The recovery of the commercially valuable scallop species, Pecten maximus, under different forms of protection around the Isle of Arran

Dissertation is submitted in part fulfilment of the MSc in Marine Environmental Management, University of York

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II. Contents

I. Acknowledgements i
II. Contents ii
III. List of Figures iii
IV. List of Tables iv
V. List of Plates v
1.0 Introduction 1
1.1 Marine Protected Areas 1
1.2 Importance of Study 3
1.3 Aims 4
2.0 Materials and Methods 5
2.1 Study Species 5
2.2 Study Site 5
2.2.1 Exploitation of the Clyde 7
2.3 SCUBA Diving Surveys 7
2.4 Data Analysis 12
3.0 Results 14
3.1 King Scallop Densities 14
3.2 Juvenile Scallop Densities 16
3.3 Size and Age comparisons 19
3.4 Exploitable and Reproductive Biomass 22
4.0 Discussion 26
4.1 Limitations 29
4.2 Further Work and Recommendations 30
5.0 Conclusion 31
6.0 References 32
7.0 Appendix 39

III. List of Figures

Figure 1. Map of Arran with layers of protection……6

Figure 2. Scallop measurements……11

Figure 3. King scallop density over time……14

Figure 4. King scallop density in 2019 between sites……15

Figure 5. Far-Control king scallop density over time……15

Figure 6. Juvenile scallop abundance over time……16

Figure 7. Abundance of juvenile scallops compared to A) Bryozoan and B) Macroalgae abundances……18

Figure 8. Juvenile scallop abundance between sites in 2019……19

Figure 9. Legal and not legal size class of king scallops in 2019……20

Figure 10. Size structure of king scallops in 2019……21

Figure 11. Age structure of king Scallops in 2019……21

Figure 12. Linear relationship between shell size and gonad size……22

Figure 13. Exploitable and reproductive biomass of king scallops over time……24

Figure 14. Exploitable and reproductive biomass of king scallops in 2019……25

IV. List of Tables

Table 1. Dates and areas surveyed prior to 2019……..8

Table 2. SACFOR scale quantified……..10

Table 3. Two-way ANOVA output table showing juvenile scallop abundances between year and type of protection……16

Table 4. Minimum adequate model from GLM on juvenile scallops……17

Table 5. Comparison of reproductive and exploitable biomass between sites in 2019……23

Table 6. Limitations……29

Table 7. Further work and recommendations……30

V. List of Plates

Plate 1. Diver conducting video surveys along transect.....9

Plate 2. Diver completing Underwater Visual Census (UVC) survey 9

Plate 3. Diver collecting first ten scallops along the transect. 10

Plate 4. Scallop measuring equipment used on the boat to record sizes of king scallops 11

VI. List of Abbreviations

EBFM – Ecosystem Based Fisheries Management

HPMAs – Highly Protected Marine Areas

King Scallop – *Pecten maximus*

MLS – Minimum Landing Size

Monkey Puzzle Bryozoan – *Omalosecosa ramulosa*

MPA(s) – Marine Protected Area(s)

NTZ(s) – No-Take Zone(s)

Queen Scallop – *Aequipecten opercularis*

TAC – Total Allowable Catch

VII. Abstract

This study assessed the interactions of a Marine Protected Area (MPA) and a No-Take Zone (NTZ) in Lamlash Bay, the Isle of Arran, Scotland, in the recovery of the commercially valuable king scallop (*Pecten maximus*). Changes in abundance, size and reproductive potential in king scallops were assessed over time. This research built on data collected by annual dive surveys from 2010-2015. Now, after ten years of the NTZ being in place (2008), and three years since the MPA was designated (2016), new data were collected in 2019 to compare the differences in densities and population structure. Fifty-five underwater SCUBA survey transects were completed within the NTZ, the MPA and in Fished areas open to scallop dredging. All scallops were counted on each transect, the first ten were aged and measured, and a subsample were collected for dissection to assess exploitable and reproductive biomass. King scallop density was 63% greater (~23 scallops/100m^2) than in the Fished areas (~8.6/100m^2) and 6% greater than at the Far-Control sites, south of the MPA (~16.5/100m^2). King scallop densities above the Minimum Landing Size (MLS) within the NTZ were significantly higher than in the Fished area. A dramatic increase of king scallops was found in the NTZ with a significant increase of ~3.4 fold from 2013-2019; in the MPA Near-Control site by ~4.4 fold since 2013; and a significant ~6.2 fold increase within the Far-Control sites in the MPA, since 2014. Reproductive biomass was significantly higher in the NTZ than in the Fished area. A generalised linear model showed that juvenile scallop abundances were affiliated with the presence of bryozoans and macroalgae. With increasing level of protection, scallops were older and larger, and there was ~8x more gonad biomass in the NTZ than the Fished sites in 2019. With a reduction in fishing pressure in the MPA and NTZ, scallop populations have been able to recover and grow to larger sizes. With increased size, scallops have larger gonads, thus more gametes are released in spawning seasons. This suggests protected areas are a key tool for implementing ecosystem-based management, which is important for the recovery of benthic species. If properly monitored and managed, this method can also provide a contribution to fishery landings from larvae exports to surrounding areas.

Scallops, No-Take Zone, Marine Protected Area, Isle of Arran, Recovery, Scallop dredging, Reproductive potential, SCUBA

1.0 Introduction

1.1 Marine Protected Areas

With the continued rise in human populations worldwide, there has been an increase in global pressure on the ocean's resources, and a subsequent demand for seafood as the density of people living by the coastline is significantly higher than at non-coastal locations (Neumann et al., 2015). Consequently, there has been a shift in diets of the consumer due to the reduction in apex predator species, by fishing down food chains, shifting the focus towards smaller marine invertebrates such as scallops (Strong & Frank, 2010). Improved technologies such as sonar have made it possible to locate marine fish/shellfish communities easily, thus increasing efficiency of harvesting to potentially unsustainable limits if not properly managed (Thurstan & Roberts, 2010). This has increased the profitability of scallop dredging, explaining the rise over the past few decades, particularly in the use of the Newhaven dredge, which is the most common method for capturing king scallops (Szostek et al., 2015). Dredging is damaging to habitat complexity as the physical impacts plough the seabed, thus disrupting nursery habitats, lowering productivity and causing fragmentation of flora communities such as hydroids and maerl beds (Boulcott & Howell, 2011). Therefore, there is requirement for more successful sustainable management, interlinking different forms of protection to balance extractive methods of fishing with conservation efforts so that all stakeholders can benefit from a common resource (Jentoft et al., 2007). Habitats then have the opportunity to recover and continue to provide ecosystem services, including acting as nursery grounds for juvenile organisms and supporting productive fisheries as biodiversity increases (Halpern & Warner, 2002). One way to achieve this balance is through the implementation of protected areas, a key tool for Ecosystem-Based Fisheries Management (EBFM), (Pikitch et al., 2004). It is a crucial step towards sustainably managing fisheries, as the complexity and quality of habitats reflect the diversity and abundance of species it provides for (Hall & Mainprize, 2004).

The formation of Marine Protected Areas (MPAs) are essential for efficient spatial management, providing socio-economic and ecological benefits. For example, there is possible larval export to surrounding areas from protected sites including No-Take Zones

(NTZs) and MPAs, whereby gametes are exported in the water column through hydrological processes. This provides an balance with areas that are open to partial or all fishing, as fisheries can then profit from the influx (Halpern et al., 2005; Beukers-Stewart et al., 2005). Additionally, protection can encourage an increase in biodiversity, abundance of species and age structure complexity within populations; avoiding age-truncation of populations and shifting baselines (Secor et al., 2015; Howarth et al., 2011). Under protection, marine organisms are given the opportunity to develop an increased longevity, grow to larger sizes and increase levels of reproductive output (Howarth et al., 2015; Roberts, 2012). These protected areas can range from permanent closures of fishing, to prohibiting certain methods such as scallop dredging (Sciberras et al., 2015).

However, most MPAs around the UK come with very little monitoring or successful management, leading to a system of paper parks, and studies on monitoring the long-term impacts of marine protection around the UK are limited (O'Leary et al., 2016). Furthermore, only 2% of global oceans are strongly or fully protected (Sala et al., 2018). Dureuil et al. (2018) found that within MPAs across Europe, there were higher events of trawling and less species such as sharks and skates present than in areas fully open to fishing. These findings spark concern for the implementation of future MPAs and the significance of their protection as there has been a rapid increase in the demand for more marine reserves in recent years. This concern is exacerbated by the rising global concern for the decline in quality of the natural marine environment. For example, it is faced with international issues such as overfishing, climate change and habitat degradation, leading to impacts such as ocean acidification (Sciberras et al., 2015). Additionally, only 1% of the world's seas are safe from all bottom-trawling fishing gear, suggesting that even within the worldwide 2% of oceans under high protection, damaging anthropogenic fishing still occurs (Solandt, 2018). Henceforth, it is essential that long-term effects of marine protection are studied to fully understand the different approaches in developing the most effective methodologies to achieving successful EBFM. It is important to ensure the spatial distribution of protection covers areas that are damaged as well as protecting the remaining parts of an ecosystem that are flourishing (Mangi et al., 2011).

It is therefore vital that the performances of different types of MPAs are compared and monitored to ensure they are having an effect, and that illegal activity is being prevented (Jentoft et al., 2007). This is why the Isle of Arran provides a unique opportunity to address these research questions as it supports a range of protection types and has a pre-existing dataset since 2010. Additionally, this is a well-timed study due to the recent UK governmental review of Highly Protected Marine Areas (HPMAs), as well as the implementation of 41 new marine conservation zones within the UK being created (GOV.UK, 2019b). This builds on the Scottish Government designating 30 nature conservation MPAs in 2014 to protect and recover key species (Scottish Wildlife Trust, n.d.). The HPMAs include all anthropogenic activity to be prohibited and they would be part of wider global picture, contributing to the aim of 30% protection of the world's oceans by 2030 (GOV.UK, 2019a; O'Leary et al., 2016). In Scotland, more recently, a list of Priority Marine Species (PMS) has been created to highlight the key species and habitats that need protection and a series of four new MPAs are being proposed to add to the already 22% of the protected network already in place (Scottish Government, 2019). These PMS include vulnerable habitats such as maerl beds and are important to protect following a long history of habitat degradation from overfishing.

1.2 Importance of Study

This study comes at a time of importance as UK shellfish fisheries are expanding, generating £74.0 million in landings in 2017, and are the third most valuable marine species in the UK, second to mackerel and nephrops (MMO, 2017; Szostek et al., 2017). UK landings of king scallops are higher than queen scallops, accounting for 75%, proving to be of great economic value for fisheries in the British Isles (MMO, 2015; Beukers-Stewart & Beukers-Stewart, 2009). EU technical conservation rules (EC, 1998) dictate Scottish shellfish fisheries, where measures such as Minimum Landing Sizes (MLS) are in place to avoid extracting juveniles under the Orders under the Sea Fisheries Act 1967 and the Inshore Fishing (Scotland) Act 1984 (Miethe et al., 2016).

Lamlash Bay, the only NTZ in Scotland, is one of four in the UK, including Flamborough Head in East Yorkshire, the Medway Estuary in Essex, and one surrounding Lundy Island (Hoskin et al., 2011; Solandt & Lightfoot, 2010). The community-led management in Arran is an example

of a bottom-up technique and is the only well studied NTZ in the UK. It is unique through its comparison of three management approaches in the same area for two commercially valuable scallops in the UK. These include the king (*Pecten maximus*) and queen scallop (*Aequipecten opercularis*), however this study focuses on king scallops (Marine Scotland, 2019). The areas compared include a NTZ, MPA, and a traditionally managed area that is fished, with national limits of certain landing sizes and limits on dredge numbers with a weekend ban, yet no quotas or restrictions on total effort for scallops. This highlights the capabilities of full marine protection compared to less protected/unprotected areas. These data collected could inform Governmental policy when setting regulations for other places that need to be protected and can act as a control site for such studies in the future.

Building on baseline data from previous years, a continuous assessment of the seabed is taking place in and around Lamlash Bay. This is vital for encouraging other studies to be completed in similar areas, creating a knowledge base of how scallop populations react to the absence of destructive fishing pressure. Few areas have been studied where different forms of protection are close and working together, making Arran very suitable for research.

1.3 Aims

1) Determine whether there is a difference in adult and juvenile scallop densities between the different areas of protection as well as with the Fished area.
2) Assess the size structure of king scallops between sites to see if there are any significant differences and to determine any trends.
3) Investigate the exploitable and reproductive biomass of king scallops.
4) Detect if the reproductive potential of king scallops is significantly higher in the NTZ than in the MPA or Fished sites, to highlight the benefits of HPMRs.

2.0 Materials and Methods

2.1 Study Species

In Scotland, the king scallop is the second most valuable shellfish species, growing up to 17cm, supporting valuable commercial fisheries, and according to the Scottish government, currently meeting existing demands (Scottish Government, 2018). However, it is important to monitor their population structures as a reduction in their abundance could lead to commercial decline. As well as their commercial value, scallops play a vital role within the benthic complex community, through the provisioning of ecosystem services including carbon sequestration and water filtration (Zhou et al., 2006). The management of scallop populations in Scotland require a MLS, excluding the Irish sea and Shetland, of 105mm for king scallops under EU legislation. However, there are no Total Allowable Catches (TACs) or quotas, except for within the South Arran MPA (Barreto & Bailey, 2014). Scallops are relatively sedentary animals that prefer course sandy sediment or gravel, hence why the substrate types were recorded at each transect site for this study.

2.2 Study Site

The Isle of Arran is located in the Firth of Clyde on the west coast of Scotland. Lamlash Bay is situated on the south-east of Arran and is Scotland's first NTZ marine reserve, created to benefit both conservation and the fishing industry by aiding the recovery of habitats and the animals that rely on them (Boulcott et al., 2012). This NTZ spans 2.67 km^2, containing depths of 0-29 m (Howarth et al., 2015). Surrounding this area, there is an MPA, which incorporates different areas of protection, excluding certain fishing techniques including creeling and scallop dredging (Stewart et al., in press). The Community of Arran Seabed Trust (COAST) implemented the NTZ in 2008, excluding all extractive activity under the Inshore Fishing Scotland Act (1984), (Howarth et al., 2015). This emerged after campaigns for better management of local fisheries, and post-designation, the surrounding MPA was introduced in 2016, encompassing a 279.96 km^2 area (COAST, 2019; Figure 1).

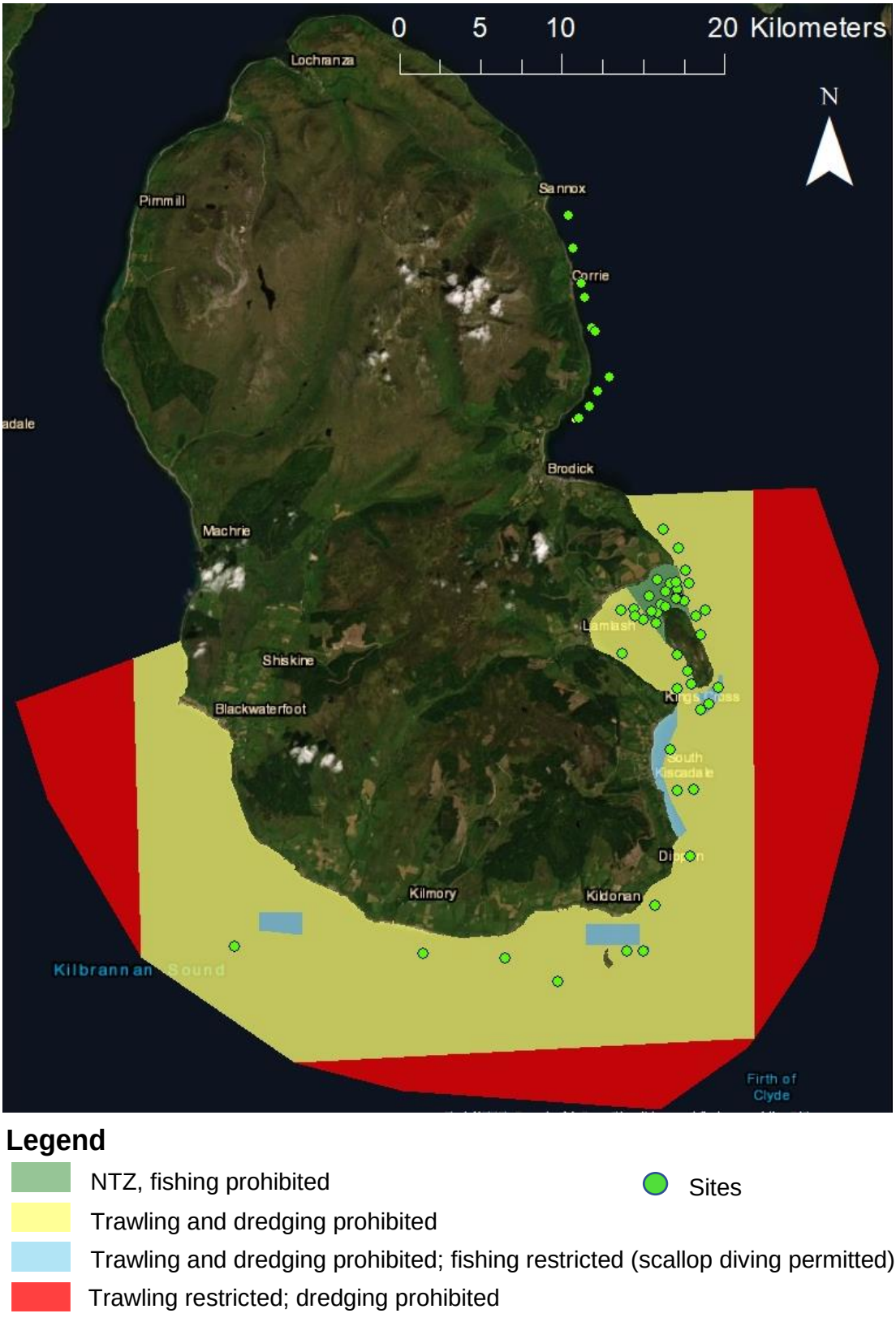

Figure 1. The Isle of Arran with all protection layers, presented on ArcMap. The red, yellow and blue make up the south Arran Marine Protected Area (MPA) and the green represents the NTZ to the north of the Holy Isle. The blue differs as there is an additional passive gear prohibition to avoid any contact with the seabed to protect Priority Marine Species (PMS) species such as maerl beds. In the outer three points of the red zone, some trawling is permitted with vessels less than 120 tonnes.

2.2.1 Exploitation of the Clyde

Historically, the Firth of Clyde was highly productive, supporting diverse fisheries such as turbot, cod and herring (Thurstan & Roberts, 2010). However, these fisheries have been degraded and exploited to an extent where they are no longer commercially fished (Christensen et al., 2003). A seasonal king scallop fishery in the Clyde began in the 1930s, which then progressed dramatically later in the 20th century (Bradshaw et al., 2002). This shellfish species is now exploited continually throughout the year, with dredging said to account for 95% of landings (Howarth et al., 2015; Barreto & Bailey, 2014).

2.3 SCUBA Diving Surveys

Data collection for this study was completed between July to August 2019, including a total of 55 research dives. These sites followed the same coordinates from previous years (2010-2015) to allow replicates to be completed, directly comparing similar underwater habitats (Howarth et al., 2015). This was ensured by recording underwater substrates and matching GPS coordinates by using two marker buoys per survey (Table 1; Appendix 1). These dive locations encompassed 15 points within the NTZ, 15 in the Near-Control site inside the MPA, 15 in the Far-Control sites within the MPA (Appendix 5). Additionally, 10 sites were created outside the protected areas on the east coast, in places open to fishing.

Table 1. Previous years of data collection and areas surveyed in the No-Take Zone (NTZ), Marine Protected Area (MPA) and additional sites this year in the Fished area.

Year	Areas Studied
2010	NTZ and outside before MPA (Near-Control)
2011	NTZ and outside before MPA (Near-Control)
2012	NTZ and outside before MPA (Near-Control)
2013	NTZ and outside before MPA (Near-Control)
2014	South Arran MPA (Far-Control)
2015	South Arran MPA (Far-Control)
2019	Replicated previous studies in areas: NTZ, MPA (Near-Control and Far-Control) and additionally new sites in a Fished area, north of protection on the east coast of Arran.

At each site, a 50-meter leaded transect line was placed across the seabed, following the benthic contours to ensure the depth did not fluctuate more than ~3m, with weighted ends and a corresponding marker buoy on each side, from which the coordinates were recorded. On average, two dives were completed each working day in a reverse profile order, occurring at depths $\leq$28m to avoid decompression stops.

The densities and population structure of king scallops were assessed as part of a larger programme of evaluating the effects of different management regimes around the Isle of Arran (Notley, 2019). Underwater Visual Census (UVC) and video recording surveys of the sea bed were completed to assess the dynamics of key benthic flora and fauna species, whilst tally-chart counts were also completed by the other diver of the mobile fauna and sessile life using underwater paper (Baker et al., 2016; Plates 1 & 2). The UVC surveying involved the use of a Super-abundant, Abundant, Common, Frequent, Occasional, Rare (SACFOR) scale to record abundances of habitats and juvenile scallop abundance (Appendix 2:A).

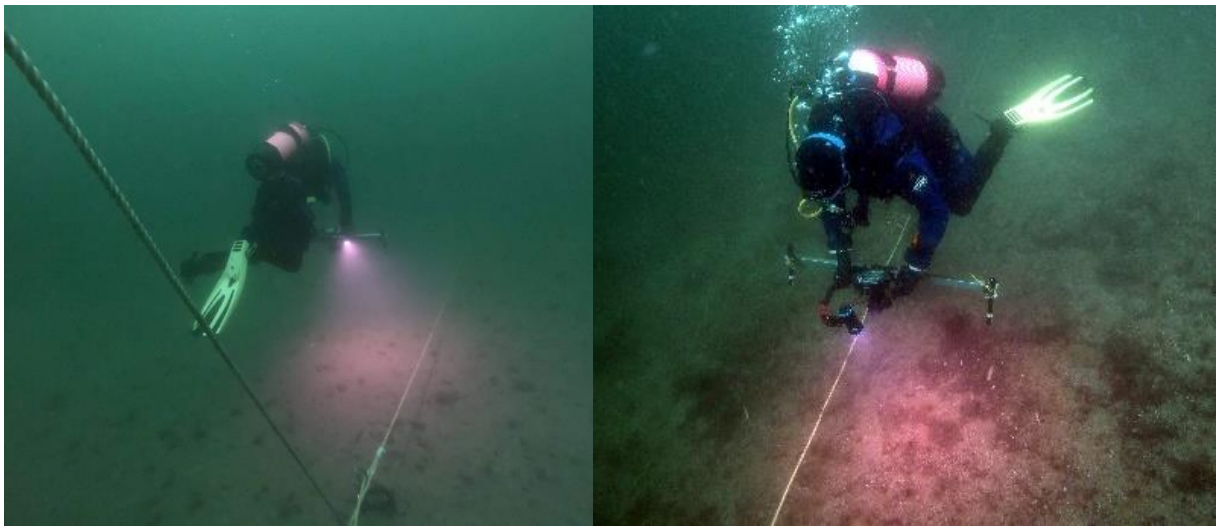

Plate 1. Diver conducting video surveys along transect survey (photo credit: Howard Wood, Community of Arran Seabed Trust).

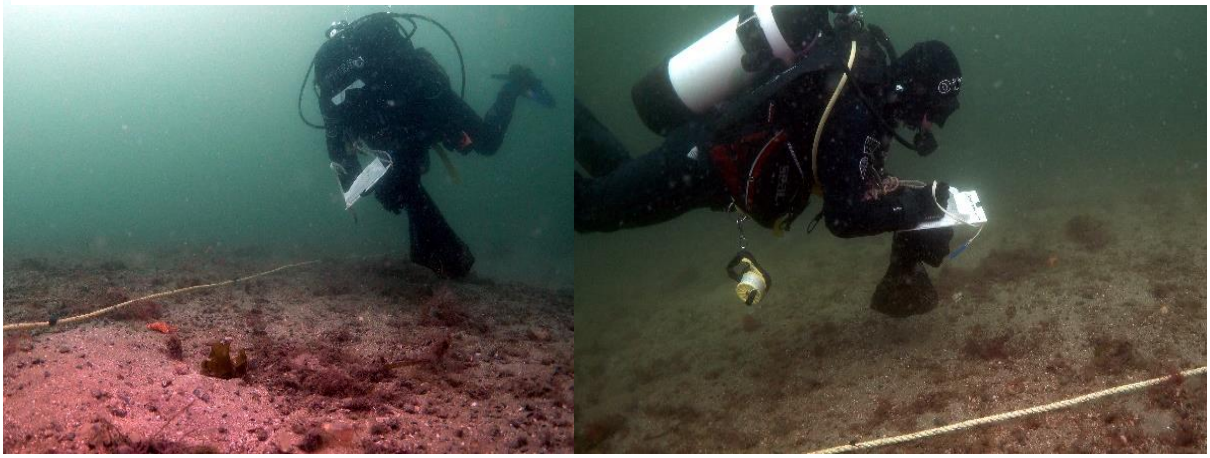

Plate 2. Diver completing Underwater Visual Census (UVC) survey (photo credit: Howard Wood, Community of Arran Seabed Trust).

King scallop counts were conducted along the transect line and the first ten scallops were collected into and brought to the surface where age and size estimates could be recorded (Plate 3). A subsample of king scallops was collected for dissection, and under a special permit, I could dissect 50 scallops from the NTZ and 100 from within the MPA. This made it possible to compare the reproductive output of individual scallops between areas. Scallops were sized and aged, with total tissue, muscle and gonad being weighed thereafter (Appendix 3). These measurements were important as the adductor muscle is the component most in demand commercially, as well as being important for scallops in avoiding predation; and the gonads indicate fecundity (Howarth et al., 2015).

Plate 3. Diver collecting first ten scallops along the transect survey (photo credit: Howard Wood, Community of Arran Seabed Trust).

I used the SACFOR scale to assess the number of juvenile scallops present at each dive site and quantified these data (Table 2). It is important to note that juvenile scallops could be either king or queen species as they cannot be identified at this stage underwater.

Table 2. The Super-abundant, Abundant, Common, Frequent, Occasional, Rare (SACFOR) scale quantified to match a numerical order before analysis could take place.

Score	Definition (SACFOR)
1	Rare
2	Occasional
3	Frequent
4	Common
5	Abundant
6	Super Abundant

The king scallop species were measured by their length (mm) on a measuring scale and data were recorded on the boat (Plate 4; Figure 2 Appendix 2:B).

Plate 4. Scallop measuring equipment used on the boat to record sizes of king scallops (photo credit: William Notley, University of York).

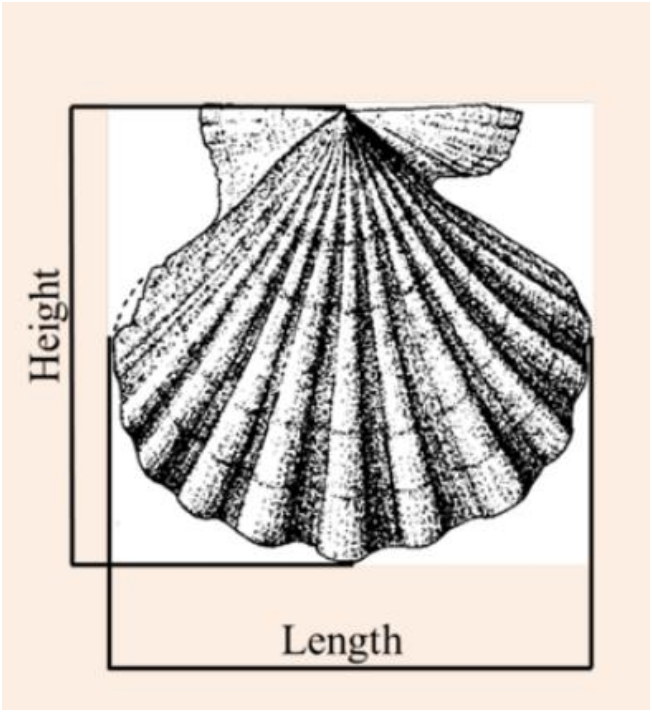

Figure 2. Diagram of a queen scallop illustrating how two different species are measured. King scallops are measured by their length, and queen scallops by their height (Berik et al., 2017).

2.4 Data Analysis

All data were assessed for normality by conducting Shapiro-Wilk normality tests, frequency distributions and establishing QQ plots using the statistical software RStudio. Non-parametric tests were used for data that could not be transformed. For all analysis, confidence levels were at 95% and significance values $\leq$0.05 were deemed statistically significant.

1. Density of K scallops

Differences in densities of adult king scallops from 2010-2019 were assessed. The non-parametric Mann–Whitney U test was used to identify if there were significant differences between the mean king scallop legal-sized densities from 2013 to 2019. The same test was used to detect differences in the NTZ compared to the Fished areas in 2019 and from 2014-2019 for the Further-Afield sites.

2. Juvenile Scallop Distribution

A two-way ANOVA was completed between 2010-2013 and 2019 data, to assess differences between the NTZ and the Near-Control over time. A post-hoc Tukey test was used to detect where the significance change existed. Kruskal-Wallace tests assessed if there were differences in juvenile abundance between sites in 2019. A Poisson Generalised Linear Model (GLM) investigated the relationship between ecological data and type of juvenile scallop abundance (Appendix 6).

3. Population Structure of king scallops

Age comparisons between the NTZ and Fished site were undertaken by a Mann-Whitney U test; size comparisons were conducted by the same test between 2010-2019 and 2013-2019; and it was additionally used to assess differences between the NTZ and Fished area in 2019.

4. Exploitable and Reproductive Biomass Data

Reproductive and exploitable biomass of king scallops were calculated through dissection data. Shell length and weight of exploitable (muscle + gonad) and reproductive (gonad) biomasses were plotted. The equations produced were applied to all scallops measured on each transect to assess the exploitable and reproductive biomass of king scallops per unit area. For Fished data, the Further-Afield equation was used; a conservative approach as until three years ago it was fished heavily and is most comparable.

I conducted Mann-Whitney U tests to assess differences in reproductive and exploitable biomass between 2013-2019 within the NTZ and at the Near-Control. A Kruskal-Wallis test assessed differences between the exploitable biomass at NTZ and Near-Control sites. A Mann-Whitney U test was used to investigate the differences in reproductive biomass between the NTZ and Fished areas as well as the NTZ and Near-Control. A linear relationship was plotted between length of king scallops and gonad size, by pooled data from all the sites except the Fished in 2019, providing a correlation coefficient and P-value. The 'size' variable had to be transformed.

3.0 Results

3.1 King Scallop Densities

Increased densities of king scallops were found over time in the NTZ with a significant increase of ~3.4 fold since 2013 (P<0.01), and in the MPA Near-Control site by ~4.4 fold since 2013 (P<0.01), (Figure 3). The density of king scallops was 63% higher in the NTZ (23/100m^2) than in the Fished sites (8.6/100m^2) when comparing legal scallop sizes (P<0.001), and 6% higher than in the Far-Control sites (16.5/100m^2) in 2019 (Figure 4). The density of king scallops was very similar between NTZ and Near-Control sites in 2019. A Mann-Whitney U test showed a significant a ~6.2 fold increase within the Far-Control sites in the MPA, since 2014 (P<0.01), (Figure 5).

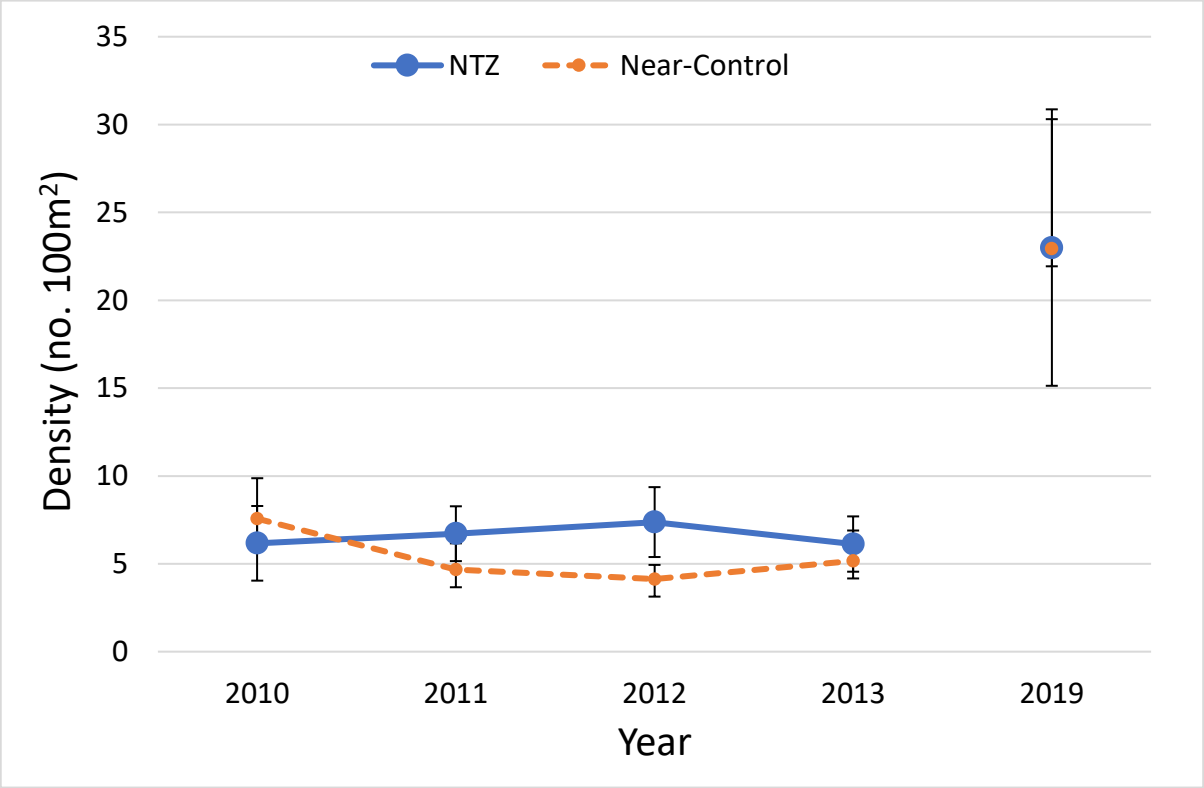

Figure 3. Mean density of king scallops in the No-Take Zone (NTZ) and at the Near-Control site in 2010, 2011, 2012, 2013 and 2019. Note that there is a 6-year gap from 2013-19. Error bars *represent ±1 SE.*

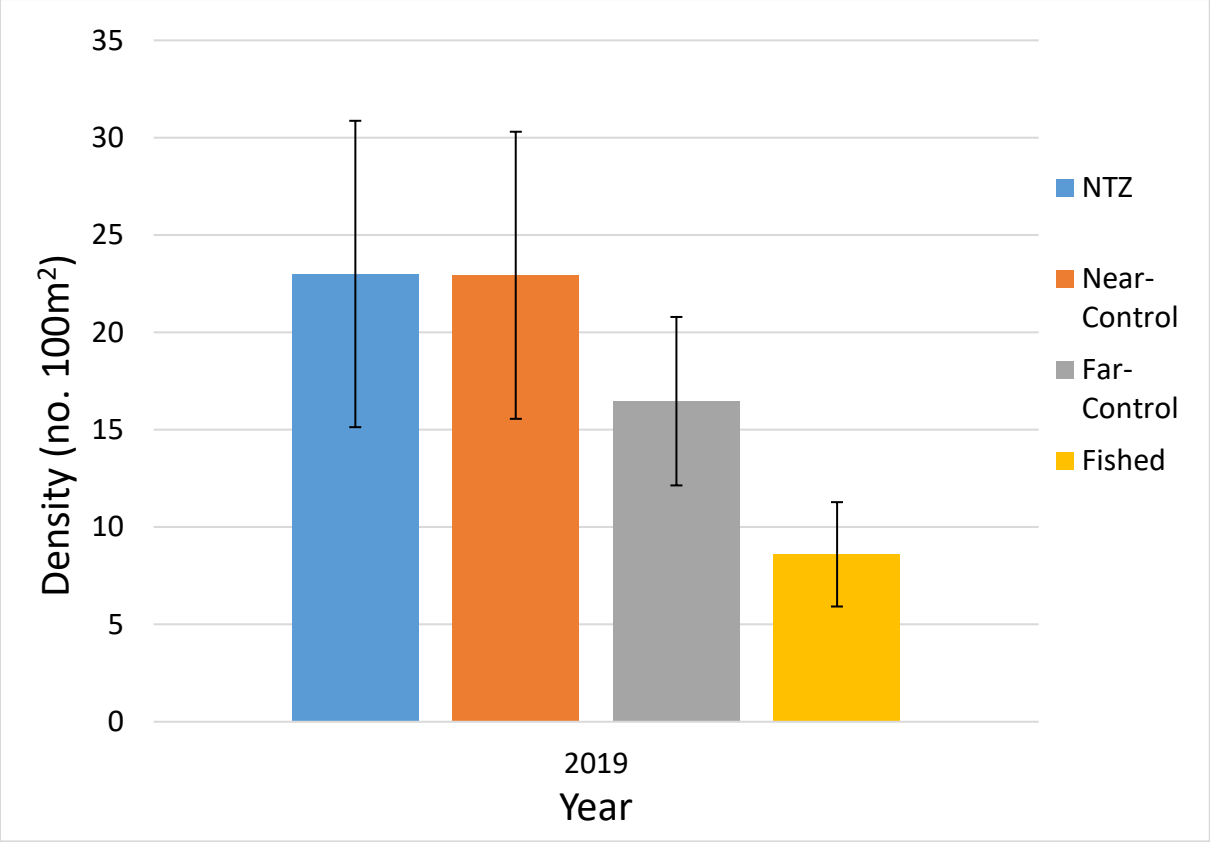

Figure 4. Mean king scallop density between the four sites assessed in 2019. No-Take Zone (NTZ): n=15, Near-Control: n= 15, Far-Control: n=15 Fished: n=10. Error bars represent ±1 SE.

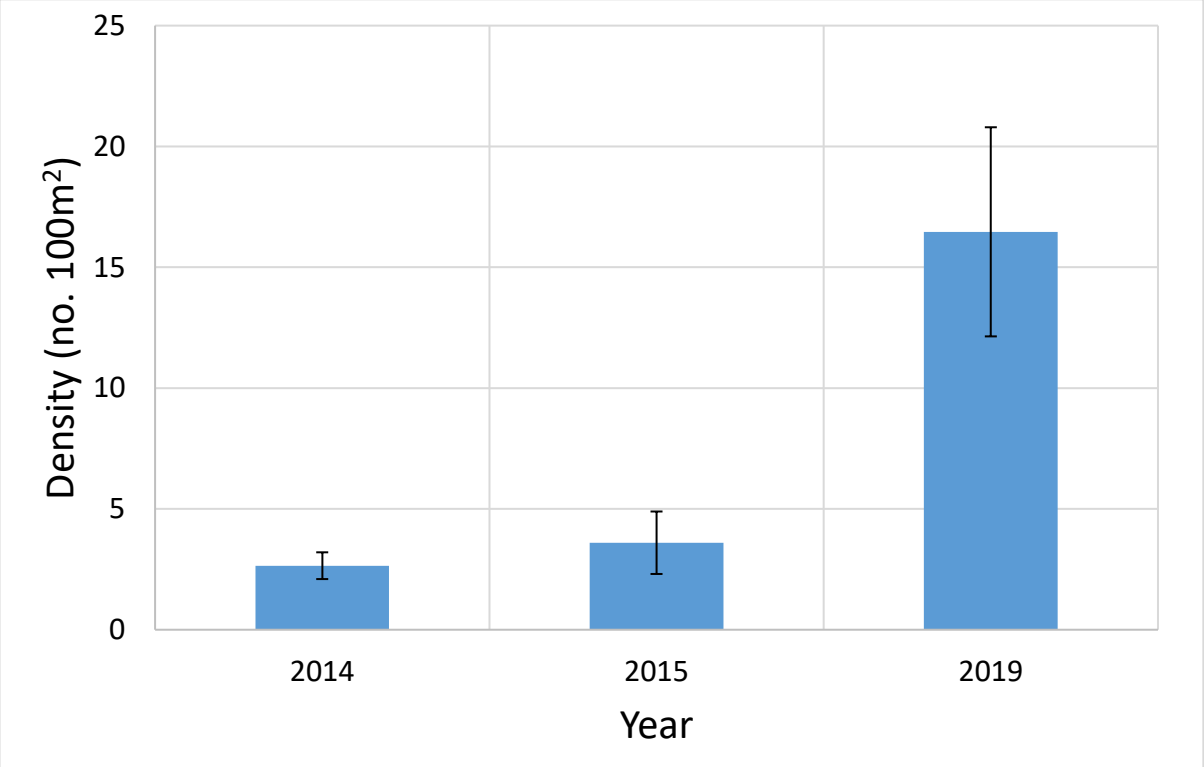

Figure 5. Far-Control mean densities of king scallops, comparison for 2014, 2015 and 2019. 2014: n=20; 2015: n=20; 2019: n=15. Note that there is a 4-year gap from 2013-19. Error bars represent ±1 SE.

3.2 Juvenile Scallop Densities

A Two-way ANOVA showed year, type of protection and their interaction to significantly affect the abundance of juvenile scallops (Table 3; Appendix 4: A). Juvenile scallops were significantly more abundant in the NTZ than in the Near-Control site for all years excluding 2013 and 2019. There were three sites where juvenile scallops were found in the MPA and none within the NTZ in 2013, and the presence of scallops were similarly balanced between sites in 2019. Juveniles have oscillated from 2010-2019, where the troughs of data have been in 2011, 2013 and 2019 (Figure 6).

Table 3. Two-way ANOVA showing the relationship of juvenile scallop abundances between years and within the No-Take Zone (NTZ) compared to in the Near-Control site. = significance.*

Test Variable	Sum Square	df	Mean Square	F	P
Year	48.82	4	12.204	8.040	<0.001*
Type of Protection	22.59	1	22.594	14.855	<0.001*
Year : Type of Protection	20.77	4	5.193	3.421	0.010*
Residuals	230.72	152	1.518		

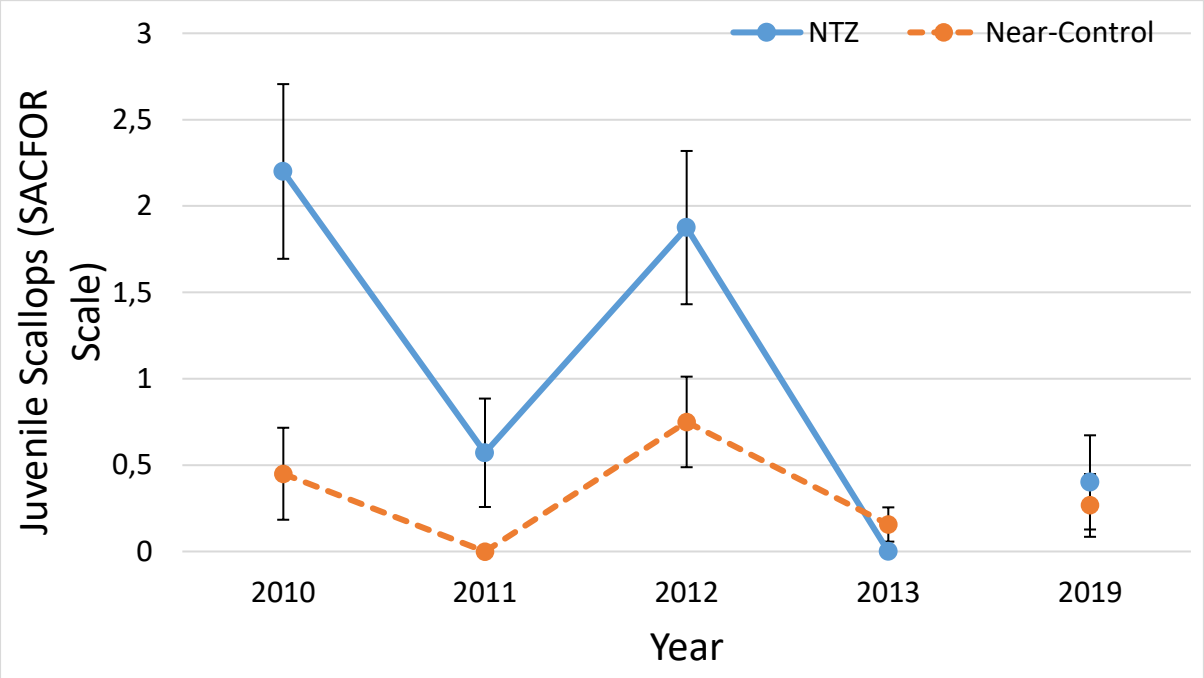

Figure 6. Juvenile scallop mean abundance in the No-Take Zone (NTZ) and in the Near-Control site from 2010-2019. Note that there is a 6-year gap from 2013-19. Error bars represent ±1 SE.

A GLM was created from a Poisson distribution to highlight that in 2019, presence of bryozoan and macroalgae most influenced the abundance of juvenile scallops over all sites in 2019 and correlated significantly (Table 4; Figure 7; Appendix 4: B). Multiple Kruskal-Wallace tests compared juvenile scallop abundance between sites in 2019, where there were no significant differences in all cases (P>0.05), (Figure 8).

*Table 4. The minimum adequate model chosen, and variables removed from models, from a backwards-forwards stepwise reduction process by a Poisson Generalised Linear Model to assess whether the ecological data from organisms and habitats determined the presence juvenile scallop, and which variables most reflected this. * = significance.*

Variable	SE	Z	P
Variables in chosen minimum adequate model			
Bryozoans	0.1313	3.247	0.001168*
Macroalgae	0.1258	2.470	0.013527*
Type of Protection	0.2245	0.817	0.413793
Variables removed from models			
Depth	0.05	-3.126	0.00177*
Live Maerl	0.61	-0.540	0.588965
Kelp	0.1303	3.395	0.000686*
Brittle Stars	0.11085	1.337	0.18108

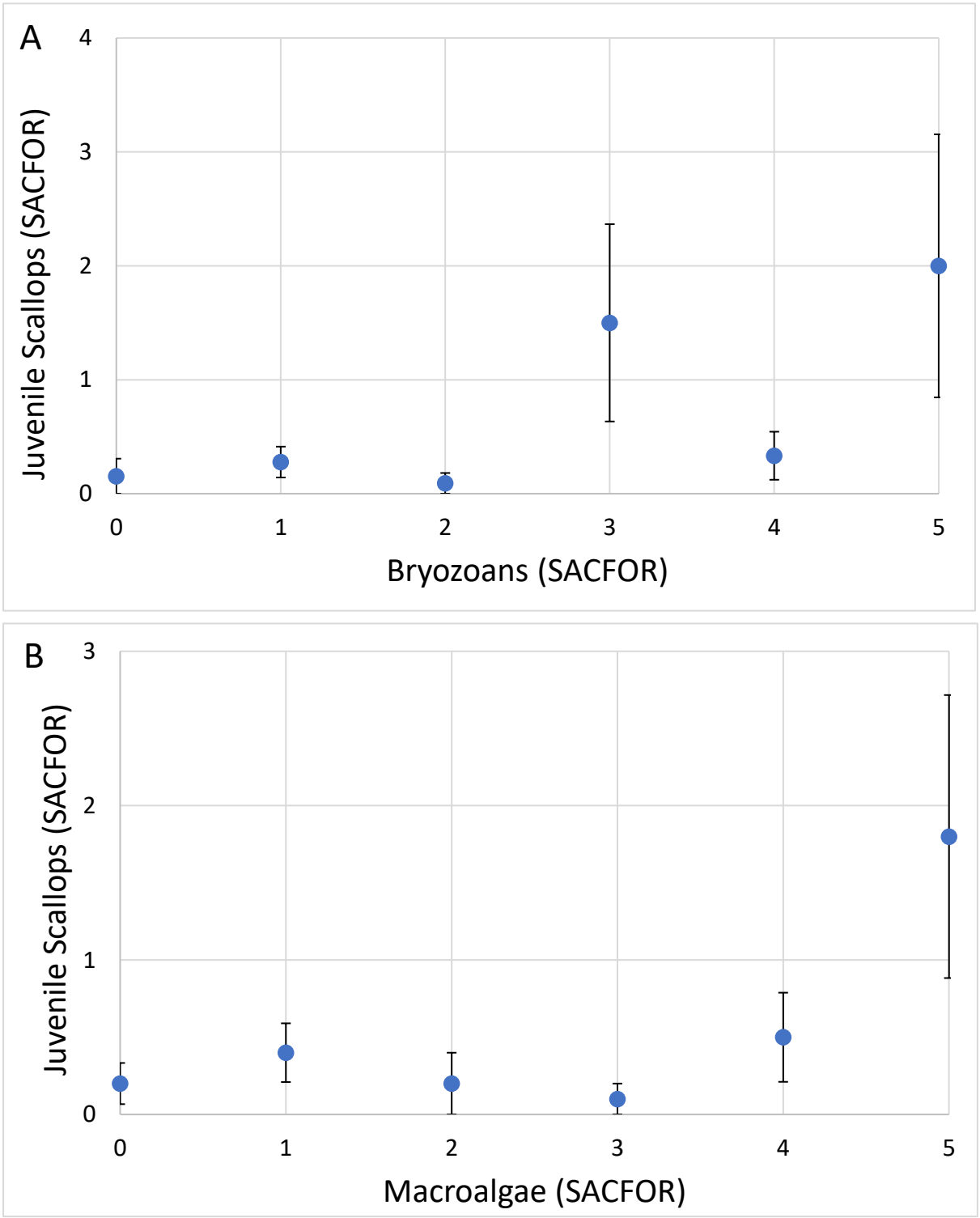

Figure 7. A) Mean abundance of juvenile scallops and their positive relationship with abundance of bryozoans in 2019; B) Mean abundance of juvenile scallops and their positive relationship with abundance of macroalgae in 2019. Error bars represent ±1 SE.

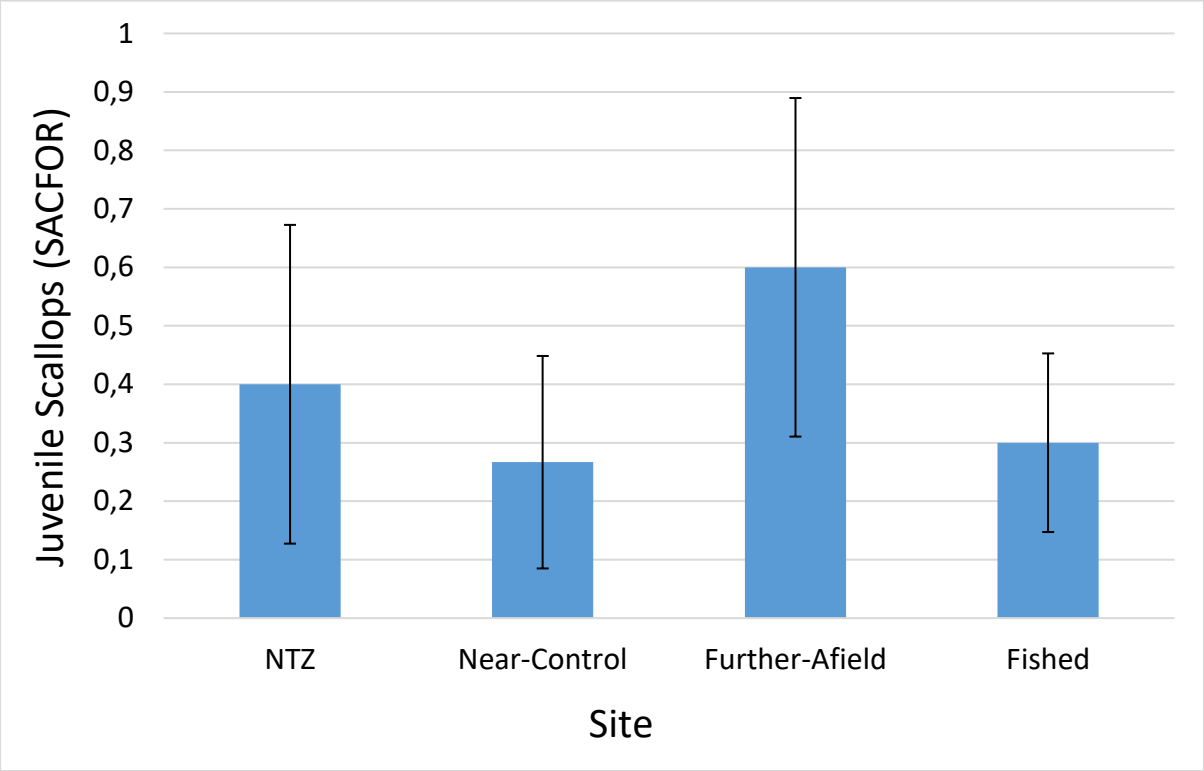

Figure 8. Different areas of protection assessed in 2019 and the mean abundance of juvenile scallops present in each area. No-Take Zone (NTZ): n=15, Near-Control: n= 15, Far-Control: n=15 Fished: n=10. Error bars represent ±1 SE.

3.3 Size and Age comparisons

King scallops were split between above and below the legal landing size limits and were compared between sites (Figure 9). There were more legal-sized scallops within the NTZ than the Fished sites ($P<0.0001$). From 2010-2019 and 2013-2019, there was a significant difference between all sizes of king scallops, $P=0.02$ and $P<0.05$, respectively. Interestingly, the Fished sites had overall more scallops <105 than any other site.

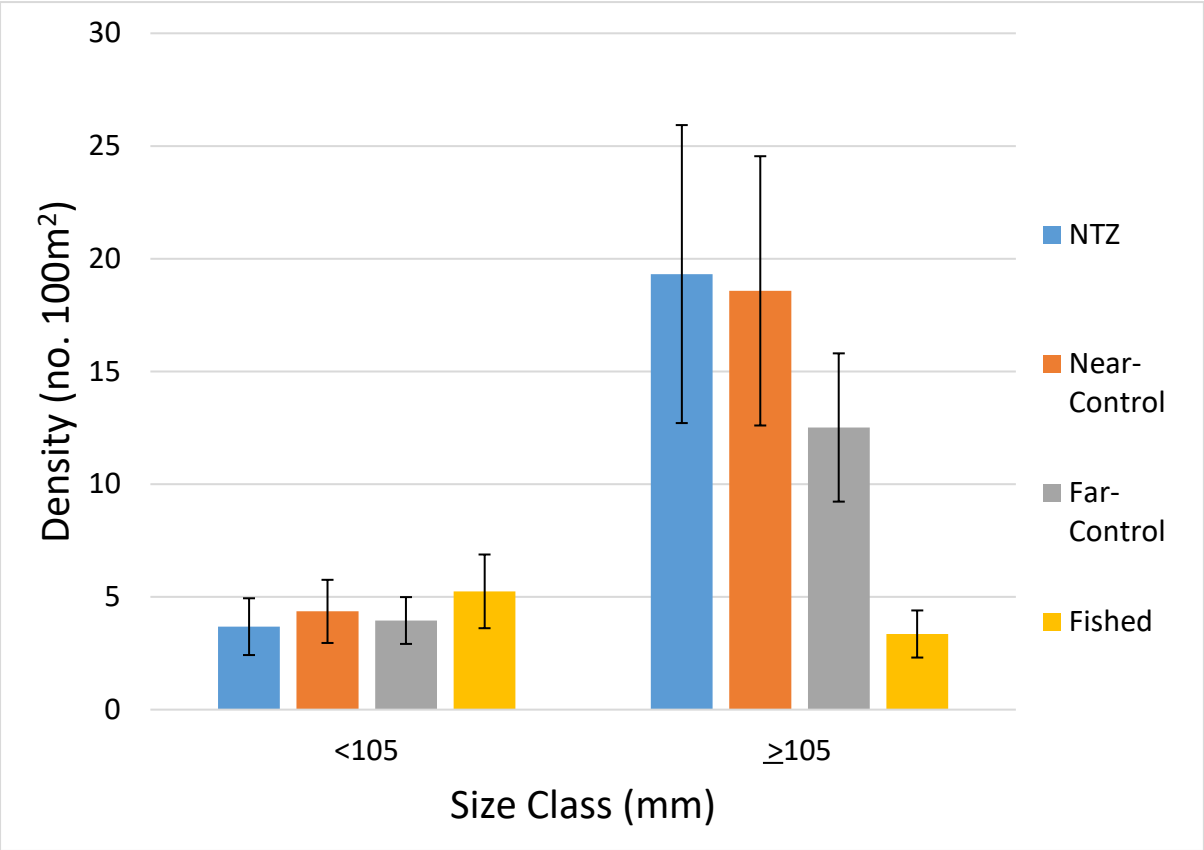

Figure 9. Mean density per size class of king scallops across all 2019 areas. For scallops <105: NTZ n=15; Near-Control n=15; Far-Control n=15; Fished n=10. For scallops ≥105: NTZ n=84; Near-Control n=89; Far-Control n=75; Fished n=16. Error bars represent ±1 SE.

When scallop size structure was assessed, the NTZ was found to be the only area that contained scallops >161mm and had more >141mm than in any other area (Figure 10). The only site that contained king scallops over 10 years of age was the NTZ, and The Mann-Whitney U test showed a significant difference between age classes of scallops in Fished and NTZ areas ($P<0.0001$), (Figure 11).

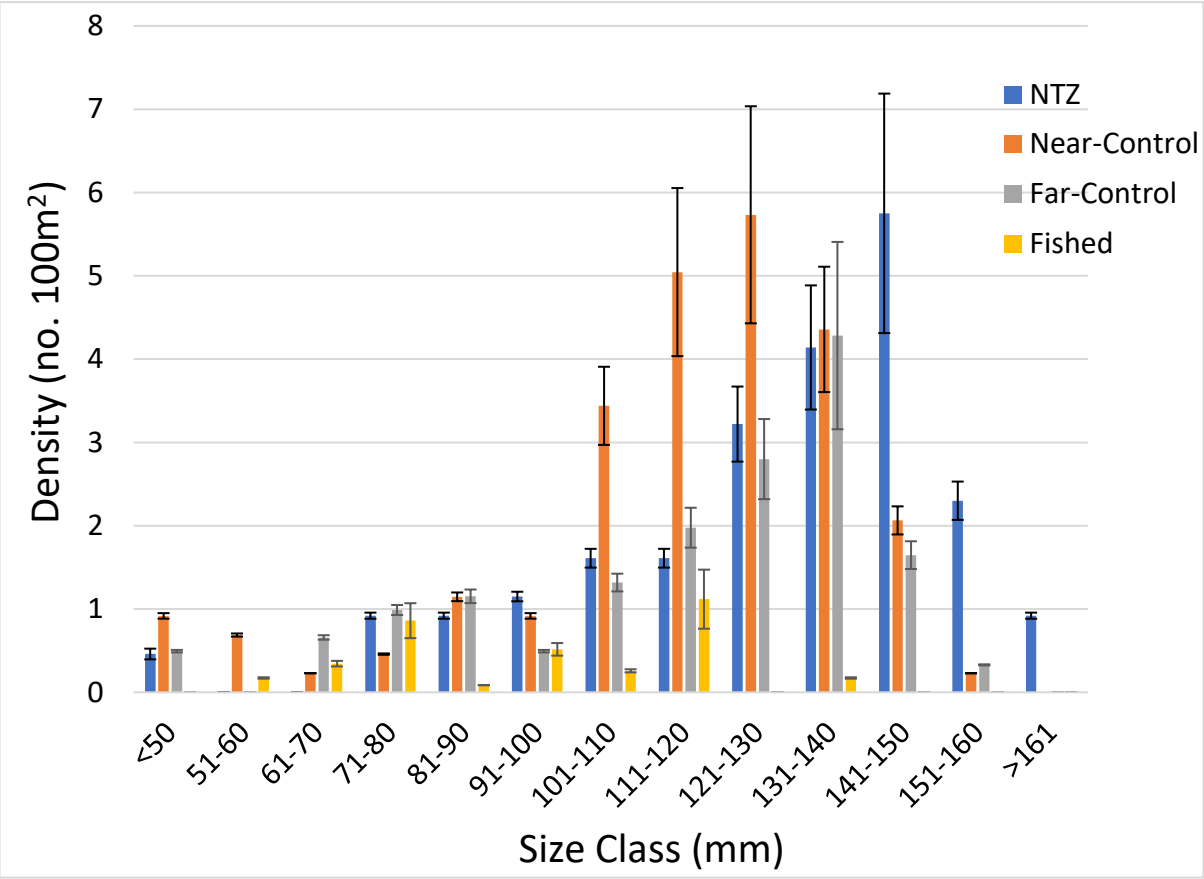

Figure 10. Mean density per size structure of king scallops. No-Take Zone (NTZ): n=15, Near-Control: n=15, Far-Control: n=15, Fished: n=10. Error bars represent ±1 SE.

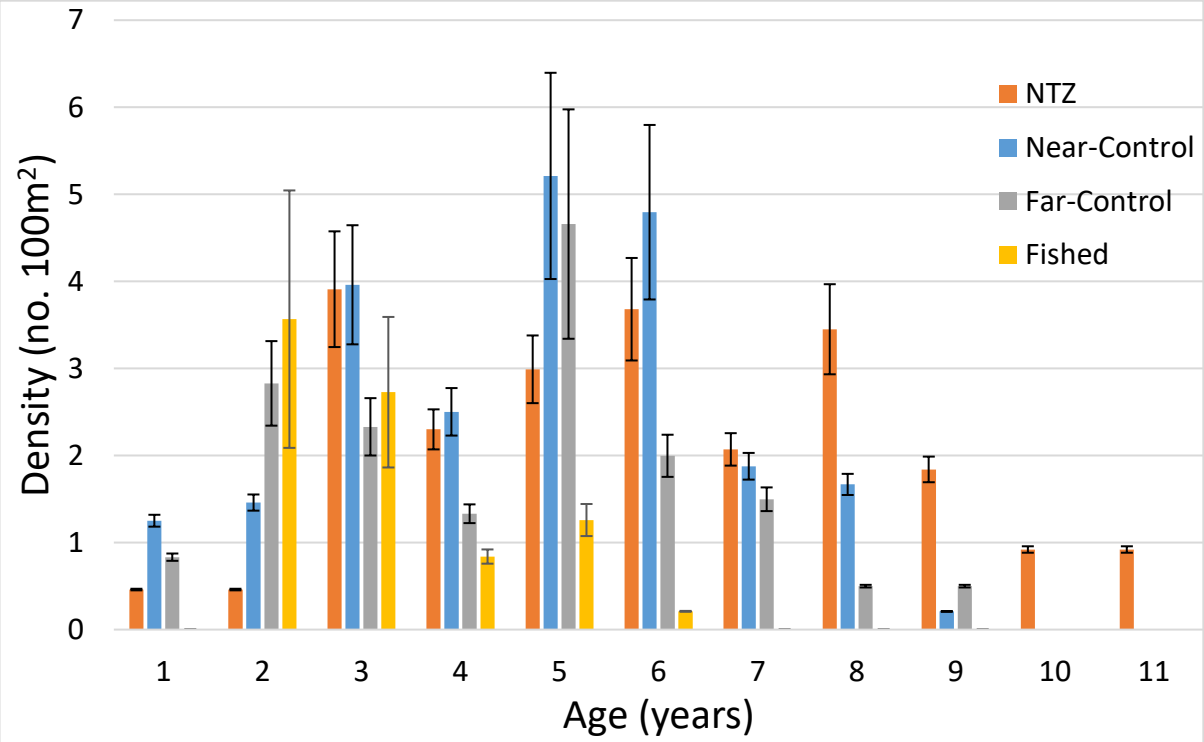

Figure 11. Mean density per age class of king scallops in 2019 across all sites assessed. No-Take Zone (NTZ): n=15, Near-Control: n=15, Far-Control: n=15, Fished: n=10. Error bars represent ±1 SE.

3.4 Exploitable and Reproductive Biomass

The pooled data on scallop shell and gonad sizes showed a strong positive relationship between the two variables (P<0.0001; correlation coefficient=0.7), (Figure 12).

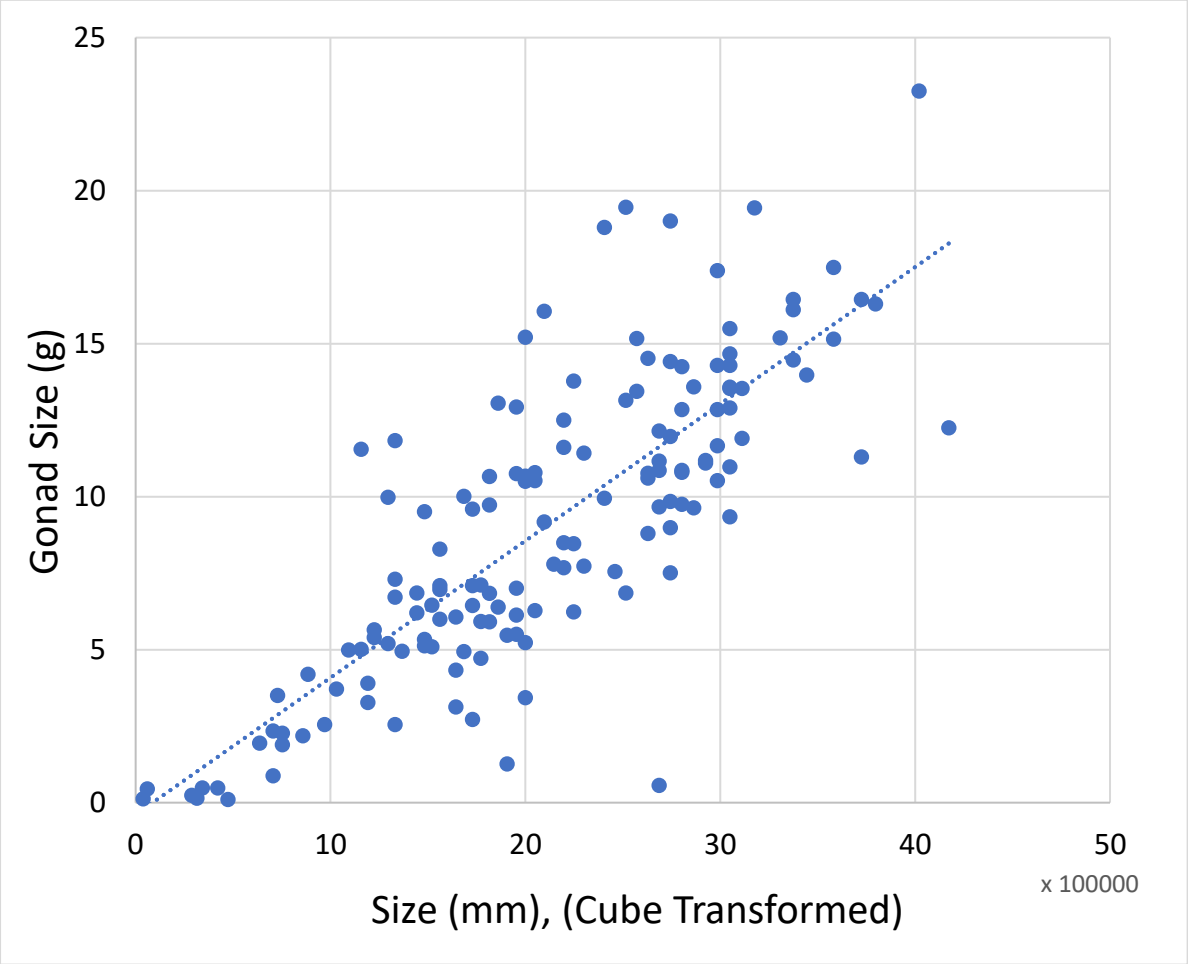

Figure 12. The cube transformed scallop shell size linear relationship with gonad size by pooled data from the NTZ, Near-Control and Far-Control. Trend line shows best-fit linear relationship.

From 2010 to 2019, there has been an increase in exploitable and reproductive biomass at both the NTZ and the Near-Control sites. The NTZ and Near-Control sites, from 2013-2019, showed increases in exploitable and reproductive biomass $P<0.01$ and $P<0.01$, respectively (Figure 13). There was a ~6.2 fold greater exploitable biomass in the NTZ than the Fished and 8.5 fold greater reproductive biomass in 2019 (Table 5). Less exploitable biomass in the Fished areas were found than at any other site, however no significant differences were found in 2019 ($P>0.05$), (Figure 14). In 2019 there was a significant difference between the NTZ and Fished reproductive biomasses ($P=0.02$), though no significance was identified between the NTZ and Near-Control ($P>0.05$).

Table 5. Comparison of exploitable and reproductive biomasses of king scallops between all sites in 2019.

Location	Exploitable biomass per 100m^2 (kg)	Reproductive biomass per 100m^2 (kg)
No-Take Zone	1.157	0.222
Near-Control	0.796	0.173
Far-Control	0.694	0.121
Fished	0.188	0.026

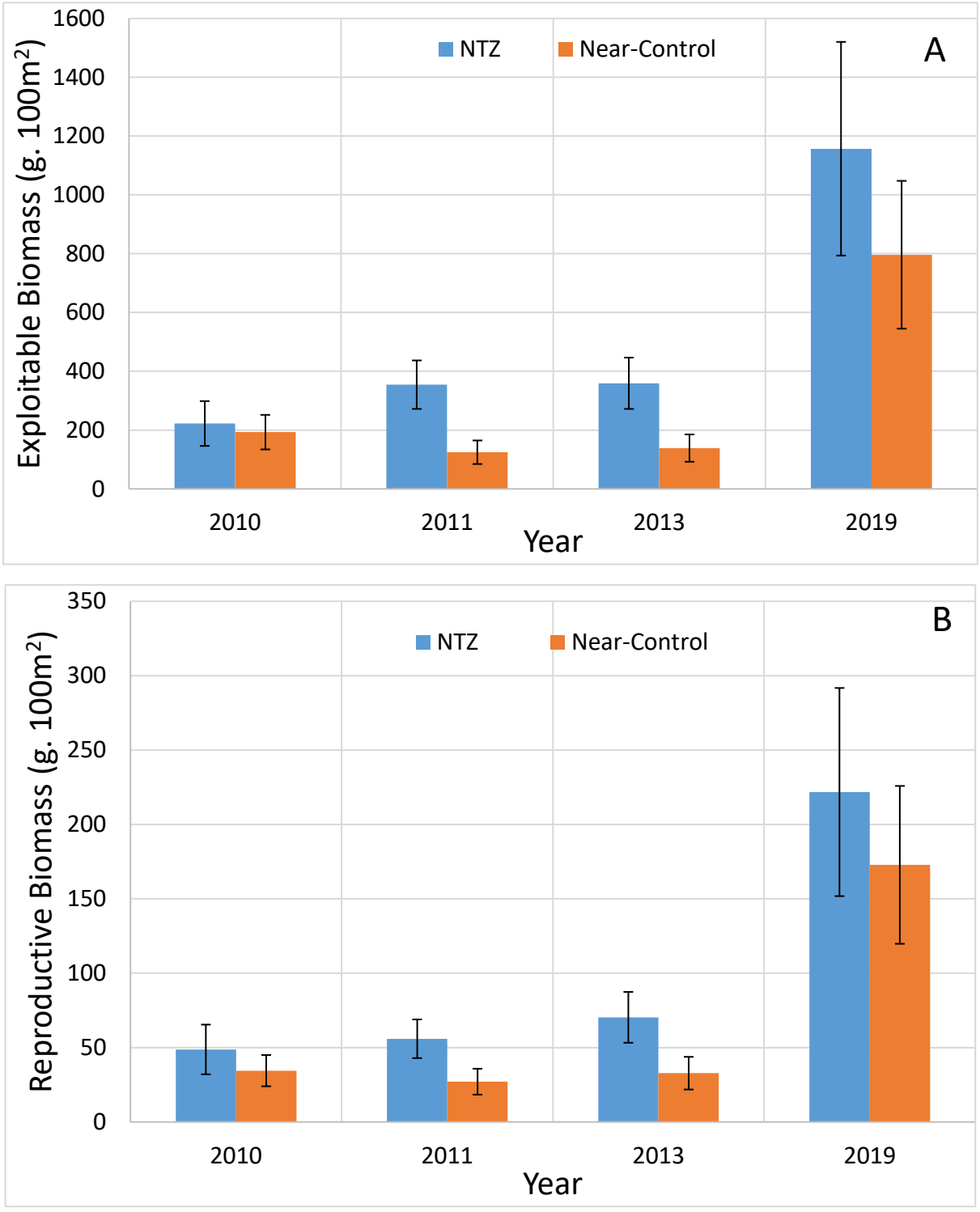

Figure 13. A) Mean exploitable biomass of king scallops in the NTZ and the Near-Control areas from 2010-2019, B) Mean reproductive biomass of king scallops in the NTZ and the Near-Control areas from 2010-2019. Note that there is a 6-year gap from 2013-19. Error bars represent ±1 SE.

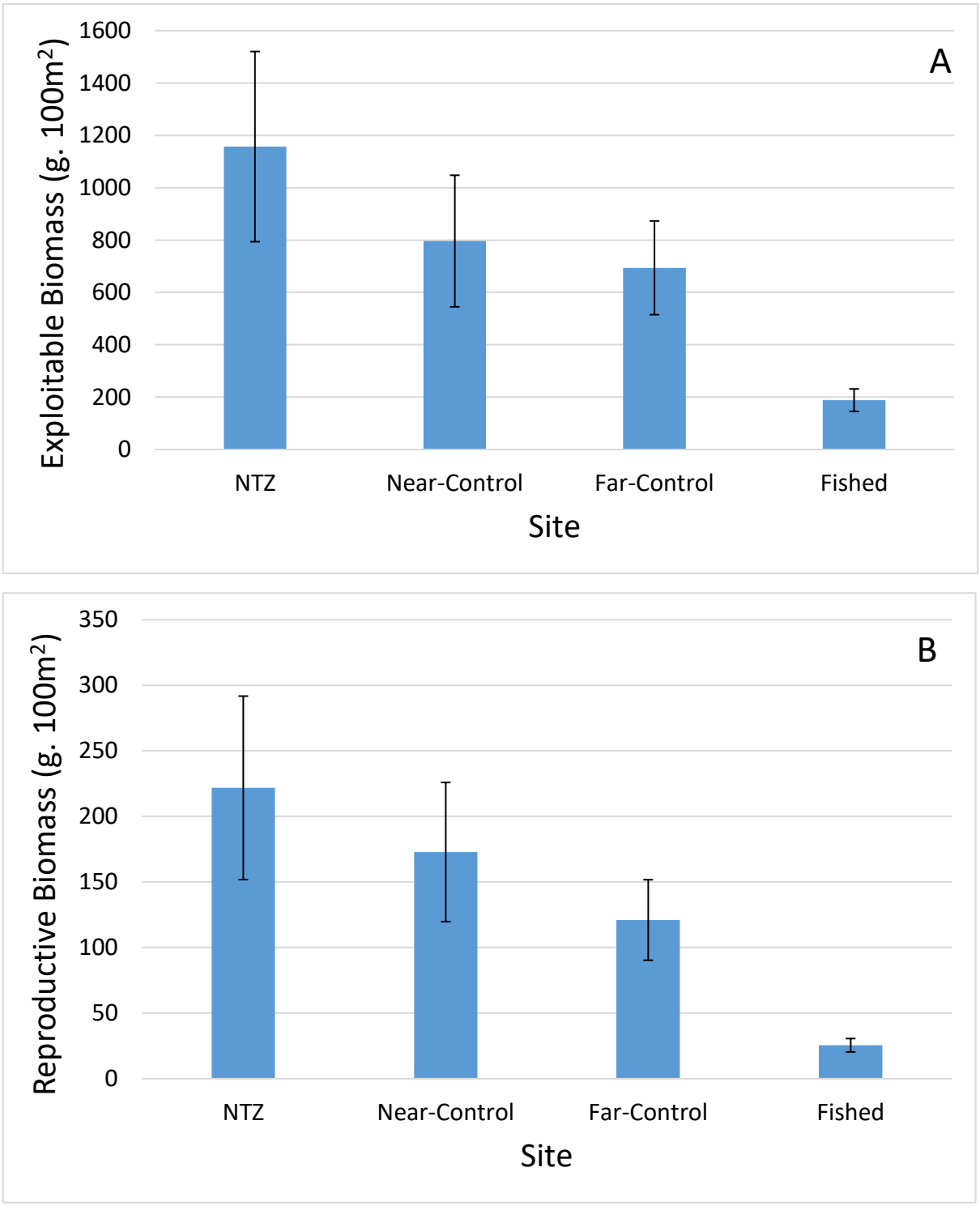

Figure 14. A) Mean exploitable biomass of king scallops between all four sites in 2019, B) Mean reproductive biomass of king scallops between all four sites in 2019. No-Take Zone (NTZ): n=15, Near-Control: n=15, Far-Control: n=15, Fished: n=10. Error bars represent ±1 SE.

4.0 Discussion

Under partial or full protection, habitats are more likely to recover and provide more complex epifaunal assemblages to support all life-stages of benthic species (Kamenos et al., 2004). Therefore, it is expected there would be a higher density of scallops within the NTZ due to protection; less in the surrounding MPA; then even less in areas open to fishing. This is an example of the 'halo effect' where export of larvae and 'spillover' occurs into areas adjacent to protection (Howarth et al., 2015). Results from this study support this theory as 63% more king scallops were found within the NTZ compared to the Fished area in 2019 (Figure 4). Furthermore, from 2013-2019, significant increases in the NTZ and Near-Control have occurred (Figure 3). Interestingly, king scallops increased significantly from 2014–2019 in the Far-Control by ~6.2 fold, indicating there has been very rapid recovery in numbers since the implementation of the MPA in 2016 (Figure 5). These data therefore suggest that fishing pressure within the MPA area was very high prior to protection. As scallops are organisms that perform broadcast spawning, the success of cross-fertilisation is dependent on the densities of populations (Kaiser et al., 2007). Thus, with more scallops present in areas protected from dredging, it is likely there will be more successful reproduction within this area (Barreto & Bailey, 2014).

The Fished area showed the size and age of scallops to be significantly lower than in the NTZ, and there were more legal-sized scallops within the NTZ, suggesting a more complex size-structure of populations under full protection (Figures 9-11). As the Fished area incorporates potentially destructive fishing methods, it is expected that animals will be smaller and less likely to grow to full size and fecundity as fishing removes them before they can reach a large size. For example, scallops under protection are less likely to be impacted and damaged by fishing gear; mortality rates will decrease from direct impacts of dredging and indirect impacts such as from increased susceptibility to disease and predation (Jenkins et al., 2011).

With an apparent increase in density, age and size structure within and surrounding Lamlash Bay, the biomass of gonads was also found to increase with size (Figure 12). With over 8x more gonad biomass in the NTZ than the Fished sites, there would be the reproductive

potential for 8x more gametes to be produced in spawning events, as gonad size is a good measure of reproductive output (Kaiser et al., 2007). These findings strikingly highlight the value of marine protection when enforced and monitored successfully, as with age, less energy is focused on growth, meaning more is available for reproduction, increasing the abundance of spat produced. Kaiser et al. (2007) also found that as well as the halt of exploitation on scallops, protection can also limit habitat degradation by reducing the number of non-target flora and fauna species being negatively impacted. This therefore avoids any major instabilities in the diverse community structure in areas under spatial protection (Jennings & Kaiser, 1998).

Despite the mean king scallop densities being very similar between the NTZ and Near-Control, it is apt to see the clear differences in mean exploitable and reproductive biomasses between these sites, both higher in the NTZ, though not significantly so (Figure 14). This highlights again that the older scallops under full protection seem to be larger and have a greater estimated reproductive potential (Roberts et al., 2001). There has been a dramatic increase in mean exploitable and reproductive biomass within the NTZ and Near-Control since 2013 with a ~3 fold increase in the biomasses of both in the NTZ and ~5 fold more of both in the Near-Control in 2019 (Figure 13). By showing a significant difference between NTZ and Fished site reproductive biomasses, the hypothesis that scallops are producing more gametes with size/age can be supported (Le Goff et al., 2017; Figure 12). Furthermore, the likelihood of repeated injury at fished sites is high as Newhaven dredges are inefficient due to ~41% catch success (Kaiser et al., 2007). Kaiser et al. (2007) also suggests that scallops damaged from repeated fishing pressure would thus contribute more of their energy to recovering from this stressor rather than to reproduction, thus reducing reproductive potential.

It would also be anticipated that in the Fished sites, juvenile scallops would be lower in quantity due to fishing disrupting the benthic habitat, reducing the optimum substrata for juvenile scallops to settle on (Howarth et al., 2015). However, these juvenile scallops have fluctuated in number since 2010 (Figure 6) and in the 2019 there was no clear structure to their spatial distribution as no mean abundances at any site were significantly different to each other (Figure 8). These findings are perhaps due to the hydrodynamics in the water column, as gametes are suspended for 15-40 days before settling, they could be exported to

areas that are not close by, further away from protection (Cragg, 2016). This is despite there being a potential higher abundance of habitat within protected areas as scallops require a structurally complex nursey ground for initial attachment in the juvenile stage (Howarth et al., 2015). Additionally, as juveniles, scallops are small and difficult to identify underwater, especially in low-light conditions. Most likely though, these fluctuations are following the usual unstable pattern of recruitment that are characteristic to most species of scallop (Beukers-Stewart et al., 2003).

Presence of bryozoans and macroalgae were shown to significantly correlate with juvenile scallops, suggesting that they settle on more complex benthic flora (Kamenos et al., 2004; Figure 7). Over time, it is likely that with the recovery of benthic habitats under increasing levels of protection in Scotland, juvenile scallop abundances will proportionally increase (Howarth et al., 2015). The monkey puzzle bryozoan (*Omalosecosa ramulosa*) is also increasing in the Clyde, which has a complex branching structure, providing a large surface area for larval settlement (H.Wood. Pers.Comm, July 2019). These results can be compared to a parallel study by Howarth et al. (2015), where in 2012 and 2013, abundances of juveniles were most correlated with macroalgae and hydroids.

The MPA was separated into two sites (Near- and Far-Control) as they were surveyed at different times from 2010-2015 and the scenarios of each site differ in terms of how much they were fished pre-protection. For example, once the NTZ was implemented, fishermen reduced their fishing activity in the Near-Control area around the Holy Isle of the MPA due to inconvenience as the barrier of the NTZ made it more difficult to fish (Howarth et al., 2015; Boulcott et al., 2018). However, the Far-Control site was known to be heavily exploited before protection which was a key factor in keeping the areas separate (Marine Scotland, 2015).

The opportunity to able to assess different approaches to management in the same area is invaluable when approaching future management techniques. The combination of a NTZ, MPA and traditional management is what makes this study site unique in the UK and unusual anywhere else in the world.

4.1 Limitations

Table 6. Non-exhaustive list of potential limitations impacting the study's results.

Limitations	Description
Fished areas were not assessed previously.	There are no data to compare 2019 findings to, however, there is now a baseline dataset for future research.
The NTZ and MPA have not been surveyed since 2013.	Additional undocumented influences could have affected the sites.
Scallop distributions can be patchy.	This makes surveying and finding significant differences difficult. For example, no scallops were found on some NTZ transects in 2019, yet others had 80+.
The SACFOR scale is subjective.	Interpretation could differ between years as different scientists are conducting research.
Depth restriction on dives.	This was to avoid decompression stops and could be missing out key areas that need to be monitored.
No prior data collection was completed before the implementation of the NTZ.	There are not sufficient data to suggest what the once natural state/quality of these habitats were. Therefore, assessments of fish and shellfish stocks cannot be fully reliable (Solandt, 2018).

4.2 Further Work and Recommendations

Table 7. Potential considerations for future work on this area and recommendations for management around Arran.

Further Work	Management Recommendations
Incorporate remotely operated vehicle video recordings in future surveys.	Reduce fishing effort in other places and encourage sustainable fishing methods such as scallop diving.
Increase number of survey sites in subsequent assessments and incorporate quadrat photo sampling for further analysis.	Establish additional permanent fully monitored MPAs into the UK.
Future data collection, in the areas incorporated in this study, is paramount to continue to monitor the interactions between different protection types and the effects on the natural environment.	Protect PMS and habitats such as maerl/seagrass in Scotland.
The findings of this study could inform in the future how protection may relate to marine strategy framework directive indicators, particularly in terms of developing seabed integrity.	In fished areas, reduce the quantity of dredges allowed per unit and the size of the metal rings (Beukers-Stewart & Beukers-Stewart, 2009).
	MPAs should encompass a representative selection of habitats rather than just focusing on those that are most susceptible to threats (Howarth & Beukers-Stewart, 2014).

If the extent of successfully managed MPAs did expand, the scallop fishery in the UK can provide much more sustainable and productive yields, offering stakeholders larger produce and a more reliable revenue (Beukers-Stewart & Beukers-Stewart, 2009).

5.0 Conclusion

To conclude, I have demonstrated that Scotland's first NTZ and the surrounding MPA have both benefitted the commercially valuable king scallop species in terms of abundance, size and reproductive potential. The abundances of these scallops are increasing over time, since the first study in 2010, and with future monitoring, are likely to continue to do so with reduced fishing pressure and anthropogenic disruption degrading the natural habitats that scallops require for productive growth and survival. The interaction of the protected sites in Arran have enabled socio-economic and environmental aspects to benefit and are a basis for implementing EBFM management recommendations in the future across the UK.

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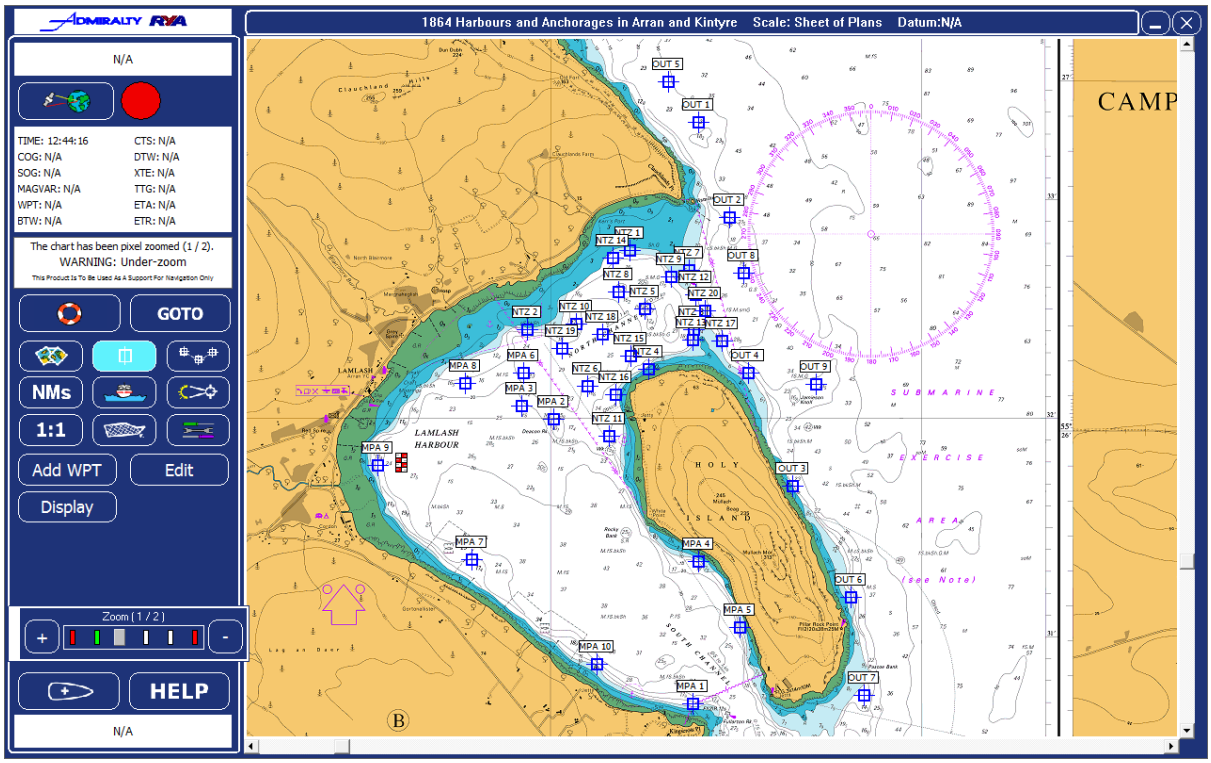
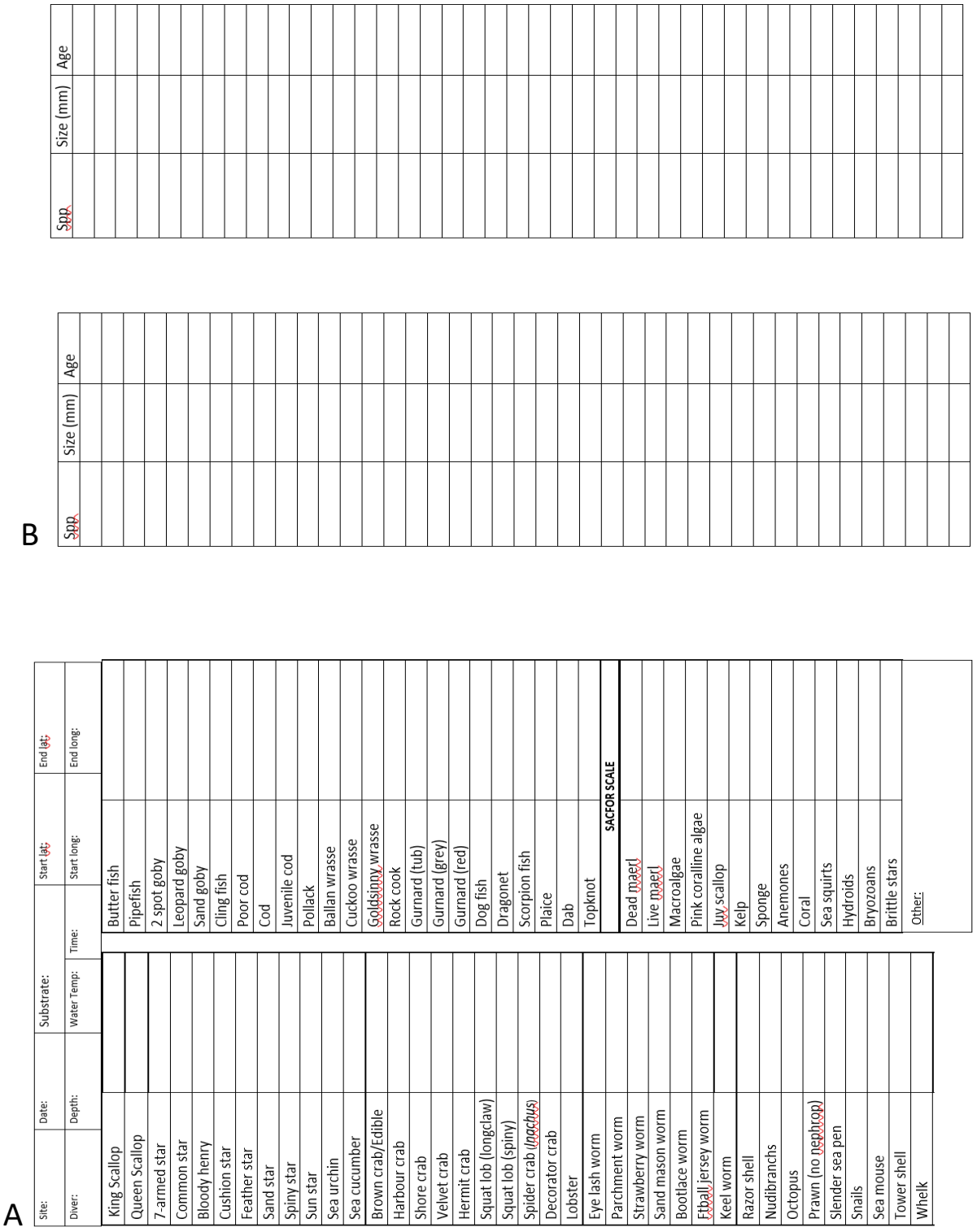
7.0 Appendix



Appendix 1. 2010 waypoints chart showing points of previous surveys by Leigh Howarth and Howard Wood within the NTZ and outside, before MPA was implemented.



Appendix 2. A) Underwater data sheet of species commonly found in the Clyde, noted in the form of a tally chart. A Super-abundant, Abundant, Common, Frequent, Occasional and Rare (SACFOR) scale was used to record the habitat types. Any extra species were noted and recorded on the data spreadsheets. B) Scallop recording sheet recording the species, age and size of scallops measured on the boat.

marinescotland

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BY EMAIL

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02 July 2019

Dear Mr Beukers-Stewart,

STARFISH ENTERPRISE – DEROGATION – 02 JULY to 31 August 2019

I refer to your recent correspondence, regarding the charter of the Starfish Enterprise, during the period of 02 July to 31 August 2019 to collect and land scallops by means of hand collecting for scientific research purposes.

I can confirm that authority is granted, in accordance with the terms of Section 9 of the Sea Fish Conservation Act 1967 and Article 43 of Council Regulation No. 850/98 to conduct this survey in the area Lamlash Bay No-Take Zone (NTZ), Isle of Arran.

This authority shall be valid in the period 0001 hours 02 July 2019 to 2359 hours 31 August 2019 under the following conditions:

- Up to 50 scallops from the Lamlash Bay no take zone and up to 100 scallaps from the South of Arran MPA are permitted to be caught and landed.
- All scallops are to be landed for scientic sampling porproses only and may not be sold commercially.
- A copy of this letter must be carried on board the vessel at all times, during these periods.
- A copy of this letter goes to my colleagues in the Fisheries monitoring centre for onward transmission to Marine Protection Vessles, and to all Marine Scotland Fishery Offices.

Yours sincerely,

Brian Meechan
Access to Sea Fisheries
Marine Scotland

Appendix 3. Marine Scotland Permission Form for starfish enterprise.

A) Two-way ANOVA Juvenile Scallops in the NTZ and in Near-Control site from 2010-2019

```
attach(Juv_Scallops_TwoWayAnova)
Year2 <- (as.factor(Year))
TypeofProtection2 <- (as.factor(Type_of_Protection))
res.aov3 <-aov(Juvenile_Scallops ~ Year2 + TypeofProtection2 + Year2:TypeofProtection2,
data=Juv_Scallops_TwoWayAnova)
summary(res.aov3)
TukeyHSD(res.aov3)
```

B) Poisson GLM of juvenile scallops in 2019

```
attach(Juv_Scallops_GLM)
ks.test(Juvenile_Scallops, "ppois", lambda = mean (Juvenile_Scallops))
hist(Juvenile_Scallops)

library()
library(MASS)

panel.cor <- function(x, y, digits=1, prefix="", cex.cor)
{
  usr <- par("usr"); on.exit(par(usr))
  par(usr = c(0, 1, 0, 1))
  r1=cor(x,y,use="pairwise.complete.obs")
  r <- abs(cor(x, y,use="pairwise.complete.obs"))

  txt <- format(c(r1, 0.123456789), digits=digits)[1]
  txt <- paste(prefix, txt, sep="")
  if(missing(cex.cor)) cex <- 0.9/strwidth(txt)
  text(0.5, 0.5, txt, cex = cex * r)
}

panel.smooth2=function (x, y, col = par("col"), bg = NA, pch = par("pch"),
                        cex = 1, col.smooth = "red", span = 2/3, iter = 3, ...)
{
  points(x, y, pch = pch, col = col, bg = bg, cex = cex)
  ok <- is.finite(x) & is.finite(y)
  if (any(ok))
    lines(stats::lowess(x[ok], y[ok], f = span, iter = iter),
          col = 1, ...)
}


panel.lines2=function (x, y, col = par("col"), bg = NA, pch = par("pch"),
                       cex = 1, ...)
{
  points(x, y, pch = pch, col = col, bg = bg, cex = cex)
  ok <- is.finite(x) & is.finite(y)
  if (any(ok)){
    tmp=lm(y[ok]~x[ok])
    abline(tmp)}
}

panel.hist <- function(x, ...)
{
  usr <- par("usr"); on.exit(par(usr))
  par(usr = c(usr[1:2], 0, 1.5) )
  h <- hist(x, plot = FALSE)
  breaks <- h$breaks; nB <- length(breaks)
  y <- h$counts; y <- y/max(y)
  rect(breaks[-nB], 0, breaks[-1], y, col="white", ...)
}



#VIF (for this section the data MUST BE DEFINED AS NUMERIC OR INTEGER)
myvif <- function(mod) {
  v <- vcov(mod)
  assign <- attributes(model.matrix(mod))$assign
  if (names(coefficients(mod)[1]) == "(Intercept)") {
    v <- v[-1, -1]
```

```
    assign <- assign[-1]
  } else warning("No intercept: vifs may not be sensible.")
  terms <- labels(terms(mod))
  n.terms <- length(terms)
  if (n.terms < 2) stop("The model contains fewer than 2 terms")
  if (length(assign) > dim(v)[1] ) {
    diag(tmp_cor)<-0
    if (any(tmp_cor==1.0)){
      return("Sample size is too small, 100% collinearity is present")
    } else {
      return("Sample size is too small")
    }
  }
  R <- cov2cor(v)
  detR <- det(R)
  result <- matrix(0, n.terms, 3)
  rownames(result) <- terms
  colnames(result) <- c("GVIF", "Df", "GVIF^(1/2Df)")
  for (term in 1:n.terms) {
    subs <- which(assign == term)
    result[term, 1] <- det(as.matrix(R[subs, subs])) * det(as.matrix(R[-subs, -subs])) / detR
    result[term, 2] <- length(subs)
  }
  if (all(result[, 2] == 1)) {
    result <- data.frame(GVIF=result[, 1])
  } else {
    result[, 3] <- result[, 1]^(1/(2 * result[, 2]))
  }
  invisible(result)
}

corvif <- function(dataz) {
  dataz <- as.data.frame(dataz)
  #correlation part
  cat("Correlations of the variables\n\n")
  tmp_cor <- cor(dataz,use="complete.obs")
  print(tmp_cor)

  #vif part
  form    <- formula(paste("fooy ~ ",paste(strsplit(names(dataz)," "),collapse=" + ")))
  dataz   <- data.frame(fooy=1,dataz)
  lm_mod  <- lm(form,dataz)

  cat("\n\nVariance inflation factors\n\n")
  print(myvif(lm_mod))
}

myvif <- function(mod) {
  v <- vcov(mod)
  assign <- attributes(model.matrix(mod))$assign
  if (names(coefficients(mod)[1]) == "(Intercept)") {
    v <- v[-1, -1]
    assign <- assign[-1]
  } else warning("No intercept: vifs may not be sensible.")
  terms <- labels(terms(mod))
  n.terms <- length(terms)
  if (n.terms < 2) stop("The model contains fewer than 2 terms")
  if (length(assign) > dim(v)[1] ) {
    diag(tmp_cor)<-0
    if (any(tmp_cor==1.0)){
      return("Sample size is too small, 100% collinearity is present")
    } else {
      return("Sample size is too small")
    }
  }
  R <- cov2cor(v)
  detR <- det(R)
  result <- matrix(0, n.terms, 3)
  rownames(result) <- terms
  colnames(result) <- c("GVIF", "Df", "GVIF^(1/2Df)")
  for (term in 1:n.terms) {
    subs <- which(assign == term)
    result[term, 1] <- det(as.matrix(R[subs, subs])) * det(as.matrix(R[-subs, -subs])) / detR
    result[term, 2] <- length(subs)
  }
  if (all(result[, 2] == 1)) {
    result <- data.frame(GVIF=result[, 1])
```

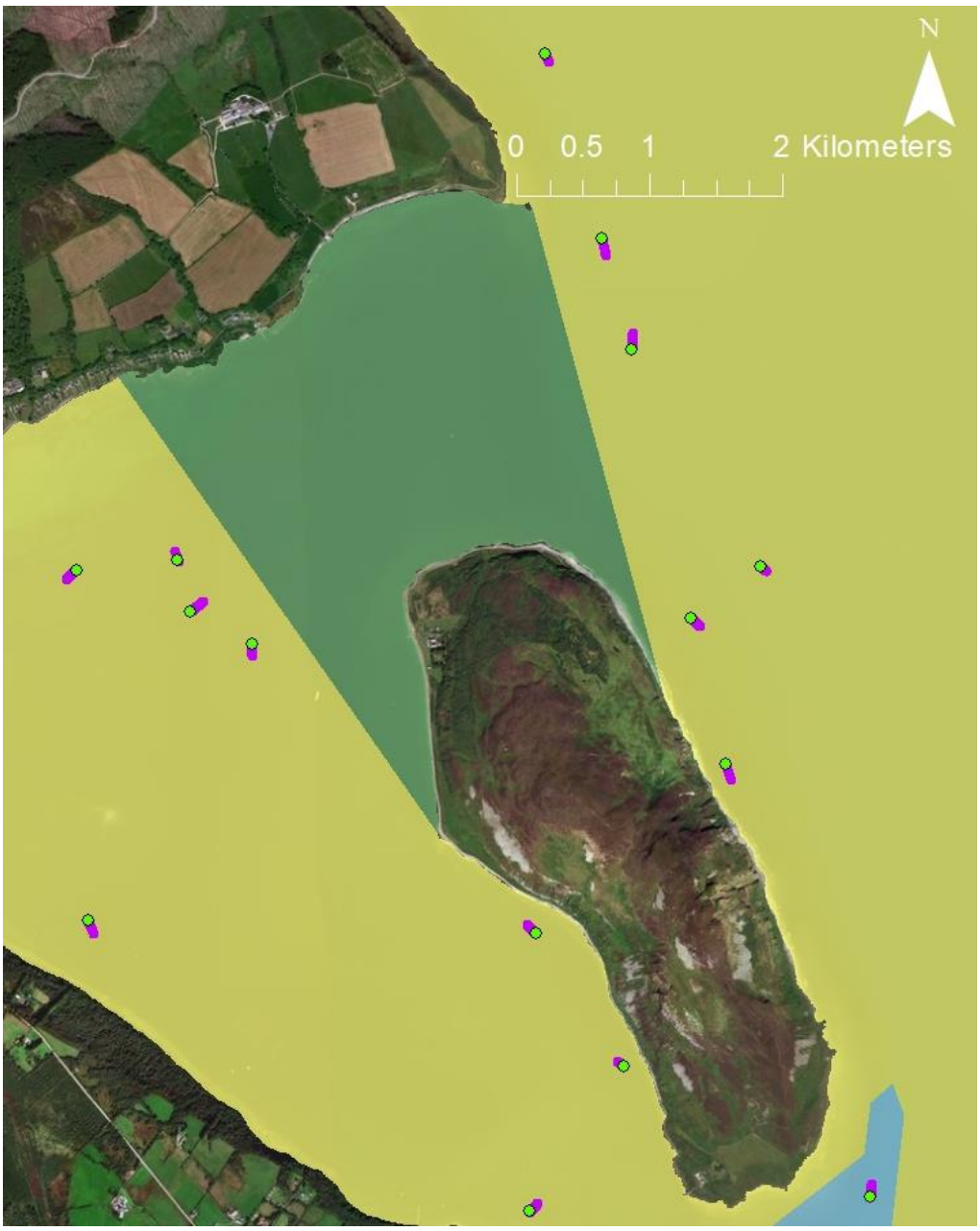
```
  } else {
    result[, 3] <- result[, 1]^(1/(2 * result[, 2]))
  }
  invisible(result)
}

corvif <- function(dataz) {
  dataz <- as.data.frame(dataz)
  #correlation part
  cat("Correlations of the variables\n\n")
  tmp_cor <- cor(dataz,use="complete.obs")
  print(tmp_cor)

  #vif part
  form    <- formula(paste("fooy ~ ",paste(strsplit(names(dataz)," "),collapse=" + ")))
  dataz   <- data.frame(fooy=1,dataz)
  lm_mod  <- lm(form,dataz)

  cat("\n\nVariance inflation factors\n\n")
  print(myvif(lm_mod))
}
Z <- cbind(Juv_Scallops_GLM[, 1:15])
pairs(Z, lower.panel=panel.smooth,
      upper.panel=panel.cor)

corvif(Z)


# dont put kelp and macroalgae together, live maerl and dead maerl, sea squirts and hydroids,
#macroalgae and depth


#group 1

rm(Z)
Z <- cbind(Juv_Scallops_GLM[,c(2,4,6,7,8)])
pairs(Z, lower.panel=panel.smooth,
      upper.panel=panel.cor)

corvif(Z)



Group2.glm                    <-                    glm(Juvenile_Scallops                    ~
Type_of_Protection+Dead_Maerl+Anemones+Macroalgae+Bryozoans, family=poisson)
summary(Group1.glm)
Group2.glm <- stepAIC(Group2.glm, direction = "both") #quick way #stepwise evaluates whether it
is worth keeping certain variables in

#AIC: 92.62
#residual dev / degrees of freedom = 37.377/40 = 0.934425 #under 1.5 so not overdispersed!
#% Deveince (1-Residual deviance/Null deviance x 100 = % devience)
(1-37.377/70.815)*100
#= 47.21881


#Step:  AIC=90.34
#Juvenile_Scallops ~ Type_of_Protection + Macroalgae + Bryozoans

#Df Deviance    AIC
#- Type_of_Protection  1   52.641 89.013
#<none>                    51.971 90.343
#+ Anemones            1   50.456 90.829
#+ Dead_Maerl          1   51.867 92.240
#- Macroalgae          1   57.778 94.151
#- Bryozoans            1   62.558 98.930

#MAM as within 2 AIC

Group2.glm1   <-   glm(Juvenile_Scallops   ~   Type_of_Protection   +   Macroalgae   +Bryozoans,
family=poisson)
summary(Group2.glm1)
#group 2

rm(Z)
Z <- cbind(Juv_Scallops_GLM[,c(5,9,11,15)])
pairs(Z, lower.panel=panel.smooth,
```

```
      upper.panel=panel.cor)

corvif(Z)

Group3.glm <- glm(Juvenile_Scallops ~ Live_Maerl+Kelp+Hydroids+predators, family=poisson)
summary(Group3.glm)
Group3.glm <- stepAIC(Group3.glm, direction = "both") #quick way #stepwise evaluates whether it
is worth keeping certain variables in

#AIC: 100.58
#residual dev / degrees of freedom = 60.207/50 = 1.20414 #under 1.5 so not overdispersed!
#% Deveince (1-Residual deviance/Null deviance x 100 = % devience)
(1-60.207/70.815)*100
#= 14.97988

#Step:  AIC=96.67
#Juvenile_Scallops ~ Live_Maerl + Kelp

#Df Deviance     AIC
#- Live_Maerl  1   60.620  94.993
#<none>            60.296  96.668
#+ Hydroids    1   60.212  98.584
#+ predators   1   60.292  98.664
#- Kelp        1   70.803 105.176

Group3.glm1 <- glm(Juvenile_Scallops ~ Live_Maerl + Kelp, family=poisson)
summary(Group3.glm1)


#group 3

rm(Z)
Z <- cbind(Juv_Scallops_GLM[,c(3,10,12,13,14)])
pairs(Z, lower.panel=panel.smooth,
      upper.panel=panel.cor)

corvif(Z)

Group4.glm    <-    glm(Juvenile_Scallops    ~    Depth+Sponge+coral+sea_squirts+brittle_star,
family=poisson)
summary(Group4.glm)
Group4.glm <- stepAIC(Group4.glm, direction = "both")

#AIC: 100.66
#residual dev / degrees of freedom = 58.292/49 = 1.1896 #under 1.5 so not overdispersed!
#% Deveince (1-Residual deviance/Null deviance x 100 = % devience)
(1-58.292/70.815)*100
#= 17.68411

#Step:  AIC=95.92
#Juvenile_Scallops ~ Depth + brittle_star

#Df Deviance     AIC
#- brittle_star  1   61.130  95.503
#<none>             59.543  95.915
#+ Sponge        1   59.094  97.466
#+ coral         1   59.381  97.753
#+ sea_squirts   1   59.539  97.911
#- Depth         1   69.823 104.195

Group4.glm1 <- glm(Juvenile_Scallops ~ Depth + brittle_star, family=poisson)
summary(Group4.glm1)


######################################################################

#diagnostic plots

par(mfrow=c(2,2))
plot(Group2.glm1)

par(mfrow=c(2,2))
plot(Group3.glm1)

par(mfrow=c(2,2))
plot(Group4.glm1)
```

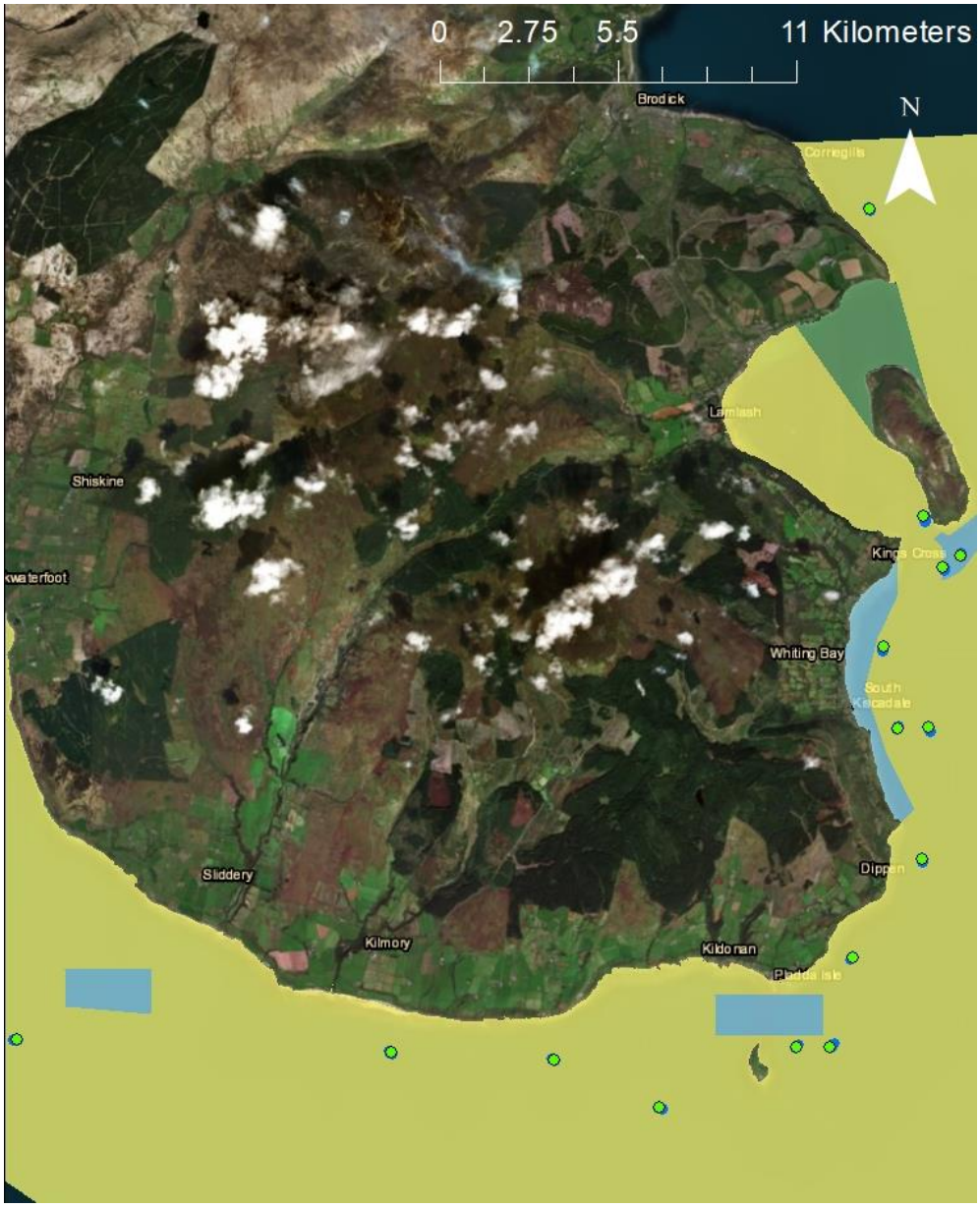
```
####################################################################


install.packages("bbmle")
library(bbmle)

AICctab(Group2.glm1,   Group3.glm1,   Group4.glm1,   base   =   T,   weights   =   T,   nobs   =
length(Juv_Scallops_GLM))
#           AICc dAICc df weight
#Group2.glm1 94.0  0.0  4  0.809
#Group4.glm1 97.9  3.9  3  0.113
#Group3.glm1 98.7  4.7  3  0.078

#GROUP 2 BEST MAM = type of protection, macroalgae, bryozoans


install.packages("visreg")
library(visreg)
windows()
visreg(Group2.glm1, scale ="response", partial=T, points=list(cex=1, pch=17))
visreg(Group3.glm1, scale ="response", partial=T, points=list
```

Appendix 4. RStudio code for certain statistical processes.

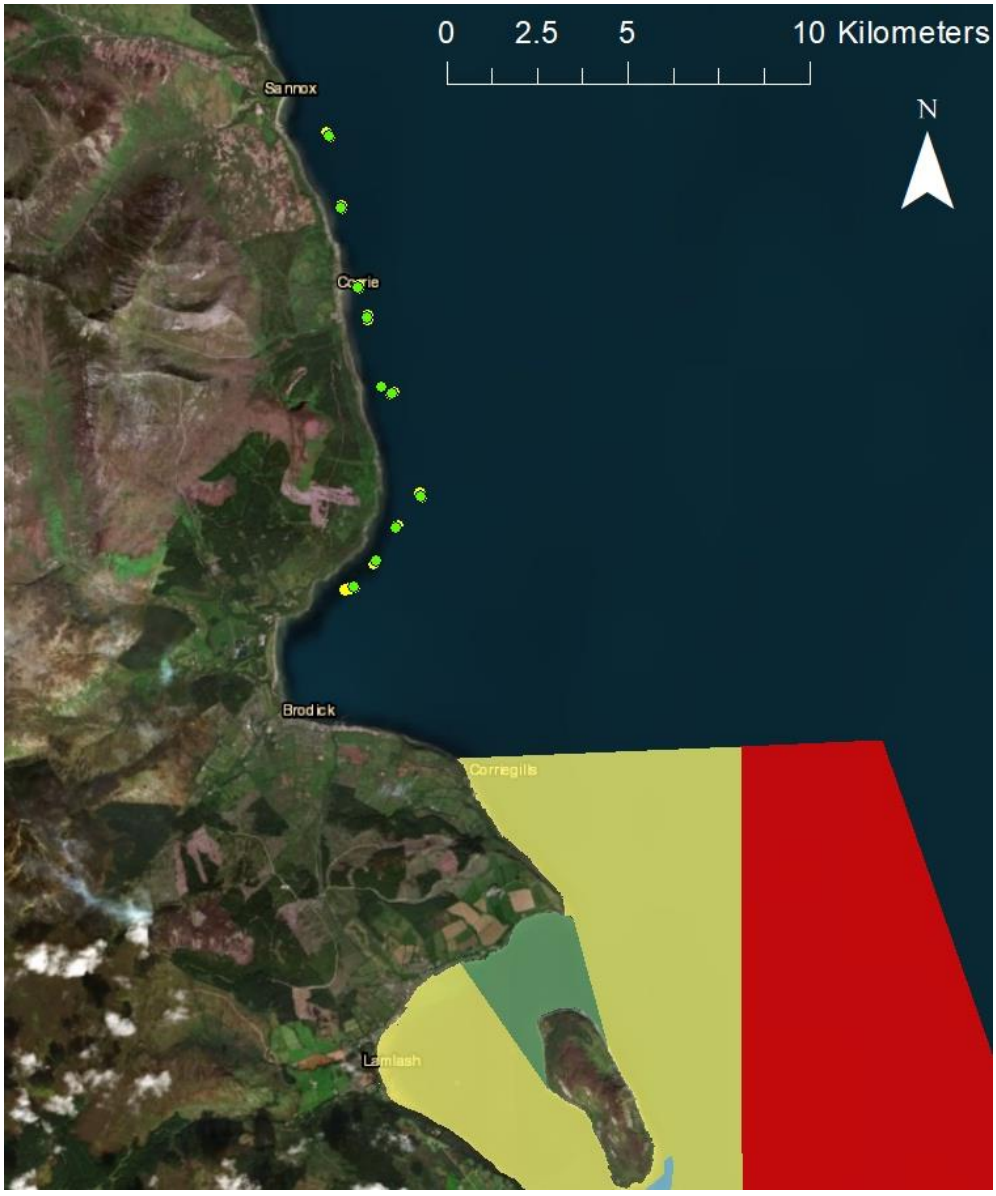
No-Take Zone (NTZ) 2019 sites surveyed within Lamlash Bay, created on ArcMap.



Near-Control sites surveyed in 2019 by divers, within the Marine Protected Area (MPA), inputted into ArcMap. These sites are replicated from previous studies in 2010-2013, before the Marine Protected Area (MPA) was in place.



Far-Control sites surveyed in 2019, within the Marine Protected Area (MPA), inputted into ArcMap. Blue sites that ban creeling too are in place to prohibit any extractive fishing method, limiting all interaction/contact with the sea bed to protect Priority Marine Species (PMS) such as maerl beds. These sites are replicated from previous studies in 2010-2013, before the MPA was in place.



Survey sites for fished areas, north of Brodick Bay, completed in 2019, inputted into ArcMap. Fished sites were chosen according to experienced diver and local Howard Wood (co-founder of COAST) and being advised by the research of Bryce Beukers-Stewart by Vessel Monitoring System (VMS) and through Marine Scotland.

Appendix 5. Detailed maps of survey points with areas of protection. On all four maps, the green dot marks the survey start position and the coloured line attached represents the direction and location of transect.

Sponge
Hydroids
Coral
Sea Squirts
Dead Maerl
Anemones
Predators (starfish species)
Pink Coralline Algae
Live Maerl
Depth
Bryozoans
Macroalgae
Kelp
Brittle Stars
Type of Protection

Appendix 6. 15 predictor variables incorporated in the GLM.