An investigation into the recovery of Lamlash MPA No Take Zone and South Arran MPA: Has protection led to improved biodiversity and habitats?

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"I, William Notley, hereby declare that the intellectual content of this thesis is the product of my own work and that all the assistance received in preparing this thesis and sources have been acknowledged"

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1. Abstract

Despite efforts to increase the coverage of Marine Protected Areas (MPAs) worldwide, studies have suggested that many MPAs fail to offer sufficient levels of protection to allow significant recovery. The United Kingdom government is therefore keen to understand how highly protected areas, No Take Zones (NTZs), are performing and whether they need to implement more in the future. This study investigated how biodiversity had changed within two separate zones in an MPA around the south of the Isle of Aran, Scotland – an NTZ, which is fully protected from fishing, and the remaining area which is open to a limited amount of fishing. The NTZ was established in 2008 and previously monitored from 2010 to 2013, while the MPA was only surveyed in 2014 and 2015, prior to its protection in 2016. Given this unique opportunity to examine how different levels of protection have affected benthic communities, we instigated a new survey of both of these zones, and a surrounding area open to all types of fishing, in 2019 Over the summer of 2019, 55 Underwater Visual Census (UVC) dives were completed to examine how biodiversity and habitat structure had changed since the previous surveys. Within the NTZ biodiversity had generally increased within all phyla apart from *Echinoderms,* due a collapse in Feather star (*Crinods*) numbers, showing that with increased protection epifauna can recover. Throughout the MPA and NTZ mean SACFOR scores indicate that several habitat substrates had potentially decreased, however there was also indications of increased kelp cover, suggesting that habitat assemblages are changing. The study also discovered unprecedented abundance and size of monkey puzzle bryozoan (*Omalosecosa ramulosa*), both within and outside the reserve. This provides further evidence that with increased levels of protection, and time, ecosystems recover. Although dramatic changes were seen within certain species such as the commercially important King scallop (*Pecten maximus*), when each zone was compared, there was little difference between diversity and habitat between the MPA region (excluding the NTZ) and the open fished / scallop dredged) zone. This suggests that after a prolonged history of fishing with methods such as scallop dredging, benthic ecosystems may require relatively lengthy time periods (> 5 years) to show significant signs of recovery.

2. Introduction

Over the past two decades, there has been a notable increase in the level of protection for the environment. This has been driven largely by International Conventions such as the Convention for Biodiversity (CBD) (CBD, 2010), who aim to reduce biodiversity loss by protecting at least 10% of global marine areas by 2020. Although this target is likely to be met in terms of a percentage protected, it is unlikely there will be active management going on within all of those areas as it takes time for designation to be implemented into action. In a recent study by World Wildlife Fund (WWF) (2018), marine biodiversity was still in decline which raises concerns not only for the individual species but also for human livelihoods and overall resilience to future pressures (Howarth., 2015a).

One of the key tools for protecting marine biodiversity has been the implementation of Marine Protected Areas (MPAs). There have been questions about the quality of MPAs which has often resulted in ineffective MPAs being called 'Paper Parks' (Devillers et al., 2014). This has typically been down to poor management plans such as being too large to patrol; a lack of funding; areas being chosen which are low in biodiversity or non-profitable exploitable resources; and a lack of community engagement (Di Santo et al., 2013, Dehens and Fanning., 2018). Discourse has arisen about the importance of marine reserve design being as important as implementation of the reserve itself. This has several subsections including size and shape, commonly referred to as the SLOSS debate (Single Large or Several Small), and whether it is implemented by government or the local community in the bottom up versus top down approach (Santini et al., 2015, Jones., 2012).

There have also been criticisms of the level of protection found within an MPA, as it is a broad term and may not truly have biodiversity at the cause of its concern (Agardy et al., 2003).

Often multiple stakeholders are involved, especially in large diverse MPAs. Discourse has led to several key features attaining to successful MPA design. These include:

Age of MPA (>10 years), size (>100km^2), well enforced, and isolation (Edgar.,et al 2014). Other papers have indicated that stakeholder engagement and compliance are also key (Pierrachi et al., 2016, Di santo., 2013, Gililand and Laffoley., 2008).
The highest level of protection is a No Take Zone (NTZ), which according to UK MPA atlas (n.d), prohibits the extraction or destruction of natural or cultural resources. Typically, these are uncommon as most stakeholders will generally lose out in the short term, such as fishermen via decreased available stocks and reduced income, therefore proving unpopular (Sanchirico et al., 2002). Given time stocks can recover and a potential spill over effect of fish inside the reserve to non-protected areas. This benefits not only the ecological status of an MPA but also the individuals dependent upon it (Stobart et al., 2009, Russ et al., 2004).

Britain has been making strong strides forward in terms of expanding MPAs and currently has 25% of its waters protected by at least an MPA (JNCC, 2019). The majority of highly protected areas, through NTZs, are situated in overseas territories. In UK Overseas Territories (UKOTS) there are approximately 1.5 million km^2 protected with a further 1.5 million promised in locations such as Ascension Island which will cover 443,000 km^2 (O'Leary et al., 2019). The rest are split over 13 other territories. A further 41 MPAs were announced in June 2019, which will increase the total area protected to 30% and will cover a combined area of 12,000 km^2 (Ogden, 2019). Although part of the problem has been introducing MPAs at all, there have been questions noted with British MPAs in terms of implementation and adequacy of protection (Plumeridge and Roberts, 2017).This has been down to a variety of reasons including inadequate limitations of fishing levels, inappropriate areas being targeted – such as where there is little biodiversity and therefore fish and unattainable standards for fishermen to meet.

There are currently only 4 NTZs located around the mainland of the UK: Lundy Island, Flamborough Head, Medway Nursery Area and a section of South Arran MPA called Lamlash NTZ. These cover just 21.07 km^2 or 0.0024% of UK seas (Solandt., 2018, JNCC, 2019) which suggests that ecological protection has been prioritised more higher in UKOTS than around the mainland of the UK. These NTZs are key as they hold the highest level of protection absolute no commercial extraction of fish. Due to their rarity within English and Scottish waters it is crucial that they are sufficiently

monitored to understand what the possible rates of recovery can be when there is minimal human interference. With recovery of these areas, there is potential to understand what these areas may have looked like historically.

Of the 4 NTZs, the South Lamlash MPA is unique, not only for including an NTZ but also because it was created through the campaigning of the local community known as the Community of Arran Seabed Trust (COAST). Not only did they campaign for its designation, but they also raise awareness the MPA (Howarth et al., 2015b) within its local community.

Situated on the South of the Isle of Arran, the largest island in the Firth of Clyde (Figure 1), it is seen as a figurehead in marine protection. It has been recognised internationally by winning the Goldman Prize for Europe in 2015 for Grassroots Community work. This has been referred to by some people as the Green Nobel prize (Thacker et al., 2006).

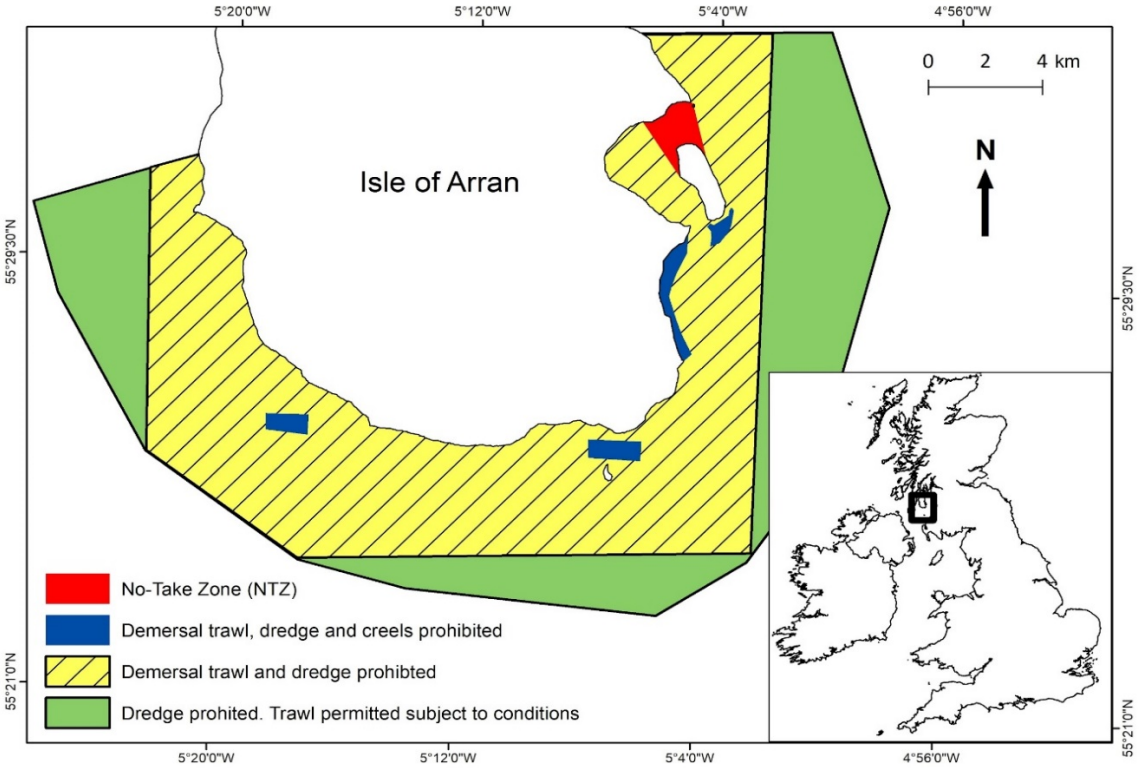


Figure 1. The Isle of Arran MPA with all levels of protection. In red is the No Take Zone (NTZ) which has remained unchanged since its original designation in 2008. Subsequent zones were added around 2015. Creel fishing is largely allowed apart from in 4 zones. Demersal trawl is permitted around the edges of the MPA in the three green zones. Sourced from (Stewart et al., in press)

The Firth of Clyde was of historic importance for the fishing of cod (*Gadus morhua*), herring (*Clupea harenaus*), haddock (*Melanogrammus aeglefinus)*, and flatfish species turbot (*Psetta maxima*) and flounder (*Platichthys flesus*) (Thurstan and Roberts., 2010). Due to mismanagement, overfishing became prevalent causing numbers to decline in the mid-1980s throughout the Firth of Clyde (Heath and Spears., 2010). These fisheries were replaced by the fishing of lower trophic level species such as king scallops (*Pecten Maximus*), the Norway lobster (Nephrops norvicus) and European lobster (Homarus gammurus) which have a total value similar to that of the previous finfish fisheries (Howarth et al., 2015a).

Although these species, particularly lobster and king scallops, can be targeted with low impact fishing methods such as Scuba Diving, they have been fished heavily by more destructive measures; Otter trawls and Newhaven dredges (Mcintyre et al., 2012). These bottom towed gears are capable of major disturbance to the seabed structure and cause loss of diversity in benthic communities via their high levels of bycatch (Bergmann et al., 1992; Kaiser et al., 2006, Stewart and Howarth., 2016). It was this loss in biodiversity and lack of intervention from the Scottish government, in spite of this change acknowledged by fishermen and scientists, which caused COAST to be created by the local community (Stewart et al., in press).

After initially campaigning in 1996, it wasn't until 2008 that the Lamlash Bay No Take Zone was implemented. From 2010 to 2013 scientific surveys were done within the NTZ and the surrounding area which noted a marked decline in biodiversity loss immediately outside of the NTZ (Howarth et al., 2015). This led to further campaigning and a subsequent MPA being designated (Figure 1) which encompasses ~270 km^2 (Howarth et al., 2015).

Although surveys have been conducted around the NTZ and further regions of the MPA (Howarth et al., 2011, Stark et al., 2015,) no study has been done covering each of the zones of the MPA in their current protection status in a single year. Therefore, considering the previous management and expansion of the MPA there is a unique opportunity to understand both temporal and spatial performance of the MPA to different levels of protection. This study, along with a co-study from James (et al., NP)

aims to build upon previous research of Howarth et al., (2011, 2014, 2015 a) to investigate:

- How the NTZ has changed over the previous decade?
- Has the more recently protected areas changed since designation?
- How does biodiversity vary throughout the MPA?

3. Methods

3.A Study area

Data was collected between the 4th July to 12th August 2019. A total of 55 surveys were completed in and around the South Arran MPA (Figure 2a). From the 4th to 28th July data was collected from 45 sites within the MPA and the NTZ following coordinates from previous studies, (Howarth et al., 2015) Figures 2a-e (all orientated North).

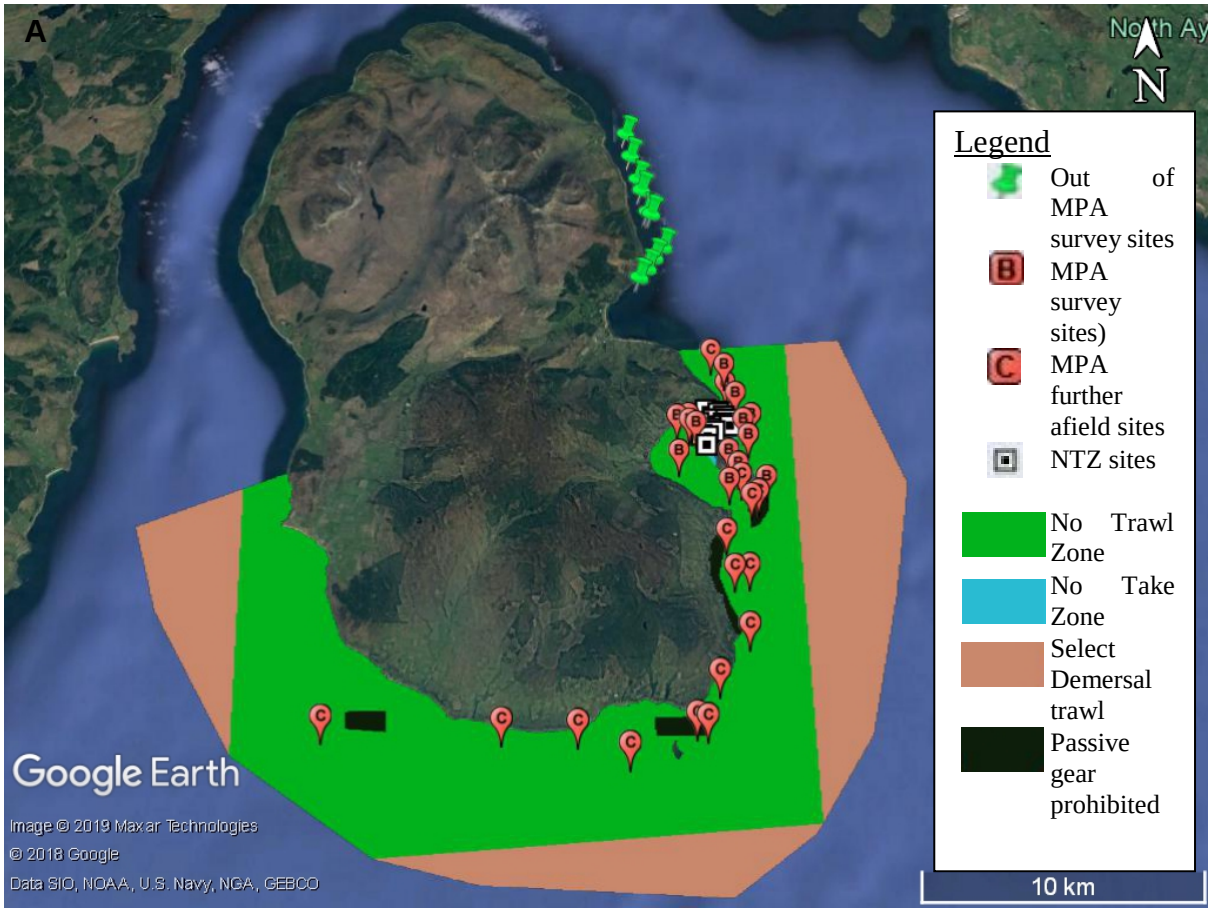


Figure 2a. South Arran MPA (Marine Protected Area) and all surveys conducted between July and August 2019

From the 2nd to 12th August, 10 new study sites were created North of the MPA around Brodick and Sannox (see Figure 2c). This was done to create further context between the NTZ, the MPA and outside the MPA where dredging is permitted.

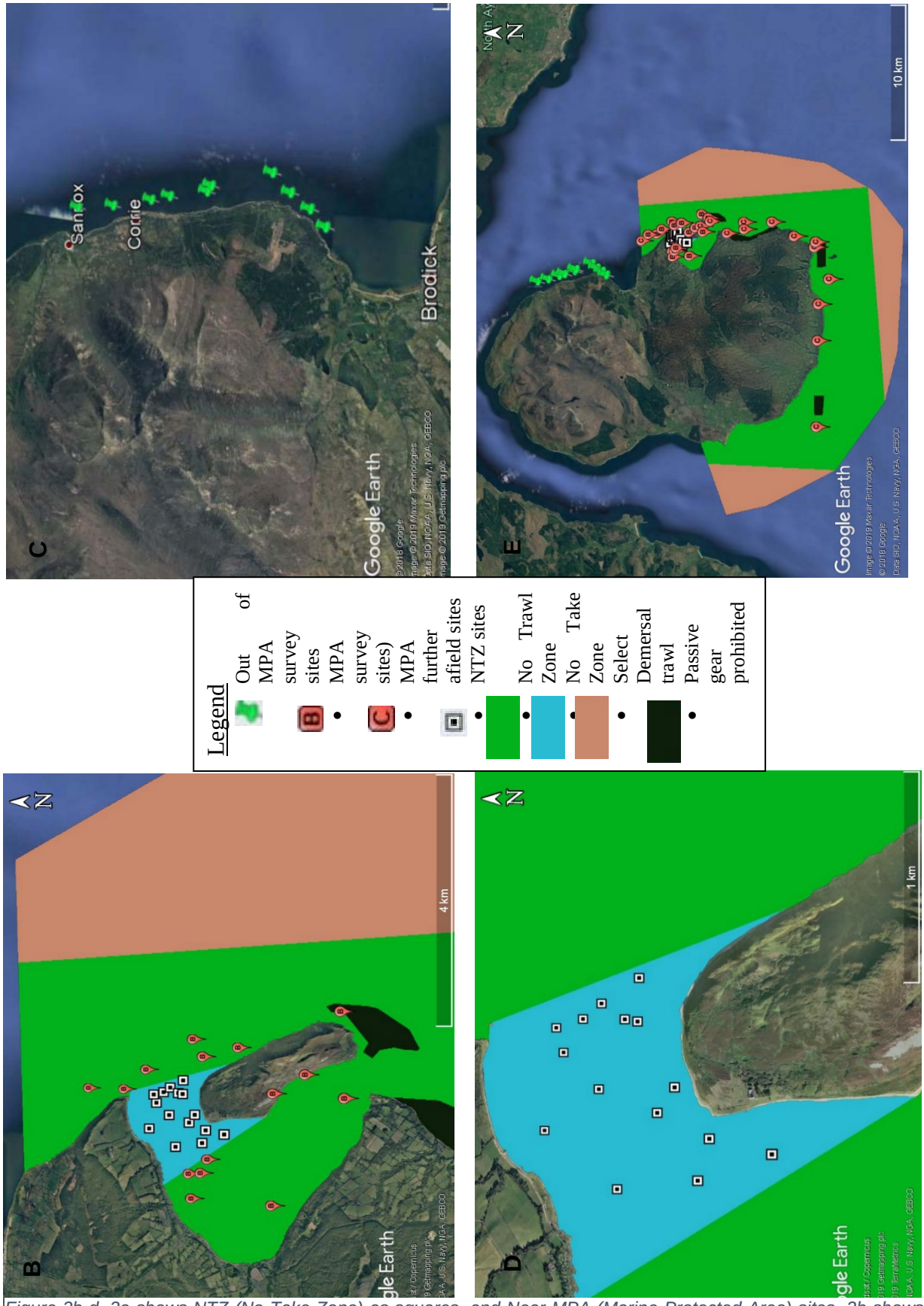


Figure 2b-d. 2a shows NTZ (No Take Zone) as squares, and Near MPA (Marine Protected Area) sites. 2b shows sites out of the MPA. 2c. shows the NTZ sites exclusively. 2d shows all sites where data was collected included the zone designated as Far MPA (c) on figure. All images are taken from Google Earth.

3.B Data Collection

Data was recorded via SCUBA diving using Underwater Visual Census (UVC), SACFOR and underwater filming.

Previous GPS locations (Howarth et al., 2014, Stark and Wood., 2015) were used to lay a 50m lead weighted line at depths no deeper than 28m. This was surveyed as a belt transect with a 1m corridor each side of the line to create a 100m^2 study area. Twenty-eight meters was chosen as the maximum depth as divers were using air and were unable to complete deeper surveys due to decompression limits. The depth range between each end of the line was set at 3m to ensure that ensure that substrate was as similar as possible.

During each dive, two divers would swim in single file. The first would film the benthos at 1m above the floor at approximately a 45-degree angle (as seen in Figure 3) using a Sony Compact RX100 IV in a Fantasia Housing (A). This was done to provide a permanent record, assist with visual counts (see below) and allow for further, more detailed, analysis.. A Weefine Smart Focus 3,000 strobe (B) was used to provide lighting. The camera was attached to a 1m bar with a laser pointer at each end to enable biomass studies for future research. Depending on complexity of the benthos and current, each side of the 50m transect would be surveyed in 8-12 minutes.

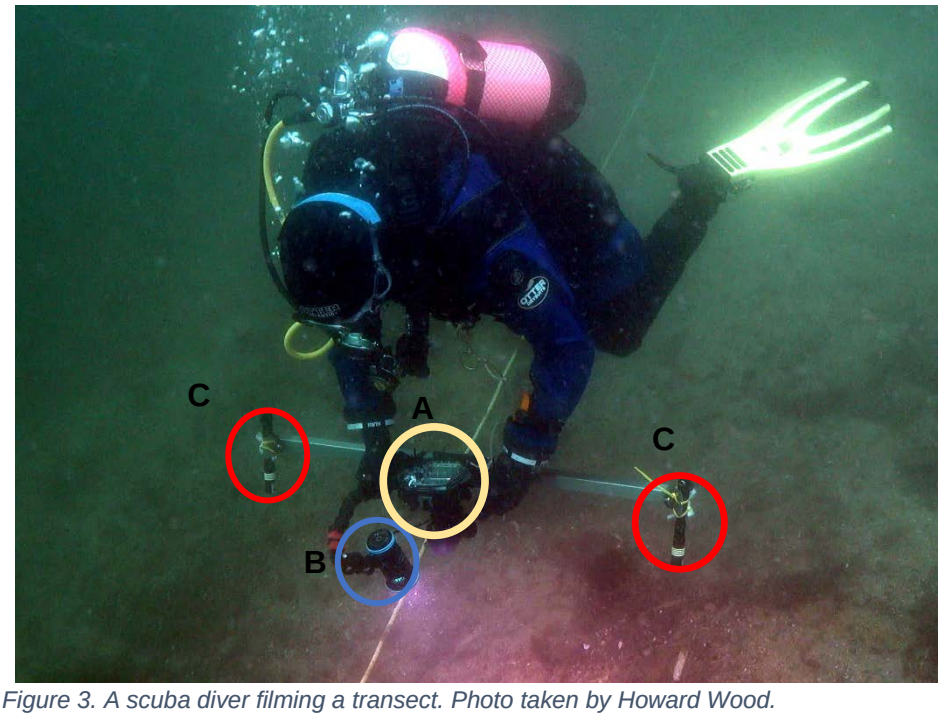


Figure 3. A scuba diver filming a transect. Photo taken by Howard Wood.

The second diver collected data on present vertebrate and invertebrate species. King and Queen Scallops were also collected as part of studies on scallop recovery (James et al., Unpublished). The UVC was based on previous studies in the Lamlash NTZ from Howarth et al., (2015) and included a section for any additional species. At the end of each dive, the second diver would complete a SACFOR scale based upon JNCCs measurement scale (JNCC., ND), for the belt transect. This uses relative abundance of substrates covering the benthos. SACFOR stands for the level of coverage: S = Superabundant (>80%), A = Abundant (79-40%), C = Common (39-20%), F = Frequent (19-10%), O = Occasional=9-1% and R = Rare (<1%). The substrates measured were dead maerl, live maerl, hydroids, bryozoans, kelp, macroalgae, brittle stars, sponge, coral, anemones and juvenile scallops.

Coordinates were similar, but not identical to previous studies due to tide and wind conditions. At each end of the line was a buoy to provide safety and to aid with entry and exit.

3.C Data Analysis

3.C.i Mobile Species

Data was organised and analysed within Microsoft Excel to produce a mean density bar charts of each species counted. Standard error was applied to each species and a mean number of individuals per site was calculated from the sum of each counted species per site. This was compared between each area, and subsequently between the NTZ and MPA for each year as done in Howarth et al., (2015). Near MPA sites and the NTZ (as in figure 2A) were then compared against Howarth et al., (2015) dataset. This meant sites were removed from the previous year's datasets as they covered 5 more within the MPA and NTZ than were studied. This was done to ensure comparability due to the highly diverse substrates and depths found between study sites.

3.C.ii. Univariate Analysis

Data was subsequently analysed within PRIMER 6.0 and transformed as "normal data". Biodiversity indexes were subsequently calculated using the DIVERSE tool for total, Total individuals, Species richness, and Shannon's index. These were all tested for significance with one-way ANOVAs in R studio.

3.C.iii. Multivariate Analysis

A resemblance matrix was created and used to create a Multi-Dimensional Scaling plot in both 3-D and 2-D. Stress of the model, how much the model had to be distorted from 3-D to 2-D, was then used to decide on how accurate the model was S=0.25 was set as a threshold (Howarth et al., 2015). This was used to investigate whether the level of protection was important to diversity.

A Hierarchical cluster analysis was performed using the SIMPROF function to determine if there were significant assemblages found within each protection.
Finally, analysis of similarity (ANOSIM) was calculated to understand if there was a difference between different protection zones.

3.D.ii Sessile Species

After the SACFOR scale was transposed into excel, a mean SACFORs was created between each protection zone with standard error applied. NTZs and MPAs were compared with previous years using ANOVAs to see if there was significance between each zone. Due to high variability within SACFORs scale and the potential of over 100% total coverage being attained, data was compared at mean scores.

PRIMER was used to provide a Multi dimension scaling plot to ascertain whether habitats were related to protection levels. Protection again used the same definitions as before. Similarity of Percentages (SIMPER) was calculated to understand if there were any dominant substrates within each protected area.

4. Results

4.a Biodiversity

A total of 6,577 individuals were recorded and identified as 73 different species (see appendix table 1). The top 11 species (See Figure 4), account for 71.7% of all recordings with King scallops (*Pecten maximus*) accounting for 15.5%. Within the most abundant species annelids (Parchment *Chaetopterus variopedatus* and Keel Worms *Spirobranchus triqueter*) accounted for 14.5% of all recordings, Arthropods (Hermit Crab *Pagarus Sp.,* Decorator, Harbour Crab *Liocarcinus depurator* and Long-claw Squat Lobster *Munida rugosa*) accounted for 23% of all individuals. Echinodermata had two species which were high in abundance- Cushion star, *Asterina gibbosa,* (6.1%) and Spiny star, *Marthasterias glacialis*, (3.6%). Apart from King scallops only nudibranchs were observed from the Echinodermata family (3.8% of all counts). Only one Chordata species, Juvenile cod (*Gaddus morhua*), was observed in high densities. This accounted for 5% of all species.

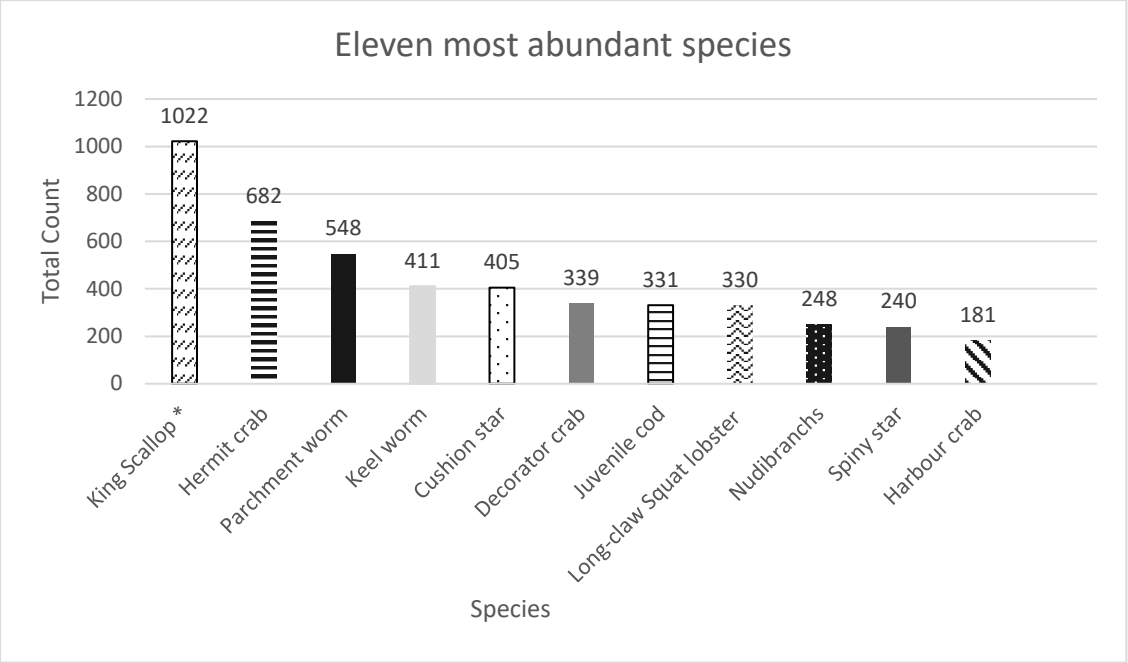


Figure 4. Top 11 most abundant species (denotes species was removed from later research due to a co-project on scallops by James (NP))*

The top 10 most abundant species were found to be in highest densities within the Far MPA sites (See Figure 5a). Near MPA and Far MPA showed similar mean densities of the most abundant mobile species of 56.88, and 56.3 per 100m^2. NTZ had the lowest density of 39.8 individuals per transect. Dredged areas had a higher density

than NTZ of 45.7 individuals per 100m^2. Two sessile species, Keel (*Pomatoceros triqueter*) and Parchment worm (*Chaetopterus variopedatus*), (Figure 5b) were found in highest densities in the Far MPA (30 p100m^2). Parchment worms were seen in greater densities in all protection zones than Keel worms

apart from in Far MPA. Although one of the most abundant, Harbour crabs (*Liocarcinus depurator)* were absent at Unrestricted. This was the only occasion one of the top ten was absent within a region. The highest density of any species, excluding *Pecten maximus,* were Hermit crab (*Pagurus bernhardus*) (21.3 per 100m^2) at Near MPA.

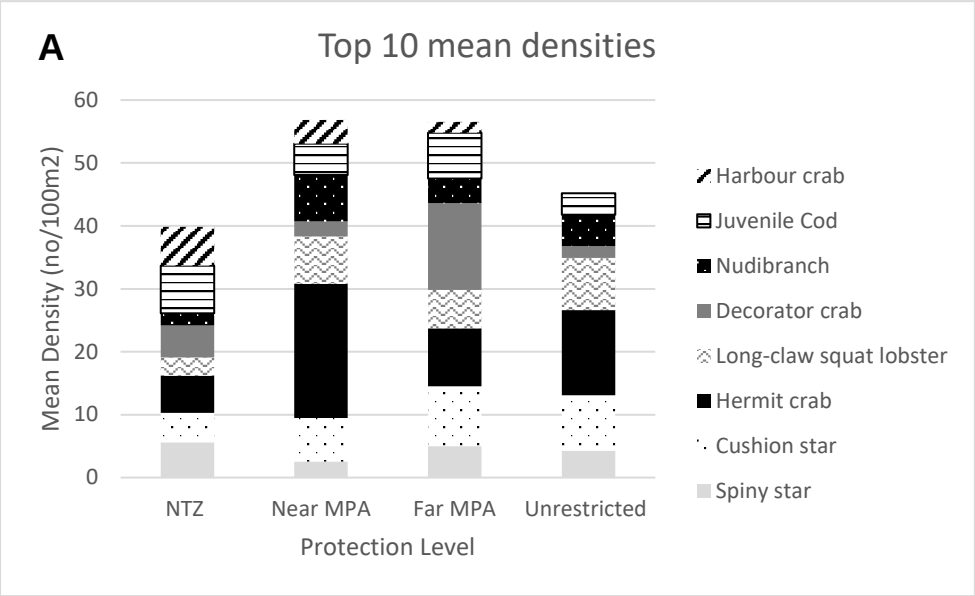


Figure 5a. Top 10 species which were mobile. Mean density per 100m2 was calculated

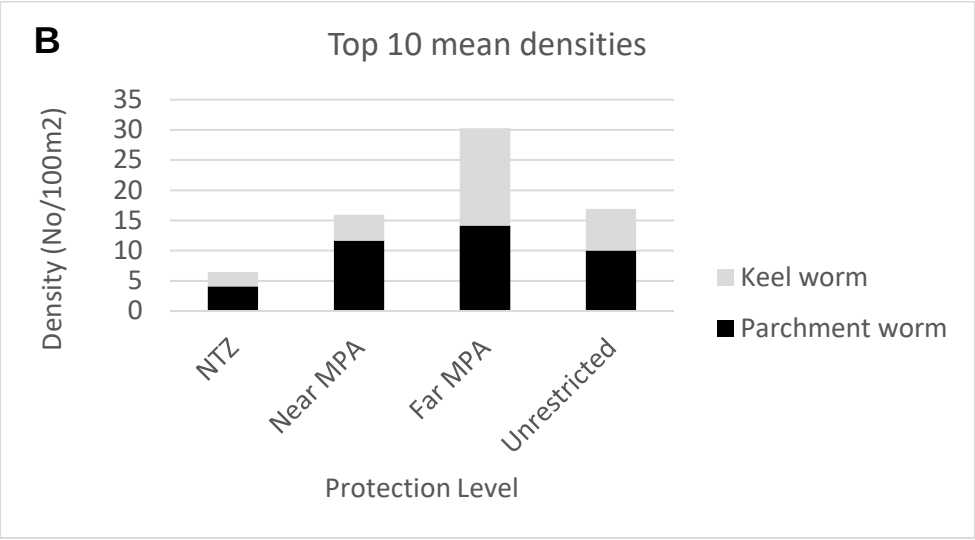


Figure 5b. Top 10 species which were sessile. Mean abundance per 100m2 was calculated

A multidimensional plot showed there to be no significant difference between each zone. Dredged appeared to have the closest consistency, however NTZ and MPA Far and Near were demonstrated to be highly variable (see Figure 6). One way ANOVAs

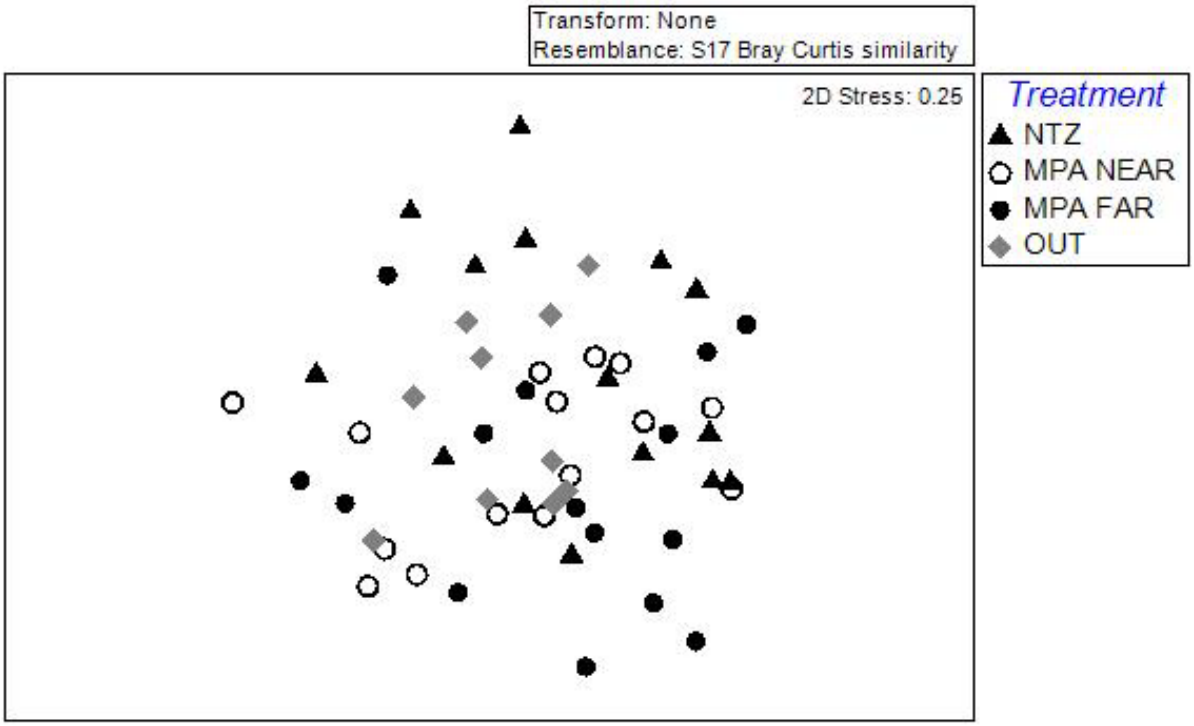
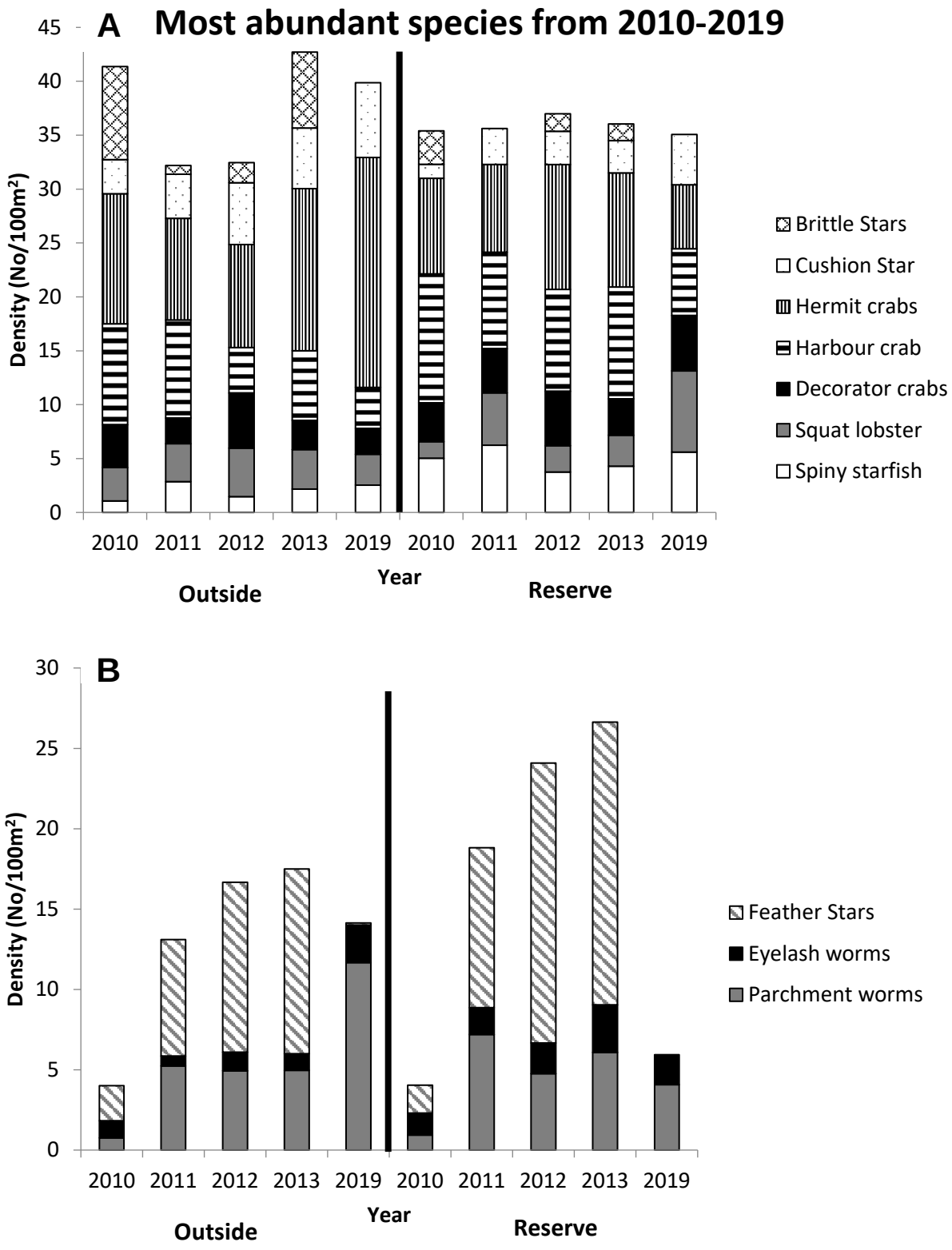


Figure 6. Multi-Dimensional Space plot of biodiversity (Shannon-Weiner) of all four protections

were run for Species richness, Shannon's and Species Abundance for each protection, all of which were insignificant $F_{(1,55)} = 1.18$ P(P=0.33), F= 0.65 (P=0.59), F=2.70 (P=0.06) (See appendix table 2).

Compared to Howarth et al (2015 and 2014) study the most abundant species had declined in both sessile and mobile categories (Figure 7a and b). Brittle stars were not counted in 2019 as they were included in the SACFOR. Squat lobsters showed a rise in both previously "Outside" (now Near MPA) MPA and Reserve. Parchment worms increased in density by 7 (per $100m^2$) outside the reserve, but decreased to an average of 4 per transect.

Analysis of similarity (ANOSIM) between each four zones showed weak r values, ranging from -0.006 for Far MPA and OUT (p=51.2) and r^2 0.213 (p=>0.99) between NTZ and Unrestricted. NTZ yielded highly significant results between Far MPA (r^2 0.132 p=>0.99) and Near MPA (r^2 0.181, p=> 0.99. See appendix Table 3)



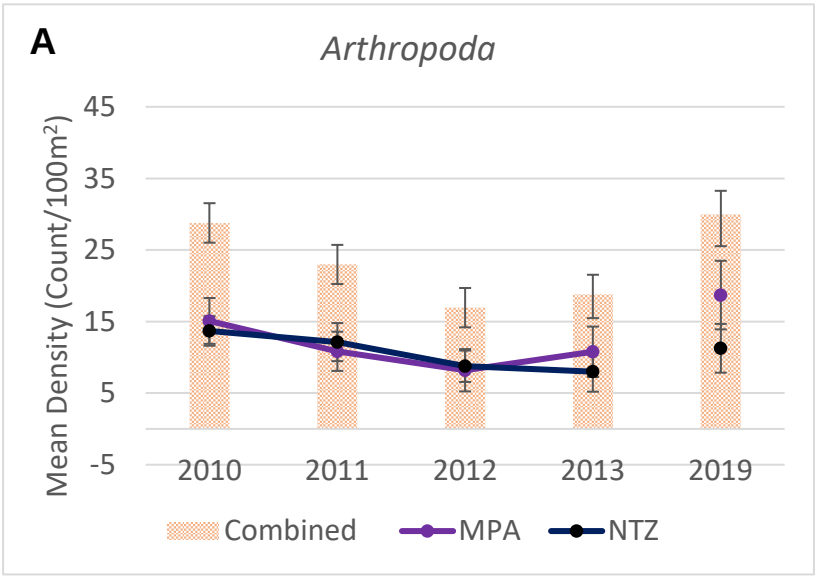
Figures 7a and b. Most abundant species, showing sessile species and using mean, from 2010 to 2019. Data from 2010-2013 sourced from Howarth (et al., 2015). Figure a shows mobile species where figure b shows sessile species

The main families, *Echinodermata, Chordata, Mollusca, Arthropoda* and *Annelida* were also compared (Figures 8a – e) both within the NTZ, and where the MPA now stands, previously stated as Outside. Arthropoda (all crabs and lobsters which were observed), show 1.5-fold increase in both the MPA and NTZ since the previous study of Howarth (et al., 2015). Since 2012, arthropods have been denser within the MPA, than in the NTZ. They were measured at 7.4 individuals higher per transect on average.

Since 2010, Echinodermata (Figure 8b) rose to a maximum density of 34 (per $100m^2$) but has since declined to a current density of 16.3. Densities have always been higher within the NTZ but are similar (10.1 in the NTZ and 6.3 in the MPA).
Mollusca initially saw a decline to 9.13 individuals per transect from 2010 to 2011(Figure 8c), but have increased markedly since to a combined density of 33.7 in 2019 (16.3 in near MPA and 17.3 in the NTZ).

Overall Chordata (fish species excluding commercial fish such as cod and haddock), increased from 39.3 to 45 individuals per transect from 2010 to 2019 (Figure 8d). Densities dropped between 2010 and 2013 to 28.6. More fish were seen outside the NTZ than within in 2019 (33, 22 per $100m^2$).

Annelida (Segmented worms), have increased from 2 to 14.2 individuals per transect, which represents a seven-fold increase (see figure 8e). As with figure 6b. densities were higher in the MPA (9.53) than in the NTZ 4.6.


A
Arthropoda
Mean Density (Count/100m²)
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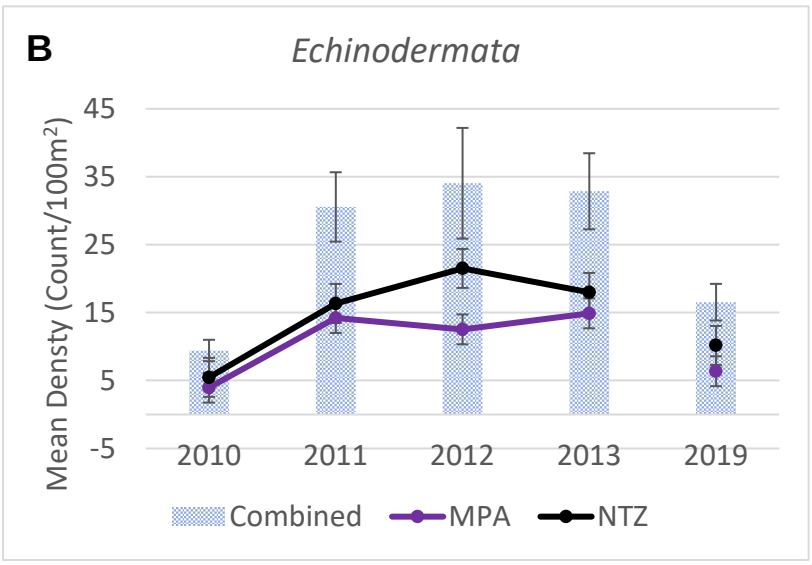
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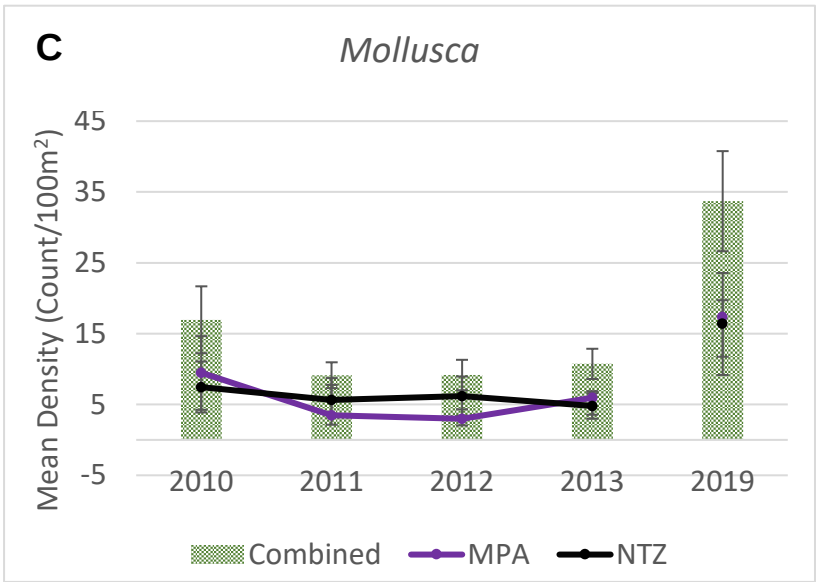
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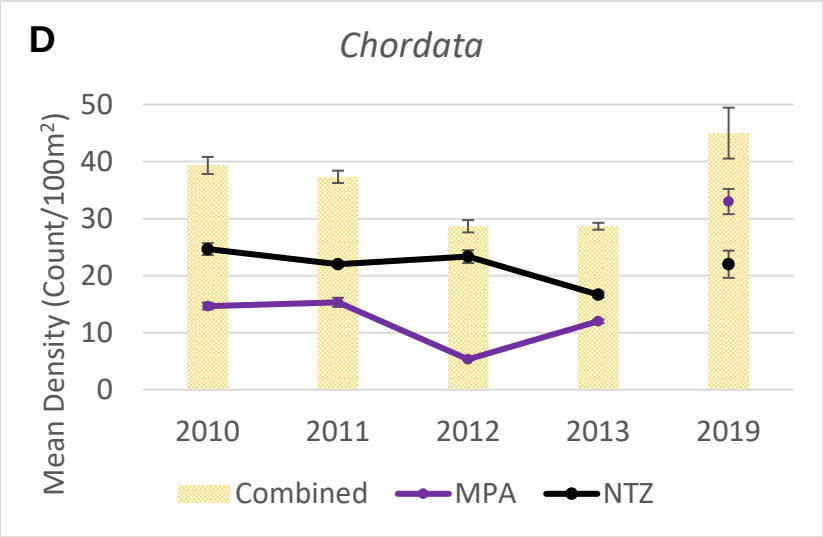

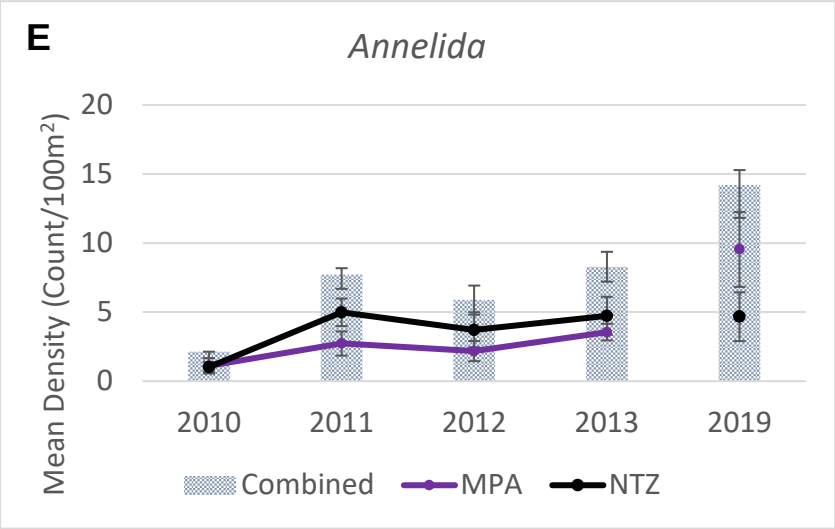

Figure 8 A-E. Families of species counted comparing 2019 densities within the MPA and NTZ to data collected from 2010-2013 by Howarth (et al., 2019). Standard error is used.

4b. SACFOR and habitat assemblage

Mean SACFOR scores fell further away from the NTZ (Figures 9a-d) with OUT having the highest average score of 1.9 (Anemone). Coral was the least common habitat found throughout all sites (0 to 0.53). Dead maerl, live maerl and macroalgae all decreased with diminished protection from 1.6 to 0.5, 0.2-0 and 2.7-0.9. Sea squirts were seen in similar densities throughout all sites, 1.3 - 1.8 as were hydroids (1.4-2). Kelp had the highest mean cover of 2.53 to 1.4 over each protection. Sponges were higher in coverage at further away sites (9d and 9e) compared to sites nearer the NTZ (9a and 9b).

Pink coralline algae was found in greatest densities within the Far MPA site (2.13) and was lowest in Out of the MPA region (0.8). Juvenile scallops were also found in highest abundance within the Far MPA (9c, 0.6) but lowest in the Near MPA region (0.27). Bryozoans were in lowest abundance in the Near MPA region and highest in the Far MPA (1.23 -2.3) but were higher in the Out zone in comparison to the NTZ (1.5-1.3).

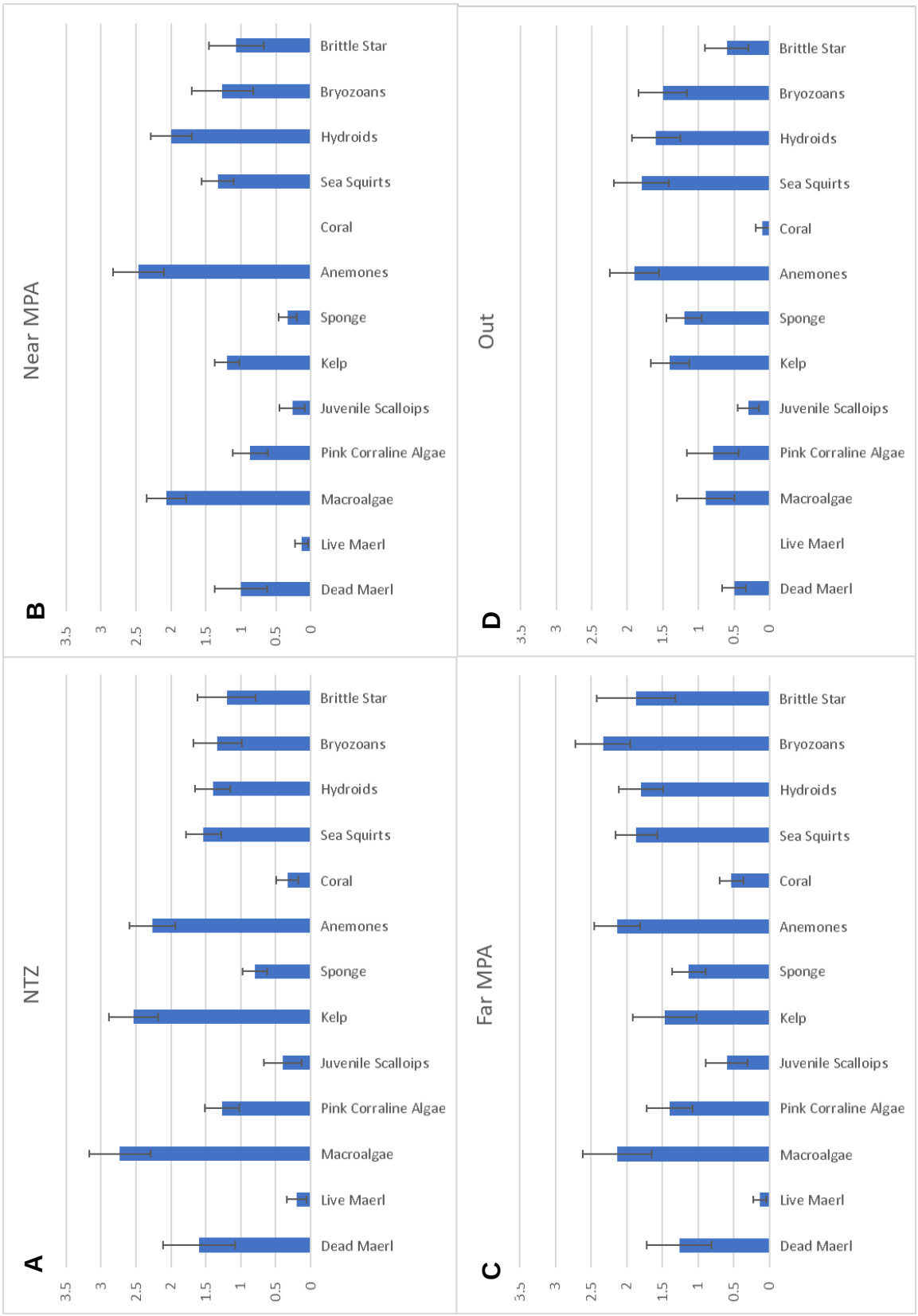

Figure 9a-d. Mean SACFOR for No Take Zone (NTZ), Near Marine Protected Area (MPA), Far Marine Protected Area and Out of Marine Protected Area. Standard Error bars have been applied.

Brittle stars were highest in density within the Far MPA (1.86,) and lowest in the Out region (0.6). They were higher within the NTZ (1.2) than in the Near (1.06).

Similarity of percentages (SIMPER) revealed that Anemones contributed to on average 10% to all sites (Appendix Table 4). Far MPA and NTZ had the most diverse make up, with 8 species accounting for >90% of the coverage. NTZ had the lowest average similarity of 50.57. Sites in the Out zone had the lowest diversity in assemblage, with 6 substrates accounting for 87% of coverage (Anemones, sea squirts, kelp, hydroids, bryozoans and sponge). Near MPA had the two highest substrate coverages, Anemones (22.56%) and Macroalgae (20.44%).

Mean SACFOR results have all declined when compared to 2010-2013 data (See Figure 10a and 10b) both within the NTZ and the MPA apart from Kelp in the NTZ which has increased by 0.48 (2.53) (See Figure 10a).

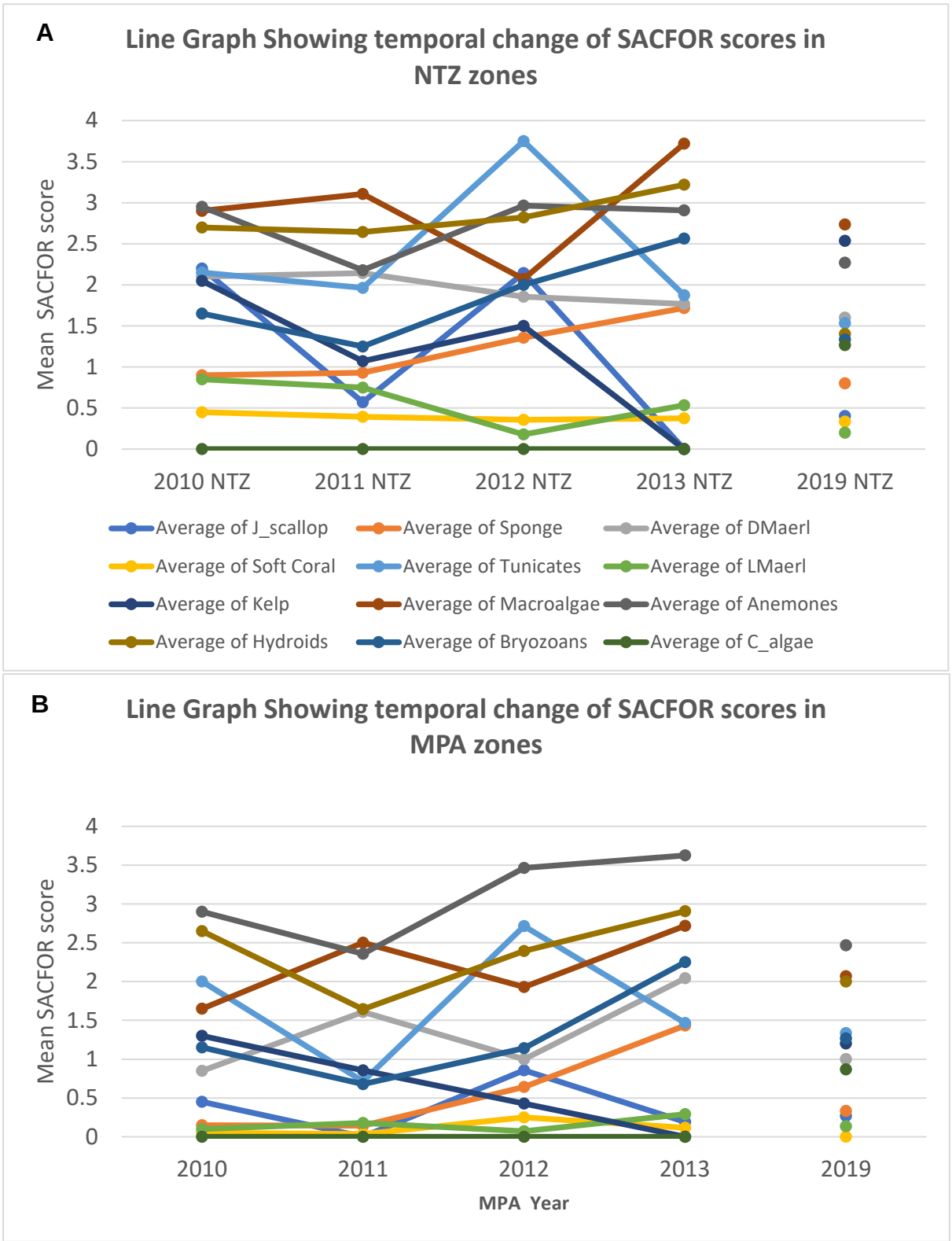

Figure 10a-b. Line graphs showing temporal change of mean SACFOR scores between 2019 data and previously collected data. Sourced from Howarth et al(., 2015). A depicts scores within the No Take Zone (NTZ) and B shows scores from the Marine Protected Area (MPA).

5. Discussion

5.1 Biodiversity

This study demonstrates that over time the Lamlash NTZ (No Take Zone) has changed in ecological diversity and density following almost a decade of protection. Results shows that the more recently designated MPA can still be considered as two separate zones in terms of biodiversity, however the increased density is found further away from the NTZ. Spatially, protected areas have a higher biodiversity and higher habitat assemblage than areas under full open access. The results generally show that with time and increased protection, biodiversity increases. This follows scientific consensus that MPAs increase biodiversity (Hilborn et al., 2004).

The only phylum to decline was the *Echinodermata* which was attributed to the decline in feather stars (*Crinodia*) and brittle stars species (*Amphipholis squamata and Ophiothrix fragilis*), who appeared in great densities from 2011 onwards. Only 6 *Crinodia* individuals were observed throughout the study, of which 2 (found on the same site) were in the MPA and NTZ which Howarth et al studied (2015). The cause of this is unclear, and was beyond the remit of the study. Cushion stars (*Porania pulvillus)* and spiny starfish (*Marthasterias glacialis*) can be considered stable as their numbers were still two of the 10 most dense species (Figure 8a). Brittle stars were not recorded numerically, which therefore limits comparison, as this species had previously been within the highest densities of all epifauna. This was due to some sites being so dense it was impossible to count all brittle starts along with all other species, within diving decompression limits for air.

Decompression limits for air was also an issue for deeper sites, as divers were typically limited to 26 minutes bottom time (Loske, 2013), which was often less due to time required for moving up and down the line.

Densities of hermit crabs are also likely to be significantly higher than accounted for within this study. This is due to a mis-identification of Tower shells (*Turritella communis*) which were likely to be inhabited by juvenile hermit crabs, and not tower shells themselves as this species burrows within the ground (Naylor., 2011. P136).

Juvenile cod (*Gadus morhua*) have maintained their increased densities, not only within the NTZ but are also now found in high densities in the Far MPA (Figures 4 and 5). This is important as they are highly migratory (Breen et al., 2015) and the South Arran MPA could be an important nursery considering its position within the Firth of Clyde and Scotland (Gibb et al., 2007). Their increased densities within the NTZ and MPA could also be down to increased densities of Kelp, which was the only habitat to increase from data collected by Howarth (et al., 2015). Kelp is also associated as a key habitat for juveniles, including cod, which could help explain juvenile cod rise (Gotceitas et al., 1995, Cote et al., 2001). Other previously commercial species were rarely seen, with only a handful of juvenile herring (*Clupea harengus*) spotted. Unlike previous studies within the Lamlash NTZ, no whiting or mackerel were spotted whilst doing UVCs (Stark et al., 2015, Howarth et al., 2015, Howarth et al., 2015). Whiting (*Merlangius merlangus*) have also been claimed to be at a competitive advantage, however this study would indicate otherwise (Elliott et al., 2018). This could either be coincidence, as they were typically seen once or twice in large schools, or down to poor levels of visibility.

An unexpected result was observed was that the Far MPA had the highest diversity indices, and not the NTZ. The NTZ was expected to yield the highest biodiversity as it is highly protected, and for a long time which are two factors key to successful MPAs (Edgar et al., 2014). This is perhaps due to dredgers targeting near the NTZ due to its historic abundance meaning the Far MPA may not have been dredged to the same intensity in recent years allowing recovery to begin sooner (Thurstan and Roberts., 2010, Mcintyre et al., 2012). Furthermore, the NTZ is a small sample area and therefore any change within this zone will have a greater impact upon the overall biodiversity than of the Far MPA. Size is also attributed to successful MPAs, as a larger MPA will be more resilient (Garcia-Rubies et al., 2013, Roberts., 2005, Kerr and Deguise., 2004). It is therefore more applicable to compare the Far MPA to previous studies done on the same sites such as in Stark et al (2015) however this was outside the remit of this study.

Although there was variation observed within ANOVAs of the biodiversity indices, none of the results were significant. This is perhaps down to the type of tests done resulting in type 2 error. Shannon-weiner test is dependent upon diversity, however there is a

small range in species richness there (2.7) which would suggest a relatively similar assemblage found within each region. However, there was a wide range of species observed (73) over all sites and with temporal comparisons it is evident certain species are in higher abundances in certain zones. For example, king scallops (*Pecten maximus*) are found in higher abundance within the NTZ and MPA than out (James et al., NP). This trend is similar for decorator crabs (Figure 8A) and inverse for keel worms (8B). It could be that high densities of certain species are seen in certain regions (protection level or substrates) and are therefore giving the appearance of similarity when there is difference. It is therefore recommended to run Generalised Linear Models (GLMSs) for each of the top 10 species to investigate this hypothesis and see if it is statistically significant that their distributions vary die to certain environmental parameters.

Howarth et al (2015) noted within his data that results on diversity of sessile species were insignificant, but this could be perhaps down to small sample size within classes. For example, the substrate maerl was recorded at only 4 sites. This will be hard to prove, as the NTZ is a small area (<3km^2) meaning that almost all of it would need to be surveyed to provide an adequate sample size. This is backed up by the Analysis of Similarity (ANOSIM) conducted for species abundance (see appendices), where results showed high significance but low r^2 values.

It may therefore be relevant to conduct independent GLMs for some of the most abundant species to see whether their distribution can be accounted for within particular zones or substrates. This was outside of the study predominantly because of time constraints.

5.2 SACFOR

From a temporal point of view, SACFOR results need to be viewed with caution. Firstly, there is large coverage differences between each numerical value, so a mean average can represent a large variation in coverage between each protected region. SACFOR has been described as “semi-quantitative” and can carry a lot of observer bias (Ware and Meadows., 2012). Virtually all results reveal a lower habitat score which suggests that habitat has degraded. However, this is more likely from differing standards between current researchers to previous. This is due to the difficulty in trying to

quantify a 100m^2 rather than 1 or 2m^2 area, which is typically used to quantify habitats along a transect. A 1m^2 area can be easily be visualised, and photographs can be taken, however it is not possible to do this across a whole transect without being very time consuming, both in and ex situ. This is likely, as Urchins (*Echinus esculentus*) and Juvenile Cod (*Gadus morhua*), both species which are reliant upon the substrate for habitat and food (Bonsdorff and Vahl., 1982), were found to have increased in densities.

One substrate which was of particular interest was Bryozoan. It had been observed that Monkey puzzle bryozoan (*Omalosecosa ramulosa*) had recently appeared in large abundance. This species made up the majority of SACFOR bryozoan coverage and therefore could be crucial to recovery due to its complex structure, making it ideal for habitats. There is little literature about this species, however as it is complex in shape it could be ideal for habitats for species such as juvenile scallops and small invertebrates (Wood et al., 2012). What appears especially unusual is the density and size of the colonies within Arran. Literature suggests the maximum size is 4mm (Rouse., 2011) and they dominate in reefs which are bare or artificial (Hiscock et al., 2010).

From this study it was found in larger sizes colonies, greater than 4cm. This species will need to be observed carefully as it clearly has a faster growth rate than maerl which is approximately 1mm per year in a healthy reef (Wilson et al., 2004). Future management may need to reduce monkey puzzle bryozoan to ensure the remains of the maerl beds are not lost via competition.

6. Conclusion

This research comes at an important time, not only as it is now over a decade since the initial implementation, but because the whole of the United Kingdom is looking to expand and improve MPAs in general. As one of only 4 NTZs around the mainland of the UK, the results are therefore important to understand the successes and limitations of NTZs which may be unique within the UK. Managing fishing pressures is also important due to the uncertainty of marine management in the forthcoming decade, with regards to Britain's withdrawal from the EU. Although highly variable, results

suggest positive trends in biodiversity. The NTZ has been successful in its implementation and will hopefully result in increased biodiversity for the wider region.

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8. Appendix

Table 1. Taxanomic species and count for every species counted during 2019 surveys. * denotes juvenile species only. ** denotes to family level *** denotes difference was decided by presence/absence of shell **** was counted as part of the SACFOR scale.

Taxanomic Phyla	Common Name	Latin Name	Count
Arthropoda	Long-clawed squat lobster	*Munida rugosa*	330
	Harbour crab	*Liocarcinus depurator*	181
	Common hermit crab	*Pagurus bernhardus*	682
	Small spider crab	*Inachus spp*	61
	Edible crab	*Cancer pagurus*	60
	Brown Shrimp	*Crangon crangon*	1
	Velvet swimmer crab	*Necora puber*	14
	Decorator crab	*Majoidea***	339
	Shore crab	*Carcinus maenas*	58
	Prawn	*Dendrobranchiata***	9
	Spiny Squat lobster	*Galathea strigosa*	7
	Scampi	*(Nephrops nephrops)*	1
Echinodermata	Red cushion star	*Porania pulvillus*	405
	Bloody henry starfish	*Henricia oculata*	46
	Common starfish	*Asterias rubens*	122
	Seven-armed starfish	*Luidia ciliaris*	78
	Spiny starfish	*Marthasterias glacialis*	240
	Common sea urchin	*Echinus esculentus*	155
	Sand sea star	*Astropecten irregularis*	92
	Sunstar	*Crossaster papposus and Solaster endeca*	61
	Brittle Star***	*Ophiura ophiura , Ophiocomina nigra and Ophiothrix fragilis*	NC
	Feather Star	*Crinoidea***	50
	Sea cucumber	*Holothuroidea***	6
Chordata	Cod*	*Gadus gadus*	331
	Haddock*	*Melanogrammus aeglefinus*	50
	Goldsinny wrasse	*Ctenolabrus rupestris*	64
	Two-spotted goby	*Gobiusculus flavescens*	9
	Dragonet	*Callionymus lyra*	31
	Plaice	*Pleuronectes platessa*	1
	Cuckoo wrasse	*Labrus mixtus*	1
	Greater pipefish	*Syngnathus acus*	9
	Lemon sole	*Microstomus kitt*	1
	Long spined scorpion	*Taurulus bubalis*	11

	fish		
	Dogfish	*Scyliorhinus canicula*	7
	Sand goby	*Pomatoschistus minutu*	23
	Juvenile fish (unidentified)	NA	25
	Dab	*Limanda limanda*	20
	Leopard goby	*Thorogobius ephippiatu*	18
	Gurnard (tub)	*Chelidonichthys lucerna*	17
	Butterfish	*Pholis gunnellus*	16
	Ballan wrasse	*Labrus bergylta*	8
	Cling fish	*Gobiesocidae***	7
	Poor cod	*Trisopterus minutus*	6
	Gurnard (grey)	*Eutrigla gurnardus*	4
	Topknot	*Zeugopterus punctatus*	4
	Bib	*Trisopterus luscus*	3
	Shad	*Alosa sapidissima*	2
	Shanny	*Lipophrys pholis*	2
	Gurnard (red)	*Chelidonichthys cuculus*	1
	John Dory	*Zeus faber*	1
Mollusca	King Scallop	*Pecten maximus*	1022
	Queen Scallop	*Aequipecten opercularis*	133
	Curled Octopus	*Eledone cirrhosa*	7
	Nudibranch	*Nudibranchia***	248
	Snails	*Gastropoda****	117
	Razor shell	*Ensis arcuatus*	32
	Sea slug	*Gastrapoda ****	12
	Whelk	*Buccinidae **	3
	Cockel	*Cardiidae **	1
Annelida	Eyelash worm	*Myxicola infundibulum*	95
	Strawberry worm	*Actinia fragacea*	8
	Parchment worm	*Chaetopterus variopedatus*	548
	Keel worm	*Pomatoceros triqueter*	411
	Sand mason worm	*Lanice conchilega*	37
	Peacock worm	*Sabella pavonina*	26
	Candy stripe flat worm	*Prostheceraeus vittatus*	21
	Bootlace worm	*Lineus longissimus*	8
	Football jersey worm	*Tubulanus annulatus*	5
	Sea mouse	*Aphrodita aculeata*	3

Table 2. One way ANOVA of Biodiversity Indexes between protection types.

Index	DF	Sum sq	Mean Sq	F	P	
Shannons						
	3	0.01465	0.004885	1.175	0.329	
	51	0.20781	0.004156			
Species Richness						
	3	26.7	8.904	0.652	0.585	
	51	696.6	13.659			
Total Richness						
	3	21648	7216	2.702	0.0552	
	51	136223	2671			

Table 3. Analysis of Similarity (ANOSIM) between different levels of protection. Number of permutations = 999

Groups	R^2 Value	P Value Level %	Actual Permutations	Number >= Permutations	Observed
NTZ, NMPA	0.181	0.6	77558760	999	5
NTZ, FMPA	0.132	1	77558760	999	9
NTZ, OUT	0.213	1	3268760	999	9
NMPA, FMPA	0.026	23.7	77558760	999	236
NMPA, OUT	0.013	35.3	3268760	999	352
FMPA, OUT	-0.006	51.2	3268760	999	511

Table 4. Similarities of Percentages (SIMPER) for each Protection level using a total of SACFOR scores.

Group In					
Average similarity: 53.63					
Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Kelp	2.53	10.15	2.48	18.93	18.93
Macro	2.73	9.01	1.36	16.8	35.73
Anem	2.27	8.88	1.59	16.55	52.28
Hyd	1.4	5.56	1.25	10.36	62.64
Squirts	1.53	5.5	1.09	10.26	72.9
Cor_algae	1.27	3.61	0.93	6.74	79.64
Bryo	1.33	3.35	0.94	6.24	85.88
Dmaerl	1.6	2.48	0.49	4.62	90.49
Group Near					
Average similarity: 53.75					
Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Anem	2.47	12.13	1.33	22.56	22.56
Macro	2.07	10.98	1.54	20.44	43
Hyd	2	9.95	1.44	18.52	61.51
Kelp	1.2	5.75	1.46	10.71	72.22
Squirts	1.33	5.56	1.16	10.34	82.56
Bryo	1.27	2.68	0.58	4.98	87.54
Cor_algae	0.87	2.1	0.57	3.91	91.45
Group Far					
Average similarity: 50.56					
Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Anem	2.13	8.34	1.58	16.49	16.49
Bryo	2.33	7.57	1.21	14.97	31.47
Squirts	1.87	6.64	1.77	13.14	44.6
Hyd	1.8	5.89	1.38	11.65	56.25
Macro	2.13	5.89	1.27	11.65	67.9
Cor_algae	1.4	3.12	0.79	6.17	81.65
Kelp	1.47	3.01	0.78	5.96	87.61
Sponge	1.13	3	0.96	5.92	93.53
Group Out					
Average similarity: 54.44					
Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Anem	1.9	10.64	1.48	19.55	19.55
Squirts	1.8	8.34	1.17	15.32	34.87
Kelp	1.4	7.93	1.72	14.57	49.44
Hyd	1.6	7.79	1.66	14.3	63.74
Bryo	1.5	7.23	1.65	13.27	77.01
Sponge	1.2	5.84	1.08	10.72	87.73