	-2.2602512	0.047611335
Low~High	-3.3875776	0.004230766
Medium~High	-0.9402325	0.416517986

Table 8 Statistical outputs from Dunn test on 3D Complexity~Shannon Diversity Index

3D Complexity~Berger-Parker Index Dunn test outputs		
Variables tested	Z	Adjusted p-value
None~Low	0.8893133	0.37383471
None~Medium	1.4553344	0.29115340
Low~Medium	1.3648640	0.20675497
None~High	2.1004959	0.10705571
Low~High	2.6593665	0.04697265
Medium~High	1.4033472	0.24077001

Table 9 Statistical outputs from Dunn test on 3D Complexity~Berger-Parker Index

Zone~MaxN Dunn test outputs		
Variables tested	Z	Adjusted p-value
1~2	0.7389701	0.65703593
1~3	2.1243944	0.11212392
2~3	1.0420219	0.49566921
1~4	2.4243456	0.07668002
2~4	1.3445396	0.35754789
3~4	0.3679651	0.79211028
1~5	2.7480668	0.05994780
2~5	1.6279375	0.25884535
3~5	0.6848942	0.61676336
4~5	0.3092679	0.75711773

Table 10 Statistical outputs from Dunn test on Zone~MaxN

Zone~Berger-Parker Index Dunn test outputs		
Variables tested	Z	Adjusted p-value
1~2	1.6738763	0.23538727
1~3	1.1989894	0.38422011
2~3	-0.5341403	0.65916049
1~4	3.1530765	0.01615595
2~4	1.1353343	0.36605038
3~4	1.7839665	0.24809701
1~5	0.2231495	0.82341918
2~5	-1.2414947	0.42884610
3~5	-0.7903152	0.53667966
4~5	-2.4539780	0.07064280

Table 11 Statistical outputs from Dunn test on Zone~Berger-Parker Index

Frame~MaxN Dunn test outputs		
Variables tested	Z	Adjusted p-value
1~2	-0.6809308	0.49591525
1~3	1.7234750	0.12720400
2~3	2.3821771	0.05163186

Table 12 Statistical outputs from Dunn test on Frame~MaxN

Correlation Test				
Variables Tested	Rho	S	P-value	Covariance
Depth~Shannon Index	-0.1731334	513820	0.04228	-0.925118
Depth~Species Richness	-0.2108146	530320	0.01307	-3.862093
Depth~Berger-Parker Index				
Depth~MaxN	-0.2724988	557340	0.001223	-2.739182
Kelp Cover~Shannon Index	0.3046933	304540	<0.001	0.08607967
Kelp Cover~Species Richness	0.3264777	295000	<0.001	0.3212509
Kelp Cover~Berger-Parker Index	-0.2713784	556850	0.001284	-0.03427136
Kelp Cover~MaxN	0.3016088	305890	<0.001	0.1727815

Table 13 Statistical outputs of spearman's rank correlation tests on Depth and % kelp cover for full dataset

Wrasse Kruskal-wallis test output			
Variables Tested	Chi^2 value	Df	P-value
MaxN~Substrate	93.684	6	<0.001
Species Richness~Substrate	94.631	6	<0.001
MaxN~3D Complexity	71.496	3	<0.001
Species Richness~3D Complexity	72.266	3	<0.001

Table 14 Statistical outputs from Kruskal-wallis test on Wrasse abundance and species richness

Wrasse MaxN~Substrate Dunn test output		
Variables tested	Z	Adjusted p-value
ABC~AGP	2.8851623	0.011736
ABC~Gravel	2.6839315	0.019100
AGP~Gravel	-0.2815135	0.961449
ABC~Kelp	-2.0650588	0.081726
AGP~Kelp	-7.8836225	<0.001
Gravel~Kelp	-7.3662219	<0.001
ABC~Maerl	1.8572115	0.120809
AGP~Maerl	0.2144220	0.968587
Gravel~Maerl	0.3185473	0.984466
Kelp~Maerl	3.4825099	0.002086
ABC~Mud	2.5661064	0.023997
AGP~Mud	0.3495238	1.0
Gravel~Mud	0.5136421	0.981349
Kelp~Mud	5.4560444	<0.001
Maerl~Mud	0.0000000	1.0
ABC~Sand	3.1551576	0.005614
AGP~Sand	0.3303661	1.0
Gravel~Sand	0.6281997	0.927278
Kelp~Sand	8.9274808	<0.001
Maerl~Sand	-0.1128083	0.955691
Mud~Sand	-0.1889818	0.939592

Table 15 Statistical outputs from Dunn test on Substrate~Wrasse MaxN

Wrasse Species Richness~Substrate Dunn test outputs		
Variables tested	Z	Adjusted p-value
ABC~AGP	2.7860358	0.016007
ABC~Gravel	2.5925564	0.025007
AGP~Gravel	-0.2703491	0.972942
ABC~Kelp	-2.1989633	0.058541
AGP~Kelp	-7.9497876	<0.001
Gravel~Kelp	-7.4396103	<0.001
ABC~Maerl	1.7999012	0.137218
AGP~Maerl	0.2144921	0.968523
Gravel~Maerl	0.3144310	0.988566
Kelp~Maerl	3.5100517	0.001881
ABC~Mud	2.4869209	0.030065
AGP~Mud	0.3496381	1.0
Gravel~Mud	0.5070047	0.988860
Kelp~Mud	5.4991942	<0.001
Maerl~Mud	0.0000000	1.0
ABC~Sand	3.0523711	0.007946
AGP~Sand	0.3304741	1.0
Gravel~Sand	0.6156733	0.941692
Kelp~Sand	9.0002561	<0.001
Maerl~Sand	-0.1128452	0.955660
Mud~Sand	-0.1890436	0.939538

Table 16 Statistical outputs from Dunn test on Substrate~Wrasse species richness

Wrasse MaxN~3D Complexity Dunn test outputs		
Variables tested	Z	Adjusted p-value
None~Low	0.0000000	1.0
None~Medium	-0.4464087	0.786362
Low~Medium	-1.0605999	0.433307
None~High	-3.7683436	<0.001
Low~High	-8.0700703	<0.001
Medium~High	-6.8608548	<0.001

Table 17 Statistical outputs from Dunn test on 3D Complexity~Wrasse MaxN

Wrasse Species Richness~3D Complexity Dunn test outputs		
Variables tested	Z	Adjusted p-value
None~Low	0.0000000	1.0
None~Medium	-0.4362298	0.795204
Low~Medium	-1.0364162	0.450012
None~High	-3.7850092	<0.001
Low~High	-8.1057604	<0.001
Medium~High	-6.9155833	<0.001

Table 18 Statistical outputs from Dunn test on 3D Complexity~Wrasse species abundance

Wrasse Spearman’s rank correlation test output				
Variables Tested	Rho	S	P-value	Covariance
Kelp Cover~MaxN	0.5837318	182320	<0.001	24.88787
Kelp Cover~Species Richness	0.5855257	181450	<0.001	17.81392
Depth~MaxN	-0.4468723	633710	<0.001	-5.347431
Depth~Species Richness	-0.448958	634630	<0.001	-3.77348

Table 19 Statistical outputs from spearman's rank correlation test on wrasse species richness and abundance with kelp cover and depth