The effect of Lamlash Bay No Take Zone on fish abundance and diversity

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Abstract: Lamlash Bay No Take Zone, a small temperate marine reserve located on the Isle of Arran in the Firth of Clyde, was set up in September 2008. The Firth of Clyde is notorious for its degraded ecosystem with finfish declining due to overfishing to the point of total depletion. In its place is an economically valuable fishery based predominantly on *Nephrops*, lobsters (*Homarus gammarus*) and scallops (*Pecten maximus*). The aim of this study was to assess the impact of the spatial protection provided by the Lamlash Bay NTZ, compared to control sites outside of the reserve. Results of statistical analysis showed no significant difference in overall abundance of individuals, species, Shannon's diversity (H'), and Pielou's evenness (J') between sites inside and outside of the NTZ (one-way ANOVAs, $P>0.05$); however abundance of Gadiods was significantly higher inside the NTZ. Size of cod (*Gadhus morhua*) was also shown to significantly increase throughout the study period. Multivariate analysis using Primer showed no statistical differences in assemblages between NTZ sites and control sites; however species assemblages were shown to differ slightly between habitats. Despite a lack of statistical evidence, high species and abundance was seen in the vicinity of all study sites, indicating potential spill over. Further monitoring, coupled with expansion of the control sites to more intensively trawled areas, could reveal a significant level of protection provided by the marine reserve.

Key words*: No-Take Zones, Ecosystem Change, Baited Camera, Fish Abundance, Habitat*

1.0 Introduction

Areas completely closed to fishing, known as marine reserves or no take zones, are becoming the predominant form of marine conservation strategies worldwide (Halpern *et al*. 2010). Not only do they form a novel approach to fisheries management benefiting over-exploited fish stocks (Willis *et al*. 2003), they also protect marine ecosystems from the more detrimental physical effects of many types of fishing gear (Micheli *et al.* 2004; Watson *et al*. 2007). Extreme changes in ecosystem function due to overfishing may have disastrous consequences for marine systems; the biomass of high-trophic level fish in the Black Sea declined by over 60% during the last 50 years, with the ecosystem changing to a completely alternate stable state (Christensen *et al*. 2003). Marine spatial protection aims to discontinue over-exploitation in areas of severe degradation, with the aim to regenerate and restore ecosystem functioning (Roberts *et al.* 2005; Ballantine and Langlois 2008).

The Firth of Clyde, in the southwest of Scotland (Fig 1), is a prime example of an area that has been severly depleted due to a lack of adequate fisheries management during a period where total fishing effort was exponentially increasing due to technological advances. Many marine ecosystems have been over exploited due to fishing pressure resulting in a loss of predatory finfish populations and ecosystems dominated by crustaceans and other invertebrates (Howarth *et al.* 2011). Fishing has historically been a major part of life on the Clyde, herring fisheries being the most economically important, but fisheries for cod, saithe (*Pollachius virens*), haddock (*Melanogrammus aeglefinus*) and whiting (*Merlangius merlangus*) having regional importance (Thurstan 2007).

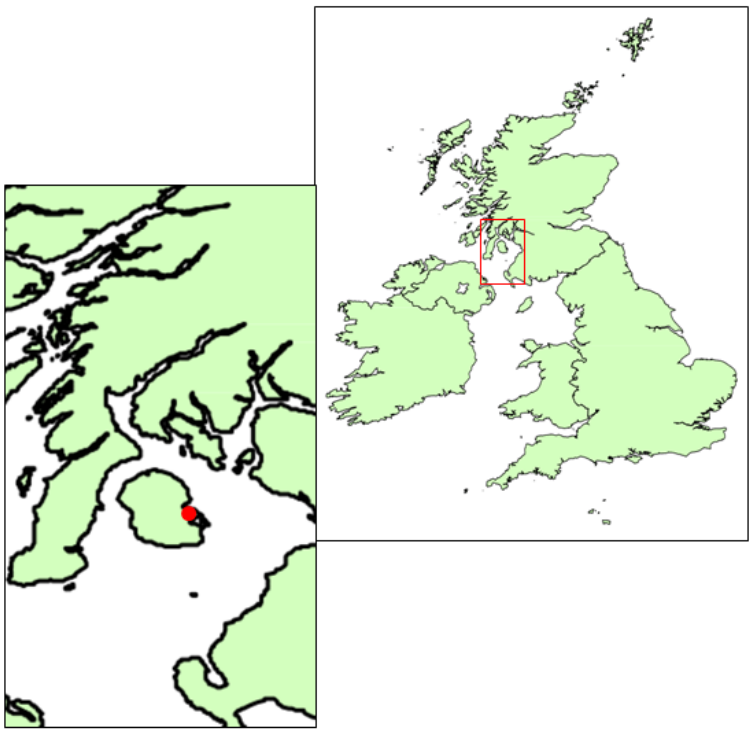

Figure 1. Map of the Firth of Clyde, and The Isle of Arran – the red dot indicates the location of Lamlash Bay No Take Zone.

Early accounts of the Firth of Clyde in the 18th and 19th century report a high abundance of species, yet the ecosystem today is a shadow of its former self (Thurstan and Roberts 2010). Intensive fishing, and the more recent popularity of bottom trawling and scallop dedging, has led to a collapse in finfish fisheries and resulted in reduced habitat complexity and therefore a reduction in species abundance and diversity (Thurstan and Roberts 2010; Fig 2). Finfish contributed to over 60% of landings (by weight) and 37% of total value of the fisheries in the Clyde in 1985, yet by 2008 this had fallen to 2% by weight and 0.5% by value (Howarth *et al*. 2013). More than ten years after the collapse of the finfish fishery the ecosystem still lacks large predatory species (Heath and Speirs 2012), yet this somewhat reduced ecosystem has ironically supported a successful invertebrate fishery with high economic value (Howarth *et al*. 2013).

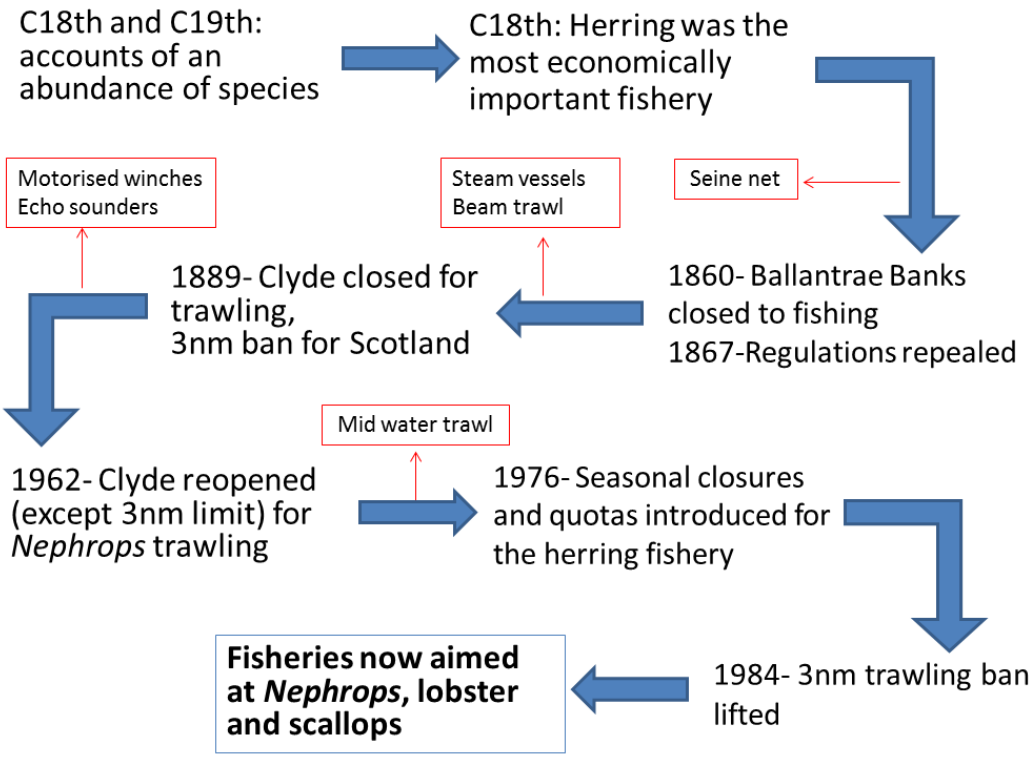

Figure 2. Notable events that led to the demise of finfish fisheries in the Firth of Clyde – concentrating on the lack of adequate fisheries management, with red boxes highlighting the technological advances in fishing gear allowing total fishing effort to rise. Source- adapted from Thurstan and Roberts (2010).

In 2008 the Community of Arran Seabed Trust (COAST) established a fully protected marine reserve in Lamlash Bay, Isle of Arran (Fig 1). The Isle of Arran is the largest island located within the Firth of Clyde and has had many associations with fishing activities (Thurstan 2007). Lamlash Bay No Take Zone (NTZ) covers 2.67km^2, and under the Inshore Fishing Act (Scotland) of 1984 prohibits all sea fishing (Howarth *et al*. 2011).

Due to the severe declines in pelagic and demersal finfish they are often overlooked during monitoring of marine reserves, yet knowledge of their reponse to spatial protection and potential recovery is vital for further implementation and design of further protected areas (Heagney *et al*. 2007). Areas that are closed to fishing are thought to generally increase abundance and diversity of species that are exploited, or previously have been, by fisheries (Jaworski *et al*. 2006; Watson *et al.* 2007; Goetze *et al*. 2011). The aim of this study was to assess the abundance, diversity and size of fish species within the NTZ and in control sites outside of the NTZ in order to assess the consequences of spatial protection on these depleted populations.

2.0 Methods

2.1 Study Sites and Materials

A total of 32 sites were surveyed – 16 inside Lamlash Bay NTZ and 16 outside (Fig 3a). Within these survey sites there were eight different habitat categories, according to substrate type, with two replicates of each habitat inside and outside of the NTZ (Fig 3b). Additionally, these replicates were chosen to select a deeper and a shallower representation of each habitat type in order to incorporate the full variety of habitats included within Lamlash Bay NTZ. Table 1 provides details for each of the survey sites.

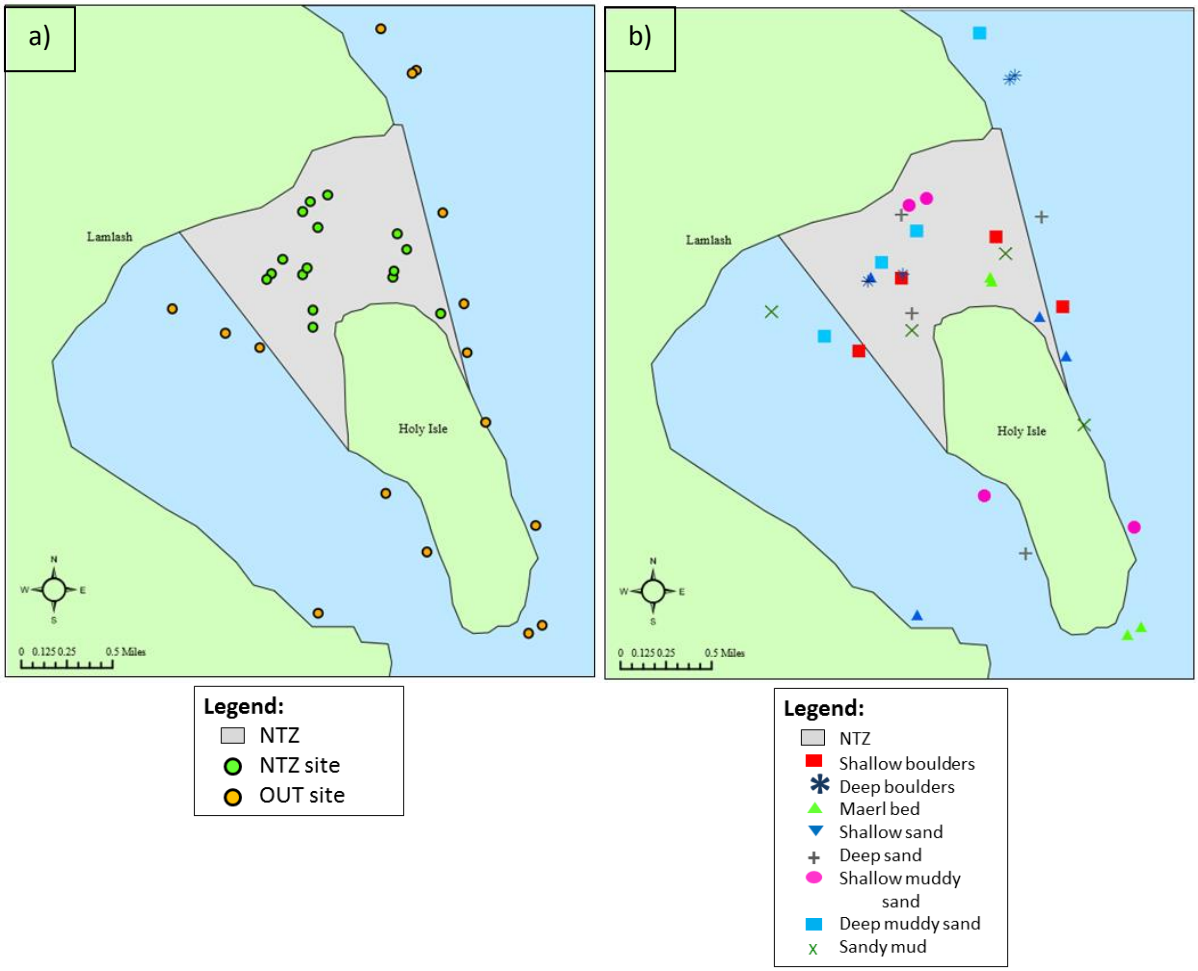

Figure 3. Location of the survey sites – a) map illustrating the location of the 16 sites both inside and outside of the no take zone; b) map showing the eight different habitat categories assigned to the survey sites.

Table 1. Survey sites and habitat categorisation - Habitats were assigned according to substrate type, with a shallow and deep replicate of every habitat both inside and outside of Lamlash Bay No Take Zone.

Habitat	Site	Depth	S LAT	S LONG
Shallow boulders	NTZ 12	10.8	55°32.568	-5°04.828
	NTZ 17	15.2	55°32.354	-5°05.609
	MPA 2	14.35	55°31.996	-5°05.94
	OUT 4	15.4	55°32.197	-5°04.434
Deep boulders	NTZ 18	27	55°32.387	-5°05.574
	NTZ 19	30	55°32.323	-5°05.905
	OUT 1	18.5	55°33.335	-5°04.763
	OUT 15	23	55°33.349	-5°04.730
Maerl bed	NTZ 3	8.45	55°32.390	-5°04.841
	NTZ 13	11.2	55°32.359	-5°04.850
	OUT 7	10.7	55°30.735	-5°03.466
	OUT 12	12	55°30.695	-5°03.579
Shallow sand	NTZ 4	15.2	55°32.249	-5°04.241
	NTZ 21	17.4	55°32.352	-5°05.869
	MPA 1	16.48	55°30.695	-5°05.850
	OUT 10	17	55°32.017	-5°04.198
Deep sand	NTZ 15	20.8	55°32.187	-5°05.507
	NTZ 24	23	55°32.653	-5°05.631
	MPA 5	21.5	55°31.061	-5°04.460
	OUT 8	22.8	55°32.677	-5°04.453
Shallow muddy sand	NTZ 22	14.5	55°32.702	-5°05.572
	NTZ 14	15.1	55°32.737	-5°05.428
	OUT 6	15	55°131.209	-5°03.560
	MPA 4	15.2	55°31.330	-5°04.829
Deep muddy sand	NTZ 8	17	55°32.581	-5°05.499
	NTZ 10	19	55°32.422	-5°05.782
	MPA 3	19.3	55°32.059	-5°06.233
	OUT 5	22	55°33.540	-5°05.043
Sandy mud	NTZ 16	11.25	55°32.106	-5°05.501
	NTZ 20	18	55°32.495	-5°04.742
	OUT 3	11.6	55°31.689	-5°04.051
	MPA 8	18	55°32.163	-5°06.686

Baited Remote Underwater Video cameras (BRUVs) were used to assess the abundance and diversity of fish species both within the NTZ and in the surrounding areas. Observations of crustaceans were also recorded, as some crustacean species are commercially sought after within the Firth of Clyde. BRUVs are non-invasive and non-destructive by nature, allowing them to be used to survey areas within marine reserves as they cause very limited damage to the marine environment (Brooks *et al*. 2011). Additionally there is no bias towards different habitat types as the BRUV technique does not depend upon the physical extraction of fish and so can be deployed in an assortment of complex and vulnerable habitats (Stoner *et al*. 2008). Figure 4 illustrates the components of the BRUV used in the study.

BRUVs depend on the dispersion of a bait plume, which aggregates fish for counting and measuring in the view of the underwater camera (Cappo *et al*. 2006). Oily fish are the most suitable for use as bait as they retain their scent in the water column for longer (Wraith 2007), and type, amount and delivery of the bait should be standardised to enable temporal and spatial comparisons (Harvey *et al*. 2007). Mackerel was used throughout the entire study period, with the bait located in a plastic box at the opposite end of the lobster pot frame (Fig 4). BRUVs were deployed from a Rigid Inflatable Boat (RIB), using a rope attached to the lobster pot frame.

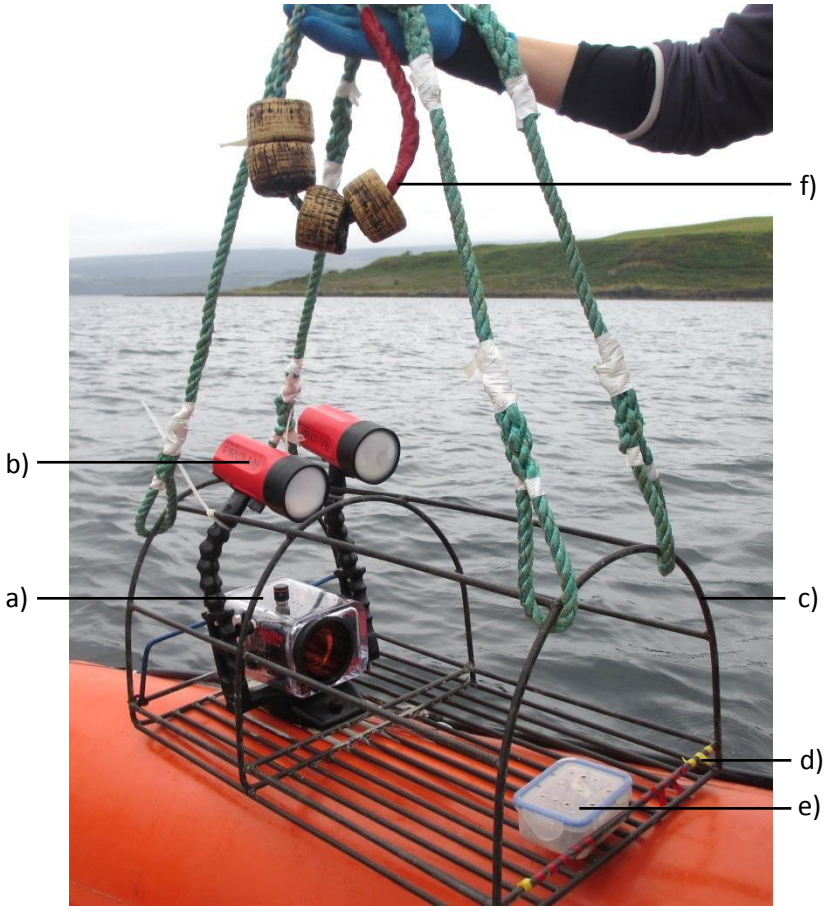

Figure 4. The components of the Baited Underwater Video Camera – a) Sony video camera in Ikelite underwater housing; b) Ikelite underwater lights, for use at depths >20m; c) metal lobster pot frame to protect camera and housing unit; d) calibration bar for sizing individuals with each section of tape representing 10mm; e) bait box containing mackerel, with holes drilled in the lid for dispersal of the bait plume; f) floats used to prevent rope from obstructing the camera's field of vision.

2.2 Video Analysis

A standardised length of 60 minutes of video was analysed for each site, starting two minutes after the BRUV hit the seabed. For each video the following observations were recorded: (*i*) the total number of species seen; (*ii*) the total number of families seen; (*iii*) the time of first appearance for each species (TFAP); (*iv*) the maximum number of individuals of each species seen on the screen at one time (MaxN); and (*v*) the time the maximum number occurred (TMaxN).

Using MaxN as a measure of abundance is a conservative measure of true abundance, as the maximum number of individuals present on screen at one time may only represent a fraction of the entire group of individuals (Cappo *et al*. 2004). However, using MaxN may reduce error that

may occur if recording every individual that enters or leaves the screen, as some methods suggest (Stoner *et al*. 2008).

Measurements of size were also recorded using the calibration bar situated on the BRUV frame (Fig 4). Each section of tape on the calibration bar represents 10mm and this was used to record size of individuals that positioned themselves perpendicular to the camera, at a set distance (above the calibration bar). Measurements of fish were recorded from nose to tail, and crab measurements were taken from the largest width of the carapace (Fig 5). Crustacean measurements were restricted to crabs, excluding hermit crabs (*Pagurus* species), due to the limited view of lobsters from the camera's field of vision.

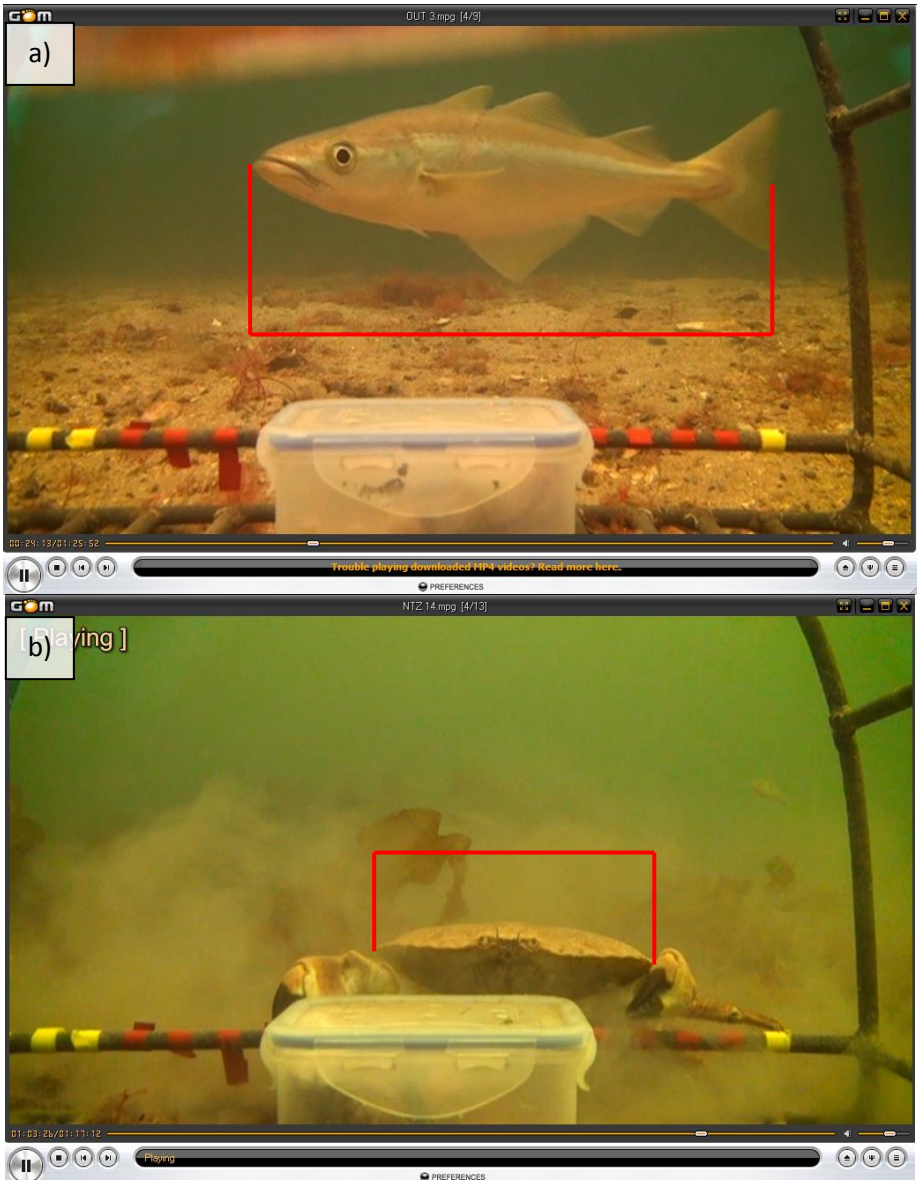

Figure 5. Measurement specifications of fish and crabs - a) fish were measured from nose to the end of tail fin; b) crab measurements were taken at the widest part of the carapace.

2.3 Statistical Analysis

Data was inputted into Microsoft Excel for formatting, and arranged into families and species creating a species sample matrix suitable for analysis using the software package PRIMER v. 6.1.5 (Clarke & Gorley 2001). Alternative univariate and multivariate tests were carried out using R (R statistical package, version 2.15.2; http://cran.r-project.org/).

- *Univariate Analysis*

The DIVERSE function within Primer was used to calculate number of species, number of individuals, Pielou's evenness (J') and Shannon's diversity (H') values for all sites within and outside of the NTZ. These measures of community structure and diversity were then assessed for normality and statistically analysed in R using a one-way Analysis of Variance (ANOVA) test to assess significant differences in communities.

Additional univariate tests were carried out to assess differences in abundance and time, and again, after testing for normality, one-way ANOVAs were used to statistically test these variables.

- *Multivariate Analysis*

Using Primer, a resemblance matrix based on Bray-Curtis similarity values was generated to show the similarity between each individual site. This was used as the basis for the majority of the subsequent statistical tests. A non-parametric multi-dimensional scaling plot (MDS) was created to graphically represent the resemblance matrix – with a 2D stress of below 0.2 indicating a reliable plot.

Using the ANOSIM function, an analysis of similarity between levels of protection (inside and outside the NTZ), and between the eight different habitats were undertaken. The results of this test provide a global R value between 1 and -1; with a value of 1 indicating a difference between the groups being tested, and a value of -1 indicating the variation within a single site is greater than the variation between sites. A significance level of below 5% would indicate a high reliability of the Global R value. Subsequently a Similarity Profile (SIMPROF) test was used to highlight any assemblages of survey sites that are significantly similar.

Lastly, the Similarity of Percentages function (SIMPER) was used to determine the highest contributors of individual species to sites inside the NTZ and control sites, therefore accounting for the average dissimilarity between the protection levels. A higher average similarity would

signify that sites within the same level of protection share a large proportion of their species composition.

- *Further statistical tests*

General Linear Models (GLMs) were carried out using R to establish a link between the total number of species at each site and a range of environmental variables. The variables tested included: total number of species, total number of families, protection (NTZ/OUT), depth, habitat complexity, macroalgae coverage, number of days since start of study, Shannon's diversity index (H') and Pielou's evenness (J'). Habitat complexity and macroalgae coverage were taken from complementary dive surveys undertaken at the same survey sites during the study period (for method see Howarth 2012).

3.0 Results

Videos were collected for all 32 sites, however due to technical problems with the video camera two of the videos fell short of the 60 minute standardised length for analysis; OUT 5 had 55 minutes available for analysis, whilst OUT 15 had only 30 minutes of video available. These sites were still incorporated into analysis as both had a similar number of species as the other control sites, as shown on graphs showing TFAP of species (Fig 6).

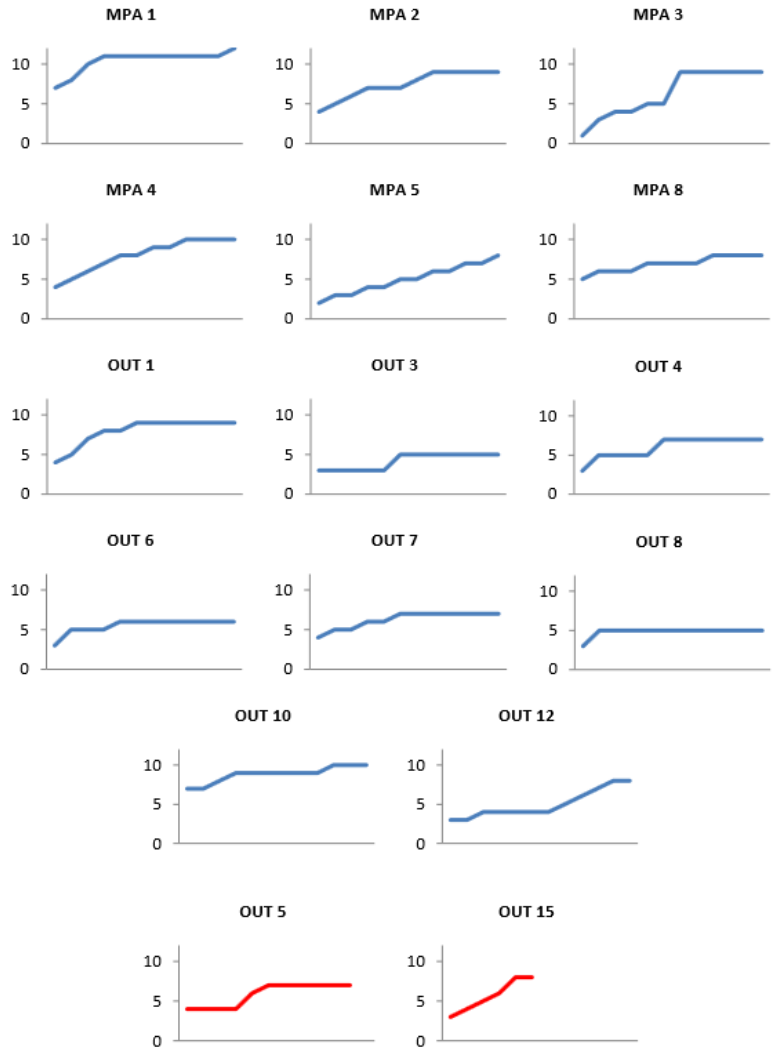

Figure 6. Cumulative number of species observed throughout the video analysis in control sites - most graphs show a steep initial increase followed by a gradual plateau effect. This indicates that OUT 5 and OUT 15 were appropriate for analysis despite the shortened analysis time. Graphs show the cumulative number of species observed (*y* axis) plotted against minutes into each recording (*x axis*).

- *Univariate Analysis*

A total of 28 species from 12 families were observed throughout the study period, 20 of these species being seen within the NTZ and 24 outside. Despite this indicating a higher number of species outside of the NTZ, the mean number of species inside the NTZ was 8.25 (± 0.88 SE) and the number of species outside was 7.94 (± 1.06 SE). The mean number of individuals within the NTZ was 27.50 (±5.84 SE) and 25.69 (±5.03 SE) outside. Neither total number of species nor total number of individuals was found to be significantly different between sites inside and outside of the NTZ (Table 2).

Table 2. One-way ANOVAs of the four abundance and diversity variables – no statistical difference was shown between sites inside and outside of the NTZ

Variable	Df	SS	MS	F	p
No. Species	1	1.78	1.783	0.636	0.438
	14	39.22	2.801		
No. Individuals	1	213.1	213.1	1.876	0.192
	14	1590.9	113.6		
Shannon's Diversity (H')	1	0.00124	0.001238	0.145	0.709
	14	0.11953	0.008538		
Pielou's Evenness (J')	1	0.0002	0.00017	0.002	0.965
	14	1.1981	0.8558		

When diversity of sites inside and outside of the NTZ was measured using Shannon's diversity index (H' log e), a mean index of 1.69 (±0.15 SE) was seen inside the NTZ compared to 1.64 (±0.22 SE) outside. Pielou's Evenness (J') was also used to show the distribution of species throughout the survey sites; with a mean evenness within the NTZ sites of 0.81 (±0.05 SE) compared to 0.79 (±0.06) of the sites outside. Again, there was no statistical difference for Shannon's diversity or Pielou's evenness between sites inside and out of the NTZ. Figure 7 shows the similarity between all four of these variables for sites inside the NTZ and outside.

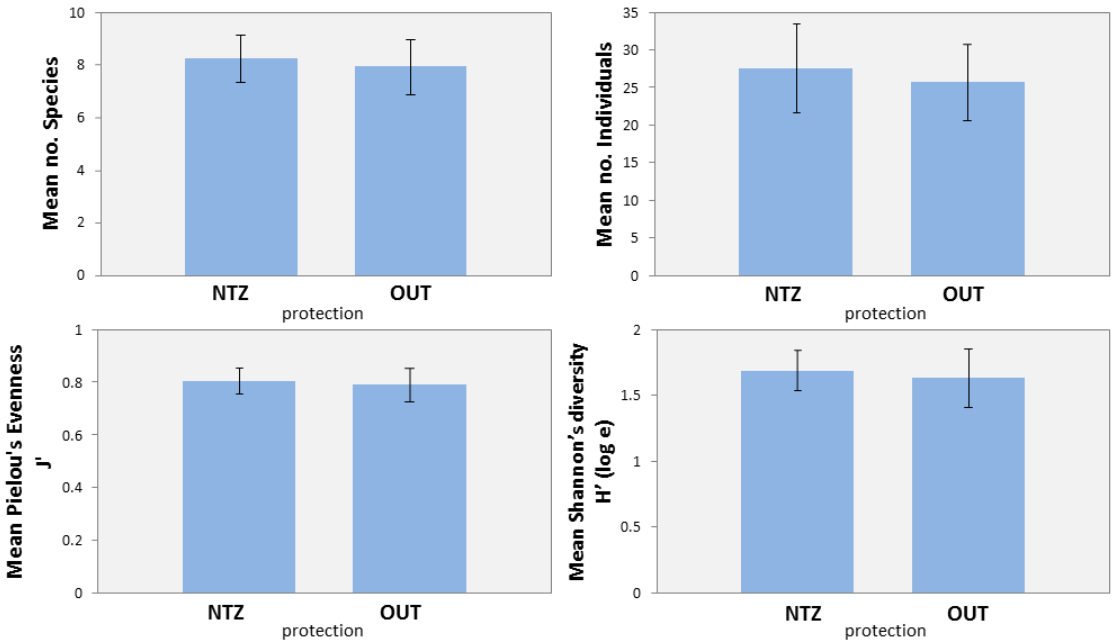

Figure 7. **Means and 95% confidence levels for univariate measures of community structure and diversity between sites within Lamlash Bay NTZ and control sites** – no statistical difference was found between any of the four variables using one-way ANOVAs (*P*>0.05).

The most diverse family observed were the Gadoids, which primarily consisted of juvenile cod, followed by Crustaceans and then flatfish (Fig 8). The abundance of Gadoids was significantly higher within the NTZ than outside (ANOVA, $F_{(1,14)}$ = 6.487 , *P*=0.023), however there was no significant difference in abundance in different levels of protection for any other groups (Fig 8).

During the study, Cod was the only species that had a consistently high level of abundance in order to obtain sufficient size measurements for statistical analysis. Figure 9 shows average size of cod throughout the entire study period, alluding to an increase in size for species inside and outside of the NTZ, with a slightly higher growth rate for individuals inside. Individuals inside and outside of the NTZ show a significant increase in size over time (ANOVA, $F_{(1,13)}$ =9.15, *P*=0.009; ANOVA, $F_{(1,9)}$ =6.43, *P*=0.03).

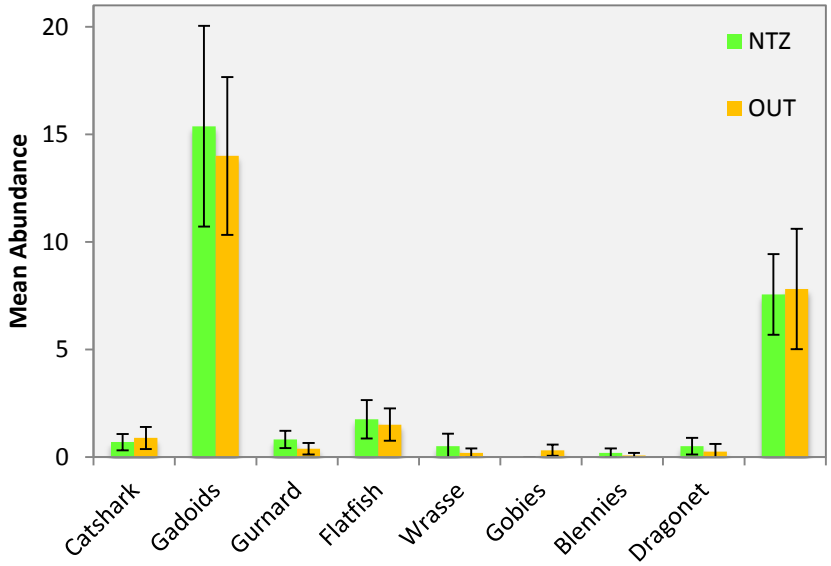

Figure 8. The mean abundance of groups of individuals observed inside and outside of the NTZ – The abundance of Gadoids was significantly higher inside the NTZ yet there was no significant difference between any of the other groups. Error bars represent 95% confidence level.

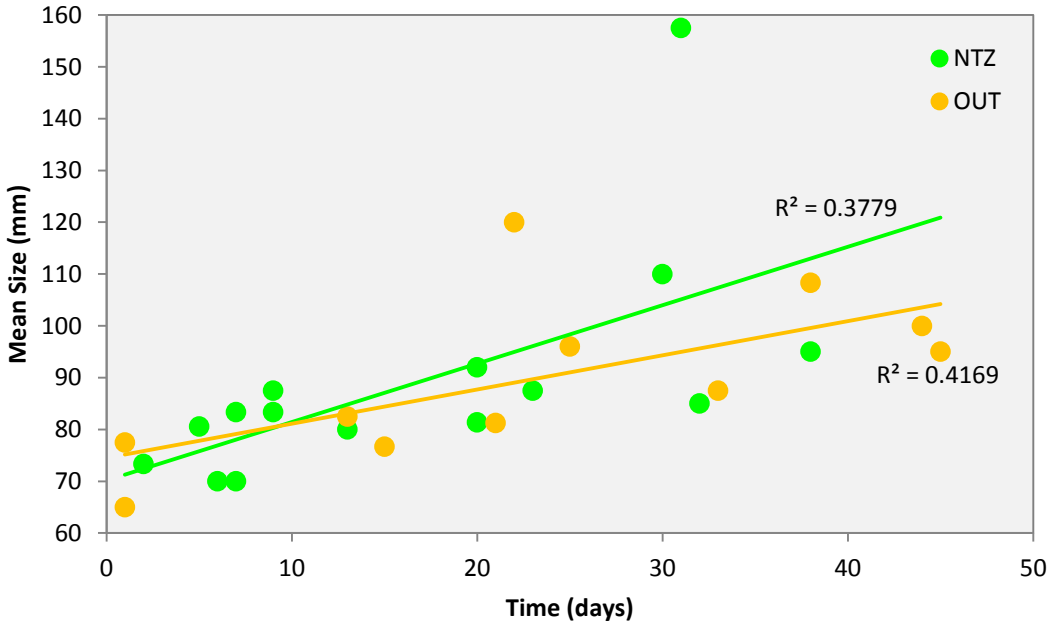

Figure 9. The mean size of cod (*Gadhus morhua*) throughout the study period – both individuals inside and outside of the reserve show a significant increase in size over time ($P<0.05$).

- *Multivariate Analysis*

A resemblance matrix based upon Bray-Curtis similarity measures showed a wide range of similarities between sites, ranging from 4% (low similarity) to 82% (high similarity). It not only revealed that sites within the same level of protection (NTZ or OUT) had a wide range of similarities, but sites across both levels of protection also exhibited a large variety of similarities (Appendix A).

MDS plots (Fig 10a) based on the Bray-Curtis resemblance matrix showed no clear separation between sites within and outside of the NTZ. However, when MDS plots were undertaken for different habitats over both levels of protection, the sites exhibited more obvious clustering between the same habitat types (Fig 10b). This therefore validates the need to distinguish sites by habitat level, as opposed to simply NTZ or OUT.

Categorising habitats was based on pre-set data, derived from three years of previous study at the same sites (Howarth 2012). However, when the categories assigned to each site were compared to habitat descriptions recorded during dive surveys, some minor discrepancies were revealed (Appendix B). The two conflicting habitats were reassigned and re-entered into Primer to show a third MDS Ordination (Fig 10c). However, the updated habitat categories made no improvement to the habitat clusters originally shown and so the original habitat data was used for all further statistical analysis.

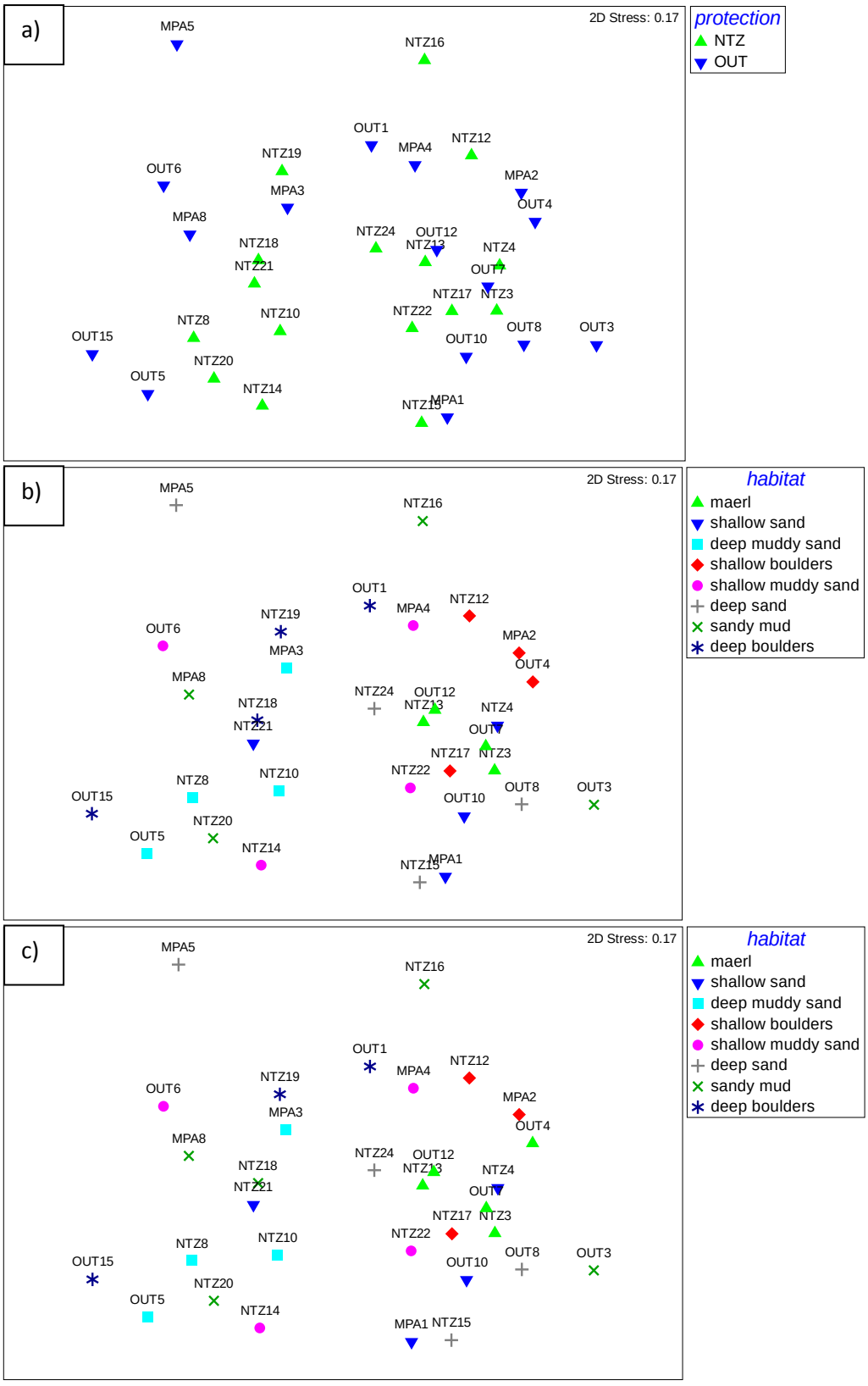

Figure 10. MDS Ordinations of Bray-Curtis similarity measures derived from untransformed abundance data - a) Different levels of protection (NTZ/OUT); b) Different habitats over both levels of protection using original habitat categorisation; c)Different habitats over both levels of protection using habitats from diver descriptions- showing no improvement to analysis.

SIMPROF test results for different habitats over both levels of protection have been graphically represented by a dendrogram (Fig 11). Three significantly different assemblages can be identified from the black lines (P<0.05), yet there is no further similarities within those assemblages- as represented by the dashed red lines (P>0.05).

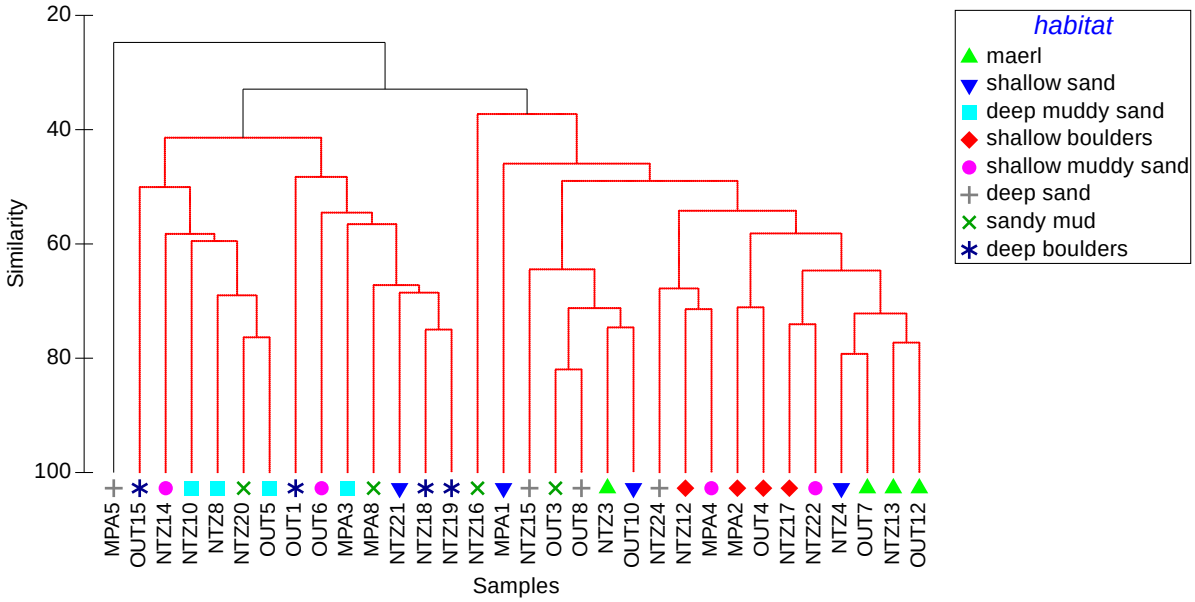

Figure 11. A dendrogram representing the results from the SIMPROF test based on Bray-Curtis similarities - Black lines represent sites that are significantly similar (P<0.05), indicating three different assemblages. Red lines represent sites that are statistically indistinguishable.

The ANOSIM between the two levels of protection resulted in a Global R value of -0.005 and a significance value of 47.6%. This illustrates no clear difference between the two groups. When the ANOSIM was applied to the eight habitat categories a Global R value of 0.24 was calculated, with a significance level of 0.4%; indicating a low level of difference between sites sampled in different habitats.

Table 3 summarises the results from the SIMPER analysis, displaying the characteristics of species composition for sites within the NTZ and outside. The analysis found average similarity between treatments to be higher for sites within the NTZ than compared to those outside.

Sites within the NTZ were characterised by seven main species, whereas control sites were characterised by eight main species. Five of the species were main contributors for both levels of protection: cod, harbour crab (*Liocarcinus depurator*), velvet swimming crab (*Necora Puber*), dab (*Limanda limanda*) and whiting. Together these contributed 83.29% of the species inside the NTZ and 82.30% of the species in control sites. Cod was identified as the most important species contributing 39.93% and 45.13% to sites in and out of the NTZ, respectively.

Table 3. SIMPER analyses of untransformed data - showing the main characteristics of species composition for NTZ sites and control sites (OUT).

Treatment	Species	Average abundance	Average similarity	Similarity /SD	% Contribution	Cumulative %	Overall Average Similarity
NTZ	*Gadhus morhua*	8.69	18.46	1.68	39.93	39.93	46.23
	Liocarcinus depurator	4.06	10.33	1.85	22.35	62.28	
	Necora puber	1.94	3.76	0.99	8.14	70.41	
	Limanda limanda	1.75	3.07	1.10	6.64	77.06	
	Merlangius merlangus	2.44	2.88	0.58	6.24	83.29	
	Melanogrammus aeglefinus	4.00	2.83	0.40	6.12	89.42	
	Eutrigla gurnardus	0.81	1.55	0.72	3.35	92.77	
OUT	*Gadhus morhua*	8.75	16.07	1.05	45.13	45.13	35.61
	Liocarcinus depurator	3.00	6.57	1.34	18.46	63.59	
	Limanda limanda	1.50	2.89	0.89	8.13	71.72	
	Merlangius merlangus	2.56	1.92	0.35	5.40	77.12	
	Necora puber	1.31	1.85	0.52	5.18	82.30	
	Munida rugosa	1.00	1.42	0.61	3.98	86.29	
	Schyliorhinus canicula	0.88	1.31	0.59	3.67	89.95	
	Cancer pagurus	0.75	0.87	0.44	2.43	92.38	

- *General Linear Models*

Two multivariate Gaussian GLMs showed that two of the nine response variables were significant to the 95% confidence level in model one, with no significant variables found in the second model (Table 4). Although the response variable (total number of individuals) was count data, indicating a Poisson distributed GLM, a linear Gaussian model explained a higher proportion of the deviance explained and so was selected as a more suitable model. The model showed an increase in species number increased the number of individuals, and a lower Pielou's evenness value also increased the number of individuals. Depth was also shown to have a slight impact, although it was not significant to the 95% confidence level.

Table 4. Multivariate stepwise Gaussian GLM's with environmental variables – a) model 1: total species, total families, protection, depth, habitat complexity, macroalgae coverage, time (days), evenness (J'); b) model 2: total families, protection, depth, habitat complexity, macroalgae coverage, time (days), diversity (H'). * denotes statistically significant variables (95% confidence level).

	Variables	Test Statistics		p	ANOVA p
a)	total species *	AIC= 216.76	%D= 62.11	$3.52e^{-06}$	0.83
	depth			0.13	
	evenness (J') *			$1.80e^{-06}$	
b)	total families	AIC= 241.39	%D= 7.12	0.13	0.66

4.0 Discussion

4.1 Spatial Protection

The aim of the study was to assess the difference in abundance and diversity of fish species within a temperate marine reserve by sampling sites within a NTZ and control sites outside of the protected area. Univariate analysis did not detect a significant difference between number of individuals, number of species, or diversity (H') and evenness (J') of species between the two levels of protection (Fig 7). Likewise, multivariate analyses found species assemblages within the NTZ and areas outside statistically indistinguishable from each other.

The lack of statistical difference between NTZ sites and control sites may be attributed to the size of spatial protection. Lamlash Bay NTZ is 2.67km^2 (Thurstan and Roberts 2010) and therefore monitoring such mobile fish and crustacean species in such a small area of protection may dilute any significant differences seen in larger protected areas. A study by Goetze *et al*. (2011) in Fiji found a lack of significant differences between abundances inside and outside of a small reserve (4.25km^2); however a slightly larger reserve (60.6km^2) showed significant differences. Similarly, smaller reserves have been shown to allow mobile species to move easily outside of the boundaries of protection (Hilborn *et al.* 2004; Watson *et al*. 2007).

The close proximity of the control sites to the boundary of the NTZ may also reduce any significant differences due to the spillover effect (Fig 3a). Furthermore, the control sites were located in areas not particularly prone to intensive trawling; species assemblages are prone to greater decline in more degraded areas (Micheli *et al*. 2004). In Nova Scotia, Fisher and Franks (2002) found that community structure in a control site, located near to a marine reserve, that had never had been closed to fishing became more similar to that of the protected area despite the lack of protection. Although many studies show that the effectiveness of marine reserves increases with size, this does not infer that small areas of spatial protection are ineffective, and their protection should not be disregarded (Claudet *et al*. 2008).

Another factor to consider is the amount of time since the NTZ was instigated. Lamlash Bay NTZ was established 5 years ago, yet it is difficult to estimate the amount of time needed for populations to recover due to the unpredictable impact of fishing and other disturbances on different ecosystems within the marine environment (Ballantine and Langlois 2008). Time periods from a few years up to decades have been suggested for recovery of populations (Claudet *et al.* 2008; Roberts and Mason 2008). Atlantic cod stocks in Canada showed none or little sign of recovery despite the cessation of direct fishing pressure for 10 years (Howarth *et al*. 2013).

An alternative explanation for the lack of significance between abundance and diversity of all individuals and species inside and outside of the no take zone may have been due to the presence of baited creel lines surrounding the study area. Figure 12 shows the locations where the creel lines were placed, illustrating the close proximity of this fishing gear to the survey sites. The almost continuous presence of the creel lines throughout the study period may have drawn individuals out of the no take zone, offsetting any potential difference in abundance.

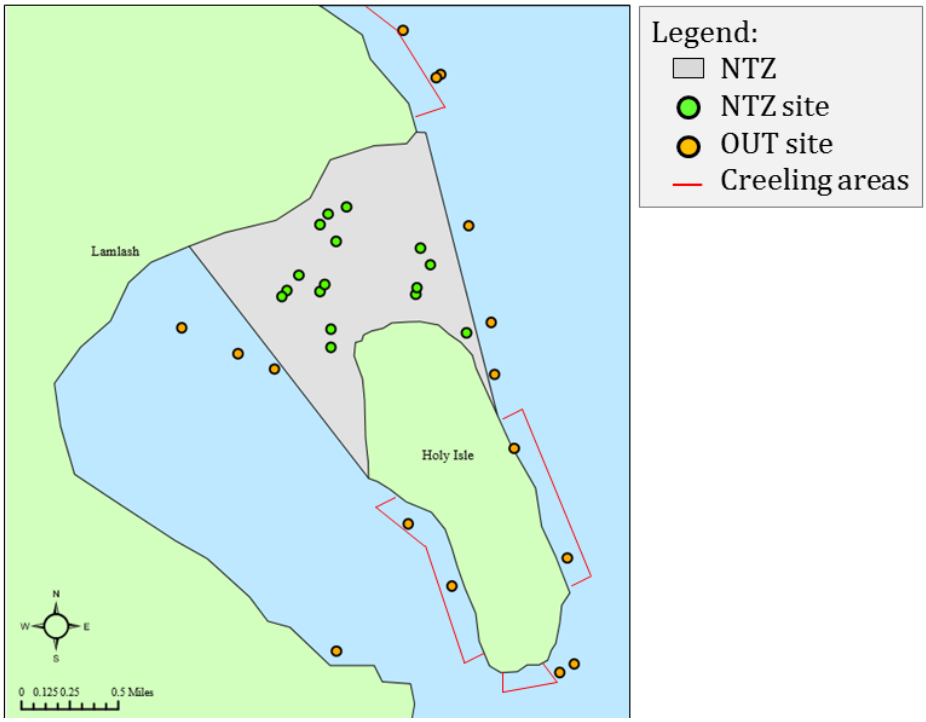

Figure 12. Map showing the locations where baited creel lines were located throughout the survey period – showing the close proximity to survey sites outside of the no take zone.

In order to assess whether the limited spatial protection offered by Lamlash Bay NTZ is having a significant effect on the recovery of the ecosystem, it may be prudent to extend the control sites to locations further away from the NTZ itself. BRUVs have been shown to work in a number of habitats and depths (Martinez *et al*. 2011), and so the study could easily be extended. This would ensure that the spillover effect, and the presence of baited creel lines, will not influence the abundance of fish species in the control sites and a true comparison can be made.

4.2 Size

Cod was used as an indicator of size, showing a significant increase over time for individuals in both NTZ and control sites. Estimates of fish size are important to assess fish growth, biomass, and to track recruitment events (Cappo *et al*. 2003). Cod are extremely valuable in Scottish

fisheries outside of the Firth of Clyde, with young cod being fully exploited by the commercial fishery before they reach the age of two (Marine Scotland 2010). This highlights the importance of the presence of juveniles within the NTZ, along with the fact that there is adequate protection for them to increase in size.

Measuring the size of individuals using single camera BRUVs has certain limitations. Measurement opportunities are only available when the subject is swimming in the same plane as the calibration scale and perpendicular to the camera (Cappo *et al*. 2003). Accuracy is severely degraded if the fish is behind or in front of the calibration bar, and reduced further if the subject rotates beyond 20° relative to the camera (Cappo *et al*. 2004). The improvement of this system would involve using stereo video techniques which have been shown to have a much higher accuracy (Harvey *et al*. 2002; Langlois *et al*. 2006).

4.3 Habitat

Distinguishing marine fish assemblages at broad scales, for example the two levels of protection used within this study, can be problematic due to heterogeneity within habitats (Harvey *et al*. 2007). However, this variability within habitats was accounted for, and when multivariate analyses were run on different habitat categories significantly different assemblages were indicated. The ANOSIM for habitats resulted in a Global R value of 0.24 with a significance level of 0.4%, indicating a low level of difference between different habitats. Furthermore, three different assemblages were identified using a dendrogram (Fig 11), which may be broadly categorised into the following classifications: (*i*) MPA 5 – suggesting an anomalous result which may be explained by the low number of individuals observed at this site; (*ii*) sites with deeper or less complex habitats, eg. deep boulders, deep muddy sand and sandy mud; (*iii*) sites with shallower or more complex habitats, eg. shallow boulders, shallow sand and maerl beds.

The incorporation of various smaller habitats into a wider protected area has often been discussed in the literature (Roberts and Mason 2008). The results of this study show different species assemblages occur within different habitat types, even on such a small scale. This further emphasises that to get the maximum conservation value from protected areas, they need to combine areas of different habitats rather than just cover a uniform area of the seabed.

Results from the SIMPER analysis (Table 3) revealed that four out of the seven species that contributed to 90% of species composition within the NTZ were fish species, contributing 62.28%. In the control sites only four out of the eight species contributing to 90% of species composition were fish, contributing 59.36% of species, with the other four species being Crustaceans. Although the contribution of fish species to overall composition is similar for NTZ

and control sites, the higher number of crustacean species in the control sites may be due to the lack of protection. Although the control sites are not heavily trawled, it has been shown that crustacean species thrive in less complex habitats (Howarth *et al*. 2013). This indicates that the protection offered by the NTZ allows habitat regeneration and therefore a species composition with higher finfish diversity.

4.4 Baited Remote Underwater Video Cameras

BRUVs are a widely accepted and highly utilised method for underwater visual surveys, and have been shown to successfully detect patterns in abundance and diversity of species over time (Malcolm *et al*. 2007). However, as with any visual survey there are various limitations associated with the method. The use of bait is highly discussed in the literature as its full influence on species composition is still not fully understood (Stobart *et al*. 2007). It is argued that the use of prey might increase the number of predatory species observed within the cameras field of vision (Stoner *et al*. 2008), which may in turn have an adverse effect on the abundance of non-predatory and herbivorous species (Harvey *et al*. 2007). Additionally, territorial species with strong site attachment may not be included in BRUV sampling methods unless the BRUV is positioned directly within their habitat (Cappo *et al*. 2004). Conversely, some studies have shown that the use of bait does not prevent the sampling of prey or herbivorous fish species (Watson *et al*. 2007).

The use of BRUVs also restricts the field of view of the observer to what is directly in the field of view for the camera. This can make the identification of certain individuals particularly difficult. In a study by Stoner *et al*. (2008) age-0 fishes in July proved problematic to identify, yet a month later their species was easier to discern. Flatfish are also hard to identify to species level due to their angle of swimming in relation to view of the camera (Martinez *et al*. 2011). Wraith (2007) observed very few flat fish despite complementary trawl samples indicating a high abundance in the same area. In order to assess changes in community structure and assemblages it is essential that effective methods for surveying demersal fish are used, and so using various complementary methods may be advisable in order to survey the full community structure (Spencer *et al*. 2005).

4.5 Environmental variables

GLMs were used to assess the potential influence of additional environmental factors on the abundance of individuals observed (Table 4). Substrate type was used as a measure of habitat complexity, which was tested in conjunction with macroalgae coverage. However, neither of the variables were found to be significant. Varied benthic assemblages are important to marine

ecosystems as they increase habitat complexity (Howarth *et al*. 2011). This increased complexity has been shown to increase survivorship of juvenile fish and exhibit greater species abundance and diversity (Bradshaw *et al*. 2003; Watson *et al*. 2005). Demersal fish are often associated with shells, algae and biogenic structures (Spencer *et al.* 2005), and juvenile cod have been shown to settle on rocky reefs, gravel and sea grass beds in coastal environments of Nova Scotia (Lindholm *et al*. 2000). This may suggest that the measure of complexity for this study needs to be further developed in order to epitomise true habitat complexity.

Additional environmental factors such as depth, temperature and current speed have been discussed in the literature as having a potential effect on numbers of fish attracted to baited gear (Heagney *et al*. 2007), as well as more biological factors such as sensory thresholds (olfactory and auditory) and swimming speeds (Cappo *et al*. 2006; Stoner *et al*. 2008). Current velocity is regarded as a highly important variable due to its effect on bait plume dispersal, and therefore the detection of the bait by individuals within the vicinity (Martinez *et al*. 2011). Studies have shown that whiting, cod and plaice (*Pleuronectes platessa*) have shown less activity towards bait in higher currents (Stoner 2004). In order to further expand the study, measurements of current velocity may be beneficial.

5.0 Conclusions

Despite the small area of protection and relatively recent implementation of Lamlash Bay NTZ, early monitoring results show positive signs for the future of the marine reserve. Although no significant difference was found between NTZ sites and control sites, there was a high abundance and diversity of species throughout the whole study site potentially indicating spillover is already having a small local effect. This indicates that increased protection from fishing within the Firth of Clyde could have a substantial impact on the regeneration of such a degraded ecosystem. Areas of spatial protection provide important information on the broader impacts of overfishing in marine habitats and the benefits that can be obtained from them (Hilborn *et al*. 2004); not only for fisheries but for wider ecosystem services and goods (Bullimore 2011).

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Appendix A. Resemblence Matrix based on Bray-Curtis similarities for all sites inside the NTZ, and all control sites – a minimum value of 4% and a maximum value of 81.97% showed a wide range in similarities between sites.

	NTZ 3	NTZ 4	NTZ 8	NTZ 10	NTZ 12	NTZ13	NTZ 14	NTZ 15	NTZ 16	NTZ 17	NTZ 18	NTZ 19	NTZ 20	NTZ 21	NTZ 22	NTZ 24
NTZ 3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NTZ 4	61.82	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NTZ 8	28.07	32.14	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NTZ 10	35.71	47.27	63.16	-	-	-	-	-	-	-	-	-	-	-	-	-
NTZ 12	50.00	56.41	29.27	35.00	-	-	-	-	-	-	-	-	-	-	-	-
NTZ13	68.00	73.47	39.22	52.00	58.82	-	-	-	-	-	-	-	-	-	-	-
NTZ 14	30.56	39.44	68.49	58.33	35.71	39.39	-	-	-	-	-	-	-	-	-	-
NTZ 15	63.41	44.44	28.92	34.15	27.27	44.74	28.57	-	-	-	-	-	-	-	-	-
NTZ 16	40.00	41.03	29.27	35.00	50.00	47.06	32.14	18.18	-	-	-	-	-	-	-	-
NTZ 17	69.39	66.67	28.00	48.98	48.48	60.47	36.92	53.33	30.30	-	-	-	-	-	-	-
NTZ 18	40.00	29.63	50.00	61.82	35.90	48.98	42.25	44.44	35.90	45.83	-	-	-	-	-	-
NTZ 19	36.73	33.33	48.00	44.90	42.42	46.51	36.92	34.67	42.42	33.33	75.00	-	-	-	-	-
NTZ 20	32.73	33.33	67.86	61.82	25.64	40.82	50.70	34.57	25.64	37.50	51.85	29.17	-	-	-	-
NTZ 21	36.92	34.38	51.52	58.46	32.65	44.07	41.98	50.55	32.65	41.38	75.00	62.07	59.38	-	-	-
NTZ 22	65.57	66.67	35.48	59.02	40.00	69.09	38.96	55.17	31.11	74.07	50.00	40.74	36.67	48.57	-	-
NTZ 24	66.67	50.00	39.13	48.89	68.97	76.92	39.34	45.07	48.28	57.89	59.09	52.63	45.45	51.85	56.00	-
MPA 1	46.15	54.55	27.85	48.72	32.26	58.33	29.79	42.31	25.81	45.07	36.36	28.17	36.36	41.38	55.42	44.78
MPA 2	50.98	64.00	26.92	31.37	57.14	57.78	32.84	31.17	45.71	54.55	28.00	36.36	24.00	30.00	46.43	45.00
MPA 3	40.91	37.21	44.44	59.09	42.86	47.37	40.00	31.43	42.86	48.65	65.12	59.46	41.86	52.83	44.90	60.61
MPA 4	45.45	55.81	40.00	45.45	71.43	63.16	43.33	28.57	57.14	43.24	41.86	54.05	27.91	37.74	44.90	66.67
MPA 5	20.00	15.38	24.39	20.00	16.67	29.41	14.29	24.24	33.33	18.18	30.77	30.30	41.03	40.82	17.78	34.48
MPA 8	28.07	25.00	48.28	49.12	19.51	43.14	32.88	36.14	19.51	32.00	75.00	60.00	42.86	66.67	48.39	43.48
OUT 1	37.74	46.15	33.33	30.19	48.65	46.81	37.68	40.51	32.43	47.83	53.85	65.22	23.08	51.61	41.38	42.86
OUT 3	68.97	49.12	13.56	20.69	33.33	46.15	24.32	61.90	28.57	54.90	21.05	23.53	14.04	17.91	47.62	34.04
OUT 4	56.00	73.47	31.37	36.00	52.94	63.64	33.33	34.21	52.94	55.81	24.49	32.56	24.49	27.12	50.91	46.15
OUT 5	21.43	18.18	70.18	53.57	10.00	28.00	55.56	34.15	10.00	24.49	54.55	36.73	76.36	55.38	32.79	35.56
OUT 6	22.22	22.64	43.64	44.44	26.32	25.00	37.14	30.00	26.32	34.04	60.38	55.32	30.19	47.62	30.51	32.56
OUT 7	66.67	79.25	29.09	48.15	57.89	75.00	31.43	42.50	26.32	68.09	37.74	34.04	30.19	31.75	67.80	55.81
OUT 8	77.97	55.17	20.00	27.12	41.86	52.83	26.67	65.88	23.26	61.54	34.48	38.46	27.59	35.29	53.13	45.83
OUT 10	74.63	57.58	23.53	38.81	39.22	55.74	28.92	66.67	27.45	63.33	39.39	30.00	48.48	44.74	58.33	50.00
OUT 12	60.00	65.31	31.37	52.00	58.82	77.27	39.39	39.47	41.18	60.47	48.98	41.86	40.82	40.68	58.18	66.67
OUT 15	13.64	9.30	48.89	54.55	21.43	21.05	36.67	17.14	14.29	21.62	46.51	27.03	55.81	37.74	24.49	30.30

	MPA 1	MPA 2	MPA 3	MPA 4	MPA 5	MPA 8	OUT 1	OUT 3	OUT 4	OUT 5	OUT 6	OUT 7	OUT 8	OUT 10	OUT 12	OUT 15
NTZ 3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NTZ 4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NTZ 8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NTZ 10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NTZ 12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NTZ13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NTZ 14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NTZ 15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NTZ 16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NTZ 17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NTZ 18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NTZ 19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NTZ 20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NTZ 21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NTZ 22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NTZ 24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MPA 1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MPA 2	46.58	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MPA 3	33.33	35.90	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MPA 4	36.36	51.28	50.00	-	-	-	-	-	-	-	-	-	-	-	-	-
MPA 5	22.58	22.86	42.86	21.43	-	-	-	-	-	-	-	-	-	-	-	-
MPA 8	32.91	19.23	48.89	31.11	29.27	-	-	-	-	-	-	-	-	-	-	-
OUT 1	26.67	50.00	39.02	53.66	16.22	37.04	-	-	-	-	-	-	-	-	-	-
OUT 3	30.00	41.51	21.74	34.78	14.29	10.17	36.36	-	-	-	-	-	-	-	-	-
OUT 4	47.22	71.11	26.32	47.37	17.65	19.61	42.55	42.31	-	-	-	-	-	-	-	-
OUT 5	25.64	7.84	40.91	18.18	30.00	45.61	26.42	6.90	4.00	-	-	-	-	-	-	-
OUT 6	21.05	20.41	47.62	33.33	21.05	61.82	43.14	17.86	20.83	29.63	-	-	-	-	-	-
OUT 7	55.26	57.14	42.86	47.62	10.53	29.09	39.22	46.43	66.67	14.81	19.23	-	-	-	-	-
OUT 8	37.04	48.15	34.04	38.30	18.60	20.00	46.43	81.97	45.28	20.34	21.05	56.14	-	-	-	-
OUT 10	51.69	45.16	36.36	36.36	31.37	29.41	37.50	63.77	52.46	29.85	24.62	58.46	74.29	-	-	-
OUT 12	52.78	53.33	57.89	63.16	23.53	35.29	46.81	42.31	54.55	20.00	25.00	75.00	49.06	52.46	-	-
OUT 15	18.18	15.38	37.50	25.00	35.71	35.56	24.39	13.04	5.26	54.55	28.57	23.81	17.02	21.82	26.32	-

Appendix B. Table showing discrepancies between original habitat categories assigned due to substrate type, and habitats assigned during diver surveys – ***** represents the sites that were changed during MDS plots (Fig 10b,c), but original categories were used for final analysis. Habitats that varied between sand, muddy sand and sandy mud were left as original habitats due to the similarities in particle size making diver identification difficult.

Site	**Original habitat category**	**Habitat recorded by diver survey**	**Site**	**Original habitat category**	**Habitat recorded by diver survey**
NTZ 12	Shallow boulders	Sand + boulders	MPA 2	Shallow boulders	Boulders + sand
NTZ 17	Shallow boulders	Sand + boulders	**OUT 4***	**Shallow boulders**	**Dead maerl + shells**
NTZ 18 *	**Deep boulders**	**Sandy mud**	OUT 1	Deep boulders	Boulders + pebbles
NTZ 19	Deep boulders	Sandy mud + boulders	OUT 15	Deep boulders	Boulders + sand
NTZ 3	Maerl bed	Dead maerl + shells	OUT 7	Maerl bed	Dead maerl + shells
NTZ 13	Maerl bed	Dead maerl + shells	OUT 12	Maerl bed	Dead maerl + shells
NTZ 4	Shallow sand	Muddy sand	MPA 1	Shallow sand	Sandy mud
NTZ 21	Shallow sand	Sand	OUT 10	Shallow sand	Sand
NTZ 15	Deep sand	Sandy mud	MPA 5	Deep sand	Sand
NTZ 24	Deep sand	Muddy sand	OUT 8	Deep sand	Sand
NTZ 14	Shallow muddy sand	Muddy sand	MPA 4	Shallow muddy sand	Muddy sand
NTZ 22	Shallow muddy sand	Muddy sand	OUT 6	Shallow muddy sand	Sandy mud
NTZ 8	Deep muddy sand	Sandy mud	MPA 3	Deep muddy sand	Sandy mud
NTZ 10	Deep muddy sand	Sandy mud	OUT 5	Deep muddy sand	Sandy mud
NTZ 16	Sandy mud	Muddy sand	MPA 8	Sandy mud	Sandy mud
NTZ 20	Sandy mud	Muddy sand	OUT 3	Sandy mud	Sand

Appendix C. Extra activities carried out with the Community of Arran Seabed Trust (COAST).

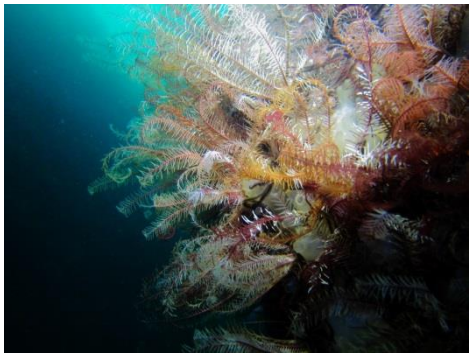
- **17/07/2013- 'Touch Tank' at the Tourist Information Centre in Brodick**

This involved greeting tourists at the Tourist Information Centre outside the ferry port and giving them a talk on 'local critters' and the local marine environment. To help with this, we had previously gone diving to collect marine invertebrates and crustaceans in order to interact with the children (and occasionally adults).

I was also involved in trying to elicit questionnaire responses for the public consultation on the MPA proposed by COAST. This involved talking through marine conservation matters and the history of COAST, before helping any willing participants to fill out the consultation questionnaire.

- **20/07/2013- Wrote the 'Species of the Month' article on Feather Stars for COAST's monthly newsletter:**
  <http://www.arrancoast.com/news/current-newsletter/past-newsletters/61-august-2013-newsletter/305-feather-stars.html>

Feather Stars



The species of the month this issue is the feather star: a surprisingly exotic animal that frequents the shores of the British coast (except for the south east coast of England). The feather star is classified as an Echinoderm, sharing traits with animals such as starfish, sea urchins and even sea cucumbers!

Feather stars display a wide variety of colours; predominantly mottled patterns of reds, oranges, pink and whites, presenting a striking image when found in a large group. The feather stars get their unique look from a set of 5 pairs of highly dextrous arms that are long, spindly and exhibit the characteristic feathery look. Their distinctive arms allow them to filter the water for food – known as suspension feeding – and tiny tube feet located along the arms catch small particles in the water and pass them along to the mouth. Unlike other starfish, feather star mouths are located upon the top side of their body.

Due to their selective feeding method, feather stars are usually located in areas with a strong current in order to gain easy access to as many floating food particles as possible. To help them survive in these harsh conditions they have up to 25 claw-like appendages, called cirri, clustered under the middle of their arms which they use to cling on to the seafloor. Although feather stars look incredibly

fragile, the cirri are remarkably strong, as many divers may have experienced when a rogue feather star happens to cling on to their equipment.

Feather stars also have a highly functional role to play within the marine ecosystem. Their unique shape and structure helps to enhance the structural complexity of the seafloor. Complex areas are extremely important as they can provide refuges from predation and from bad environmental conditions (strong currents and tides) for many species; even commercially important ones such as juvenile cod and juvenile scallops.

The Isle of Arran provides many of different complex habitats, and the new marine protected area that is being proposed by COAST would include several of these. By providing protection from the more damaging fishing methods, the sea floor is allowed to regenerate and maintain its complexity. The implementation of the marine protected area would not only allow feather stars to thrive and further enhance this structural complexity, but would also greatly benefit a multitude of other species residing in similar habitats.

Latin name: *Antedon bifida*
Habitat: Free-moving, but prefer areas with fast flowing currents. They also help to increase the structural complexity of many habitats.
Distribution: Common around most of the British coast (except the south east)
Size: up to 15cm across
Sources:

Naylor, P., 2005. Great British Marine Animals. 2nd ed. Cornwall: Sound Diving Publications, pp. 192.

- **06/08/2013- Carried out a dive for COAST to retrieve marine critters for their touch tank**

- **07/08/2013- Lamlash Bay Agricultural Show**

COAST had a stall at the local agricultural show, again to elicit responses to the public consultation on the proposed marine protected area. There was also a touch tank provided to enable children to experience creatures from their local marine environment.

- **09/08/2013- Drove the boat for COAST divers so that they could retrieve marine critters for their touch tank**

(Unfortunately I had a cold so I couldn't dive!!)

- **09/08/2013- Shore scramble with COAST and National Trust Scotland at Kildonan**

An afternoon was spent on the rocky shore finding and identifying marine creatures with local children- there was an incredible turnout with about 50 people there.

There was also the opportunity to go and take a look at the local seal colony, which was a highlight of many children's day.